Innovation Networks and University Roles in the Guangdong-Hong Kong-Macao Greater Bay Area: A Network Perspective Analysis (Postprint)

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Abstract

[Purpose/Significance] The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is endowed with abundant scientific and educational resources, and is striving toward the goal of establishing an international science and technology innovation center. Conducting a comprehensive examination of the GBA' s science and technology innovation supply constitutes the first step toward refining policy initiatives. [Method/Process] Based on scientific paper and patent data spanning 2012 to 2016, this study performs visualization and structural analysis of the Knowledge Innovation Network (KIN) and Technology Innovation Network (TIN) within the GBA. Concurrently, employing South China University of Technology as a case study, it evaluates the status, role, and performance of mainland research universities within the GBA regional innovation network, investigates the difficulties and challenges encountered by universities in participating in regional innovation processes, and proposes targeted policy recommendations. [Results/Conclusion] The research demonstrates that: (1) The knowledge innovation network structure in the GBA is mature, exhibiting an overall core-periphery distribution pattern; (2) Mainland universities lead the GBA in paper publication volume, yet exhibit insufficient capacity in constructing and leading innovation networks; (3) The frontier of knowledge innovation in the GBA is trending toward new engineering disciplines, with pronounced gradient effects across regions; (4) High-tech enterprises dominate the GBA' s technology innovation network, and the models of technological cooperation and development differ between Guangzhou and Shenzhen.

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Preamble

Innovation Network and University Role in Guangdong-Hong Kong-Macau Greater Bay Area: A Network Perspective Analysis

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Abstract:
[Purpose/significance] The Guangdong-Hong Kong-Macau Greater Bay Area (GHMGBA) is rich in scientific and educational resources and is striving to build an international science and technology innovation center. A thorough examination of the region' s science and technology innovation supply is the first step toward improving policy initiatives. [Method/process] Based on scientific paper and patent data from 2012 to 2016, this paper conducts a visualized structural analysis of the region' s Knowledge Innovation Network (KIN) and Technology Innovation Network (TIN). Using South China University of Technology as a case study, we evaluate the status, role, and performance of mainland research universities within the GHMGBA regional innovation network, explore the difficulties and challenges universities face in participating in regional innovation, and propose targeted policy recommendations. [Result/conclusion] The findings indicate that: (1) The GHMGBA knowledge innovation network exhibits a mature structure with an overall core-periphery distribution pattern; (2) Mainland universities lead the Bay Area in paper publication volume but lack capacity in network construction and leadership; (3) The frontier of knowledge innovation in the Bay Area is trending toward emerging engineering fields, with significant gradient effects across regions; (4) High-tech enterprises dominate the Bay Area' s technology innovation network, with Guangzhou and Shenzhen employing different models for technology cooperation and development.

Keywords: technology innovation, regional innovation network, GHMGBA

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In March 2017, Premier Li Keqiang proposed constructing the "Guangdong-Hong Kong-Macau Greater Bay Area Urban Agglomeration" in the government work report to promote coordinated development between Guangdong' s nine cities and Hong Kong and Macau, thereby advancing deeper economic development and opening-up. The 2018 government work report further elevated the strategic positioning of the GHMGBA, listing it alongside major regional strategies such as the "Beijing-Tianjin-Hebei Integration" and "Yangtze River Economic Belt," while downplaying the initial "urban agglomeration" attribute to emphasize a more comprehensive and profound integration approach. Currently, using innovation-driven development as the core strategy to achieve the Bay Area' s construction goals has become a shared understanding among governments in mainland China, Hong Kong, and Macau.

The GHMGBA currently hosts numerous research institutions and technology enterprises, making it a highly competitive innovation region. In 2017, the Bay Area was home to seven universities ranked among the world' s top 300, accounting for 28% of all selected universities in mainland China, Hong Kong, Macau, and Taiwan, making it one of the regions with the densest distribution of world-class research universities. In engineering disciplines, South China University of Technology (ranked 22nd), City University of Hong Kong (24th), and Hong Kong University of Science and Technology (31st) are among the global top 50, while Sun Yat-sen University and City University of Hong Kong rank within the global top 150 in natural sciences. Simultaneously, the GHMGBA is a hub for high-tech, internet, and manufacturing enterprises. Guangdong Province alone hosts over 20,000 high-tech enterprises, and in 2016, the province' s large-scale industrial enterprises ranked first nationally in domestic technology transaction volume, foreign technology import value, and total R&D expenditure, with total R&D investment exceeding 200 billion yuan and growing at an annual rate of over 10%. The Chinese Academy of Sciences' 2017 "China Regional Innovation Capability Evaluation Report" rated Guangdong Province as having the strongest comprehensive innovation capability, leading other provinces and municipalities in enterprise innovation, innovation environment, and innovation performance.

The GHMGBA' s innovation development is currently at a juncture of multiple policy opportunities. On one hand, previously implemented innovation-driven development strategies continue to release policy effects. Since 2014, Guangdong Province has pursued an innovation-driven development strategy, positioning itself as a "comprehensive innovation reform pilot province," while Guangzhou and Shenzhen have respectively targeted becoming a "core area for comprehensive innovation reform" and an "innovative city," with the Pearl River Delta region also launching the construction of a "national independent innovation demonstration zone." On the other hand, GHMGBA construction provides a new platform for innovation development. The plan to build the GHMGBA into an international science and technology innovation center serves as the central government' s main lever for promoting economic development and social construction in the region.

Despite these favorable factors for achieving innovation-driven development in the GHMGBA, significant gaps remain compared to the goal of establishing an international science and technology innovation center. Compared with the San Francisco Bay Area, New York Bay Area, and Tokyo Bay Area, the GHMGBA's scientific and technological innovation capacity is relatively insufficient, and its innovation-driven contribution to the local economy remains inadequate. Therefore, a critical question demanding urgent attention is how to leverage the Bay Area' s scientific and educational advantages to accelerate the construction of a well-functioning, stable-output regional innovation system that truly enables leapfrog economic and social development. This paper examines the GHMGBA' s innovation network structure to explore effective pathways for promoting innovation, aiming to provide valuable insights for government decision-making.

2.1 Regional Innovation Network

The concept of the Regional Innovation Network emerged in the early 1990s, with Freeman and Camagni first proposing its theoretical prototype, which subsequently evolved into one of the mainstream fields in innovation research. According to Cooke' s definition, a regional innovation network typically refers to a localized organizational form where enterprises, universities, research institutions, intermediary organizations, and governments collaborate through stable formal and informal connections during the innovation process. Compared with the earlier concept of regional innovation systems, the regional innovation network concept strips away environmental variables such as innovation culture from regional innovation systems, focusing instead on the interactive relationships among various actors in the innovation system and concentrating on specific innovation processes. This paper employs the regional innovation network concept in a more narrow sense, defining it as a "network of inventors" that focuses on micro-level actors participating in the science and technology innovation process, such as universities, other public and private research institutions, and enterprises, thereby limiting the research scope to the supply side of regional innovation networks.

As innovation theory has matured, regional innovation networks have gradually become an established research paradigm that not only specifies research objects but also integrates specific methodologies. In regional innovation networks, nodes and relationships constitute the basic elements, and their combination determines the structural characteristics of the innovation network. Enterprises, public sector organizations, universities, research institutions, and intermediary organizations serve as nodes scattered throughout the network, with connections forming between nodes around the innovation process. Human resources, equipment, information, capital, knowledge, culture, and technology circulate and exchange within the network, promoting the emergence, accumulation, and commercialization of innovation. Typically, regional innovation networks contain massive numbers of nodes and relationships. From the perspective of complexity science, the nonlinearity, dynamics, irreversibility, and openness of such networks, as well as their self-organizing and adaptive characteristics, make innovation processes more concealed yet simultaneously more efficient and uncertain.

An implicit theoretical expectation in regional innovation network research is that network structure affects both individual innovation performance and overall network performance, enabling policymakers to adjust innovation network structures and improve innovation management policies accordingly. Regarding overall network structure, innovation network communities exhibit evolutionary progression characteristics. Primitive networks initially appear as discrete fragments, gradually transforming into core-hub structures, then transitioning to multi-center small-world networks, and finally developing into the most complex core-periphery structures. These four stages constitute the ideal evolutionary process of innovation communities. More complex network structures imply higher network density and shorter average path lengths between nodes, which facilitate knowledge dissemination and promote mutual learning among individuals in the network, thereby enhancing overall innovation performance. Additionally, local network structures may also affect individual innovation performance, such as the number of direct and indirect connections between individuals, structural holes, relationship reciprocity, and strong ties and dual-layer network structures.

Compared with international research, domestic empirical studies on regional innovation networks are still in their infancy. Current theoretical research partly focuses on knowledge flow, learning processes, collaboration, and evolution within innovation networks, while policy research concentrates on innovation network performance evaluation and indicator system construction. Among studies examining Chinese urban agglomerations and the Pearl River Delta region, Zhou Can et al. visualized the Yangtze River Delta urban agglomeration' s innovation network, noting that cross-boundary inter-firm networks constitute the primary pathway for technological innovation in the region. Xie Weiwei et al. argued that the green innovation network structure in Yangtze River Delta cities remains unreasonable, with insufficient inter-city innovation linkages. Chen Xionghui et al. evaluated the innovation network structure across Guangdong' s 21 prefecture-level cities, concluding that innovation capacity development is unbalanced among cities without forming agglomeration effects. Additionally, Wang Peng and Wang Yanyan analyzed the innovation cooperation network between mainland China and Hong Kong, emphasizing that similar talent structures and key research institutions are critical factors for building cross-regional networks. Overall, current domestic empirical research on regional innovation networks remains insufficient, and policy-oriented analyses focusing on the specific morphology of regional innovation networks in the GH-MGBA/Pearl River Delta region have yet to emerge.

2.2 Universities and Regional Innovation Networks

Higher education institutions are core actors in regional innovation networks, and university development and knowledge innovation activities have direct positive effects on regional innovation. Regarding the specific mechanisms through which universities influence regional innovation, two mainstream analytical models exist in academia: the Engaged University theory and the Triple Helix model. In the classic exposition of Engaged University theory, Youtie and Shapira distinguish three evolutionary forms of university roles in innovation networks, proposing that modern universities actually serve as regional "Innovation Hubs." This role transcends the traditional forms of knowledge repositories and knowledge factories, emphasizing the proactive infusion of tacit knowledge about innovation into the local context. In the transition toward this third university form, "networking" behavior is most critical, requiring universities to encourage cross-boundary knowledge exchange by breaking down internal academic departmental boundaries and external boundaries with other innovators, particularly strengthening connections with local communities to foster an innovation culture. The Triple Helix model posits that university participation in regional innovation primarily relies on establishing cyclical, intersecting relationships with government and industry, resembling a triple-helix co-evolution structure. The three parties jointly build science parks, incubator facilities, research projects, and investment programs, with universities maintaining an "academic entrepreneur" identity throughout. Overall, the two models respectively emphasize the knowledge production and knowledge transfer stages of the innovation process, with varying expectations regarding universities' market behaviors, but both underscore the importance of universities proactively building innovation networks.

Empirical research on innovation networks indicates that universities' roles in building innovation networks can be summarized as three types: "Gatekeeper," "Connector," and "Leader." From a knowledge flow perspective, universities maintain more contact with external innovators and can access more heterogeneous information. When universities are deeply embedded in local innovation networks, they can facilitate the input of heterogeneous information into the local network, creating conditions for innovation emergence. In this sense, universities serve as Gatekeepers of regional innovation networks, screening and controlling information flow, which enhances network information quality and diversity. Additionally, since education is universities' most fundamental function, talent flows rapidly around universities, placing them at the center of talent mobility networks. When talent localization is high, universities can connect separated network components through informal relationships, serving as network Connectors. Researchers have found that local employment of Stanford University graduates contributed to the early connection of Silicon Valley' s innovation network, while MIT' s pattern of most students leaving upon graduation delayed network connection in the Boston area. Finally, universities can also emerge as Leaders of innovation networks, a phenomenon particularly evident in some developing regions and areas with fewer research universities. By deepening participation in local innovation environments or directly entering markets through university-run enterprises, universities can directly guide the extension and expansion of regional innovation networks.

3 Data and Methods

As previously discussed, network analysis is the mainstream method for studying regional innovation network structures. This paper employs network analysis to provide a panoramic depiction of the GHMGBA' s science and technology innovation network over the past five years, addressing the limitation of previous qualitative approaches that could not see the forest for the trees. Simultaneously, using South China University of Technology' s innovation network participation as a case study, we connect individual network actors with macro-level network structures to provide a more comprehensive answer to our research questions. SCUT was selected as the case primarily because it is the best-performing research institution in engineering and technology among GHMGBA universities (as mentioned above) and represents one of the potential leading institutions for science and technology innovation in the new phase of Bay Area development.

For analytical convenience, this paper divides the Regional Innovation Network (RIN) into two components: the Knowledge Innovation Network (KIN) and the Technology Innovation Network (TIN). KIN and TIN respectively focus on different stages of innovation, representing upstream and downstream segments of the innovation chain. The former better reflects the state of original and theoretical innovation within the region, while the latter more effectively presents the development of more applied and highly developed innovations (see Figure 1 [Figure 1: see original paper]). For data acquisition, the sample data used to construct the Knowledge Innovation Network (KIN) was obtained from the Web of Science Core Collection. As the world' s largest and most comprehensive scientific paper database covering all disciplines, Web of Science inclusion serves as an important basis for academic research evaluation. Since engineering technology represents the primary domain of R&D activities and features the densest innovation connections between research institutions and industry, it strongly characterizes local science and technology innovation networks. Consequently, this paper systematically extracted all scientific paper information in the engineering discipline published in the Web of Science database between 2012 and 2016, strictly limiting author addresses to the 11 cities of the GHMGBA, yielding a total of 45,594 paper samples. Based on these samples, we constructed a database containing paper titles, abstracts, keywords, author information, institutional information, and disciplinary information. Similar to the KIN data, we extracted GHMGBA patent data from Web of Science between 2012 and 2016, supplemented and verified with data from the National Intellectual Property Administration' s patent database, to form the basis for constructing the Bay Area' s Technology Innovation Network (TIN). Only invention patents were retained, excluding design and utility model patents. Given that the KIN analysis selected engineering technology papers as data, there is strong connectivity between KIN and TIN.

Network analysis requires first converting traditional attribute data into relational data, which is generated through co-occurrence of sample attributes. This paper operationalizes the regional innovation network as both an affiliation network based on author affiliations or patent holder institutions, and a fields network based on disciplinary attributes (see Figure 1). In the resulting network maps, nodes represent research institutions and enterprises participating in the regional innovation network, while connections between nodes indicate co-authorship or co-ownership of patents, with connection weights representing the quantity of collaborations. For the generated collaboration and discipline networks, visualization mapping and network metrics (such as network centrality) help us understand overall network structure and the position of individual nodes, providing an empirical foundation for answering research questions. We employ both methods comprehensively in the following analysis.

4.1 The GHMGBA Knowledge Innovation Network Exhibits a Core-Periphery Distribution Structure

Figure 2 [Figure 2: see original paper] displays the institutional network structure of the Knowledge Innovation Network (KIN), where circular nodes represent institutions (yellow nodes indicate South China University of Technology), and connections between nodes indicate co-authorship. The network overall demonstrates a core-periphery distribution pattern, with mainland China' s top universities and research institutions and Hong Kong' s universities occupying more central positions, such as the Chinese Academy of Sciences, Peking University, Tongji University, University of Hong Kong, and Hong Kong Polytechnic University. This indicates these institutions maintain the most diverse connections with other research units and relatively high coverage of network actors. Compared to centrally positioned institutions, peripheral institutions face disadvantages in knowledge dissemination and receiving knowledge spillovers, particularly concerning tacit knowledge transmission. From network evolution theory perspective, core-periphery innovation networks feature maturity and sustainability, representing an advanced stage of community evolution. This suggests the GHMGBA knowledge innovation network has reached a high development level, with the academic innovation landscape in engineering technology initially established. Statistical analysis of institutional nationalities reveals that only approximately 5.3% of engineering and technology papers from the Bay Area involve international collaboration, indicating GHMGBA institutions prefer local or domestic partnerships and rarely collaborate with foreign innovation groups. This both demonstrates abundant local science and technology innovation resources that can meet cross-institutional collaboration needs and reflects the overall insufficient outward orientation of the Bay Area' s innovation network.

4.2 Mainland Universities Lead in Publication Volume but Lag in Network Construction and Leadership

Examining the combination of institutional network structure and individual node performance reveals mismatches between innovation performance and network position for some institutions. While South China University of Technology ranks first in the GHMGBA in terms of engineering discipline SCI paper publications, it does not occupy a central position in the institutional network. Calculating network centrality using degree centrality, SCUT' s node score is only 0.01, far behind the Chinese Academy of Sciences (0.09), University of Hong Kong (0.06), and City University of Hong Kong (0.06). Plotting a scatter diagram of degree centrality against SCI paper publication quantity (Figure 3 [Figure 3: see original paper]) shows a certain positive correlation between institutional paper publication volume and network centrality, yet SCUT appears as a significant outlier. Extremely low network centrality combined with extremely high individual performance suggests SCUT suffers from insufficient embeddedness in the GHMGBA knowledge innovation network and inadequate network construction and guidance capabilities. Theoretically, this hinders SCUT's diffusion of knowledge achievements to other network members and impedes further integration of the innovation network. To more intuitively present structural differences between SCUT and other universities in the network, we selected SCUT, South China Normal University, City University of Hong Kong, and the Chinese Academy of Sciences to plot ego-network maps (Figure 4 [Figure 4: see original paper]). The comparison shows SCUT' s collaboration density is far lower than the latter two centrally positioned universities and only slightly more complex than the peripherally positioned South China Normal University.

4.3 Engineering Knowledge Innovation Trends Toward Emerging Fields and Intelligence, with Obvious Regional Gradient Effects

The discipline network map of the knowledge innovation network (Figure 5 [Figure 5: see original paper]) reveals that the Bay Area' s mainstream engineering disciplines currently include computer science, materials science, communication engineering, automation and control systems, and energy and power engineering. Unlike the core-periphery structure of the institutional network, the discipline network approximates a core-hub morphology with low network density and infrequent interdisciplinary crossovers. Further analysis of computer science papers shows significant changes in institutional members compared to the engineering discipline institutional network. City University of Hong Kong, Shenzhen University Town, Chinese University of Hong Kong, Hong Kong Polytechnic University, and the Chinese Academy of Sciences rank as the top five high-producing institutions in computer science in the GHMGBA. Unlike SCUT' s strong comprehensive performance in engineering disciplines, the university only ranks sixth in computer science (see Table 1). Similar phenomena appear in other emerging engineering fields such as intelligent manufacturing. These results demonstrate that frontier discipline development within the regional innovation network is forming gradient differentiation across regions. Hong Kong and Shenzhen are advancing rapidly in emerging engineering fields, while Guangzhou maintains its innovation advantages in traditional engineering domains. Clear inter-city division of labor trends have emerged within the regional innovation network, which aligns closely with the industrial structure and market conditions across the GHMGBA and conforms to the expectations of innovation network geographical proximity theory.

4.4 High-Tech Enterprises Dominate the Technology Innovation Network, with Guangzhou and Shenzhen Employing Different Development Models

Visualizing the technology innovation network reveals few instances of multi-institutional co-ownership of patents, with the institutional map of the technology innovation network appearing extremely fragmented (visualization results cannot be reported due to space limitations). This aligns with findings from studies using European data. Given the limited analytical value of network mapping, this paper employs descriptive statistics from the technology innovation network as the basis for analysis (see Table 2 and Table 3). Patent ownership data shows that the top 10 invention patent holders in the GHMGBA are primarily private technology enterprises in Shenzhen and Zhuhai, concentrated in communications, electrical appliances, and computer industries. Among public research institutions, SCUT enters the top 10 patent holders and represents the only Guangzhou-based institution. This indicates that private enterprises currently serve as the main force for technology innovation in the GHMGBA, with technology innovation showing regional concentration trends. Further statistics on institutions co-holding patents with SCUT reveal that local Guangzhou state-owned enterprises account for the highest proportion (concentrated in energy and equipment industries), suggesting SCUT' s technology co-development activities primarily follow a university-state-owned enterprise cooperation model, forming a sharp contrast with Shenzhen' s private enterprise-dominated development model. Similar to the knowledge innovation analysis results, SCUT' s patent applications concentrate in chemical engineering and materials science (see Table 4), aligning with its disciplinary strengths but showing low alignment with the GHMGBA' s intelligent technology innovation development direction.

5 Conclusions and Policy Recommendations

This paper provides a preliminary analysis of the GHMGBA' s knowledge and technology innovation networks. The results show that the GHMGBA possesses a relatively mature knowledge innovation network structure with high localization and abundant innovation resources. However, the knowledge innovation network also suffers from a lack of leading research institutions and weak internal integration. The GHMGBA' s technology innovation network is dominated by private high-tech enterprises, with a frontier technology cluster emerging around Shenzhen and Hong Kong. Compared with Shenzhen, Guangzhou' s technology cooperation and innovation model remains relatively traditional, which somewhat limits local technology innovation vitality and hinders exploration and development of frontier technologies. Overall, the supply-side structure of the GHMGBA innovation network is mature, providing a solid foundation for building an international innovation center. Future efforts should maintain policy support and resource investment to continuously enhance regional innovation competitiveness.

Combining findings from both knowledge and technology innovation networks reveals that the GHMGBA presents a prosperous innovation landscape while simultaneously facing internal crises. Most notably, a tension exists between traditional and modern innovation approaches, specifically manifesting as "anti-networking" innovation behaviors among mainland educational and research institutions. For example, SCUT, as the largest publisher in engineering fields and top patent holder, maintains few collaborations with external institutions while primarily cooperating with state-owned enterprises—exhibiting both minimal network engagement and preference for organizations with institutional affinity. These behaviors contradict modern innovation network requirements and hinder the emergence of original and fundamental innovations. SCUT is not an isolated case; the issues it reflects are somewhat universal among mainland educational and research institutions. As the primary innovation supply actors, universities should reverse the "anti-networking" trend, proactively engage with other innovation and market actors, and become the main force in building regional innovation networks. Based on these conclusions, we propose the following policy recommendations:

First, further expand science and technology openness in the GHMGBA. Encourage mainland universities in the Bay Area to establish stable, long-term partnerships with foreign academic institutions, simplify approval procedures for academic exchanges, create green channels for introducing high-end foreign scientific and technological talent, increase policy support for international cooperative education, and strive to cultivate outstanding mainland universities into Gatekeepers of regional innovation networks.

Second, encourage qualified mainland universities in the Bay Area to expand their science and technology innovation cooperation scope within the region. Accelerate the process of resource sharing and co-construction of higher education between mainland and Hong Kong/Macau, establish a unified labor market for scientific and technological talent across the three regions to promote talent mobility, and support qualified mainland or Hong Kong universities to become leading research institutions in the GHMGBA regional innovation network to optimize the governance structure of the Bay Area' s science and technology innovation network.

Third, while maintaining urban innovation division of labor, encourage Guangzhou, Zhuhai, Foshan, and other cities to deploy in frontier technology innovation fields. We recommend using the GHMGBA' s construction of an international innovation center as an opportunity to coordinate the revision of science and technology development plans across Bay Area cities, deploy in technology innovation frontiers, and create agglomeration advantages in technology innovation.

Fourth, improve mainland university technology cooperation and transfer policies, guide universities to innovate jointly with private enterprises, and smooth technology transformation channels. Formulate and improve intellectual property laws and regulations, allow researchers to flexibly engage in market activities, and protect innovation earnings.

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