

The pattern, evolution, and mechanism of venture capital flows in the Guangdong-Hong Kong-Macao Greater Bay Area, China

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Abstract: As an important innovation flow, venture capital has been examined in urban network research. However, the segmentation of capital categories and the cross-scale connection of capital remain scarcely analyzed. This study focuses on the structure and industry differentiation of venture capital flows in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) and its cross-scale network characteristics. Based on a venture capital database covering capital amount, investment subject address information, and industry information (2000–2018), this article examines the spatial distribution and network structure of venture capital in the GBA by means of a distance-based test of spatial concentration approach and social network analysis. Key findings show that: (1) Venture capital institutions and startups in the GBA present a high-concentration distribution pattern. In the past 20 years, venture capital activities in the GBA have substantially increased, forming a complex urban network structure with Guangzhou, Shenzhen, and Hong Kong as the core of this network. (2) Different types of venture capital show significantly different urban network structures, with manufacturing, the Internet industry, the financial sector, the cultural media industry, and the medical and health industry as the five industry types with the largest capital flow in the GBA. (3) Cross-scale research on the venture capital network reveals the position of the GBA as a capital hub in China, which forms a dense venture capital connection network with major cities on a national scale. (4) The network structure of venture capital in the GBA is influenced by multi-dimensional proximity, institutional factors, urban economy, and path dependence. Along with these three key mechanisms, the GBA has grown into a national-scale and even global-scale venture capital center.

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1 Introduction

Globalization has led to the rise of city-regions as new capital accumulation spatial units. Since China's reform and opening up in 1978, it has motivated city-regional development. Until now, China has formed a new nationwide spatial pattern of urban agglomerations, which defines the strategic position of the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl River Delta (PRD) national-level urban agglomerations (Zhang *et al.*, 2018; 2021). These urban agglomerations have played a pioneering role in the urbanization process. They are important spatial carriers of China's current economic growth and hubs that anchor capital and technology (Li *et al.*, 2017; Fang *et al.*, 2020). With the innovative transformation of the urban agglomeration economy, the combination of venture capital network dynamics and urban agglomeration research is becoming the frontier of geographic research.

Among them, the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is undoubtedly exceptional. As it is adjacent to Hong Kong and Macao, the PRD has risen rapidly after the reform and implementation of the "front shop, back factory" model (Hui *et al.*, 2020). Furthermore, deeper integration of the PRD with Hong Kong and Macao has also promoted the rise of the GBA. As a typical sub-national and cross-system urban agglomeration in China, the GBA's capital diversity, as well as its growth and transformation, has received extensive attention in theoretical research (Yang, 2012). There are two world-class financial cities in the GBA, namely Hong Kong and Shenzhen, and simultaneously, big manufacturing cities such as Foshan, Dongguan, and Zhongshan have emerged in the Circum-PRD region. The interweaving of innovation, entrepreneurship, and venture capital fully demonstrates the development vitality of the GBA. In the *Outline of Development Plan for Guangdong-Hong Kong-Macao Greater Bay Area* released in 2019, establishing an international science and technology innovation center has been clearly identified as the focus in the next stage of development. Therefore, acting as a hub urban agglomeration that anchors venture capital as well as innovation and entrepreneurship, GBA needs to be further investigated about its venture capital network structure and its characteristics of the cross-scale contact with cities in China.

In recent years, the network structure and dynamics of urban agglomerations have widely attracted the attention of scholars. With the transformation from Fordist to post-Fordist production paradigm and the compression of time and space by information technology, capital, innovation, and knowledge have gradually replaced traditional production factors. Furthermore, the traditional "space of place" has been replaced by the "space of flow" (Li *et al.*, 2017). The combination of flows and network analysis methods is of great significance for understanding the spatial structure of urban agglomerations. Therefore, a large number of theoretical and empirical studies have depicted the spatial network of urban agglomerations in different dimensions, including stream of people (Li *et al.*, 2020; Wang *et al.*, 2021), logistics (Akhavan *et al.*, 2020), producer service linkages (Yeh *et al.*, 2015) and aviation, high-speed rail and other traffic flows (Cheung *et al.*, 2020). Furthermore, investment in different localities (Pan *et al.*, 2017; He *et al.*, 2020), patent and research paper cooperation

network (Li *et al.*, 2019; Ma *et al.*, 2021) have also been studied. The combination of these elements and methods of network analysis reveals the characteristics of functional and institutional network structures of urban agglomerations, which are significant to understand the urban agglomeration space under the spatiotemporal compression by technology and information.

Venture capital, as one of the elements of innovation flow, is widely regarded as the main driving force of entrepreneurship and economic development, acting as an important part of local innovation infrastructure by directly providing capital for creativity, technologies, and new business ideas (Florida, 1993; Zook, 2002; Wray, 2012). Research on venture capital in economic geography mainly focuses on the following four aspects (Wray, 2012): (1) depicting the spatial layout (organizations and flow) and network structure of venture capital (Adler *et al.*, 2019), (2) institutional mechanism of geographical differentiation of venture capital (Alperovych *et al.*, 2020; Bustamante *et al.*, 2021), (3) geographical exclusion characteristic of capital (Kuebart, 2019; Lee *et al.*, 2019), and (4) “spatial proximity” in venture capital behavior (Colombo *et al.*, 2019). A preliminary study on venture capital and its network structure has been conducted (Pan *et al.*, 2016).

However, there are two deficiencies in the existing literature. On the one hand, research on the network structure of venture capital flow is still not enough. The venture capital network research usually does not clearly distinguish between the two different connections (the investment event connection and the total investment amount connection), nor does it investigate the heterogeneity of industry structure. On the other hand, research on the urban agglomeration network, especially venture capital network research, pays little attention to investigating the interweaving of mega-city regions with local- and national-scale urban systems (Li *et al.*, 2017). Analyses of inter-city connections at the local scale tend to ignore the hub function of urban agglomerations at the national level. As far as the GBA is concerned, its cross-system particularity makes “borders” have unique influences on the flow of capital, which is more innovative in venture capital case studies (Makkonen, 2016). Owing to scarce data from Hong Kong and Macao, venture capital research usually cannot fully reveal the degree of integration of Hong Kong and Macao in the capital network.

To have a deeper understanding of the venture capital network structure and its cross-scale dynamic in urban agglomeration areas, this article takes the case of the GBA, investigates the venture capital dynamic and network structure, and further determines the capital connection characteristics between the GBA and other node cities on the national scale. This study aims to examine three research questions: (1) Pattern: What are the distribution characteristics of venture capital entities in the GBA? What are the spatial structure and heterogeneity of the venture capital flow industry types? (2) Cross-scale connection and evolutionary characteristics: What are the structural dynamics of venture capital in the GBA, including the GBA scale as well as the national scale and its variation over time? (3) Mechanism: What is the formation mechanism of such a venture capital network structure in the GBA? Answering these three questions will provide empirical results for a deeper understanding of the functional network of urban agglomerations in the dimension of capital. Additionally, it will provide insights into the forming policies for sustainable development of urban areas in China.

Subsequent sections of the article have been structured as follows. Section 2 introduces

the regional context of the GBA and details related to the research data and methods of study. Section 3 analyzes the local characteristics, network patterns, and cross-scale connection characteristics of venture capital in the GBA. Section 4 analyzes the formation mechanism of this network pattern. Finally, Section 5 presents the conclusion and discussion.

2 Research design

2.1 Study area

The GBA, located in the coastal areas of southeast China, is the frontier of venture capital in China. The GBA includes nine cities in the PRD, namely Guangzhou, Shenzhen, Dongguan, Foshan, Zhongshan, Zhuhai, Huizhou, Jiangmen, and Zhaoqing. It also includes two special administrative regions, namely Hong Kong and Macao, with a total area of 56,000 km² (Figure 1). In 2020, its GDP reached RMB 11,365,477 million yuan, accounting for 11.2% of China's total GDP, and its resident population reached 8,617,200, accounting for 6% of China's total population¹.

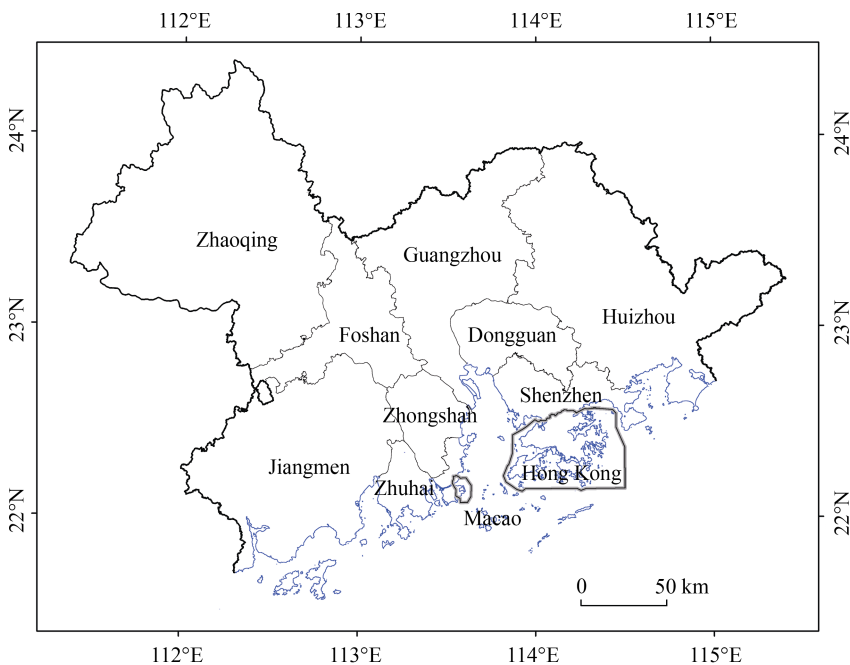


Figure 1 Study area (Guangdong-Hong Kong-Macao Greater Bay Area)

Owing to the convergence of diversified capital and multiple governance forces, and as one of the most typical export-oriented economic zones in China, the development of the GBA has been of interest to the academic society. Hong Kong and Macao have gone through a long integration process with the PRD, from the “front shop, back factory” labor division to comprehensive integration, and because of their special cross-system characteristics, the

¹ Economic statistics were obtained from the National Economic and Social Development Statistical Bulletin; Hongkong and Macau data was obtained from the Statistics Department of the Special Administrative Region Government; population data was obtained from the Seventh Census Bulletin

governance structure has been conceptualized as that of typical hybrid capitalism (Ye *et al.*, 2019; Wu *et al.*, 2021a). In 2019, the *Outline of Development Plan for Guangdong-Hong Kong-Macao Greater Bay Area* further clarified the GBA as a national strategic area. In this plan, the central government clearly proposes to build the GBA into a vibrant world-class urban agglomeration as well as an international science and technology innovation center with global influence. Such positioning reflects the development focus and ambition of the GBA at the next stage. This was immediately followed by the Guangdong Province and launched the *Three-year Action Plan for Guangdong Province to Promote the Construction of Guangdong-Hong Kong-Macao Greater Bay Area (2018–2020)*. This plan establishes 100 specific planning and implementation measures in detail for the next three years. According to the plan, building an international financial hub with Hong Kong and Macao is defined as the dominant task, specifically by supporting Guangzhou to build a regional private equity trading market, promoting Shenzhen to develop a capital market with the Shenzhen Stock Exchange as the core, and promoting Macao-Zhuhai cross-border deep financial cooperation. Promoting the establishment of a venture capital market to support the next stage of “innovation-driven” development and the transformation of the GBA will be one of the priorities of the GBA in the future.

2.2 Data

The venture capital data used in this article was sourced from the China Venture Capital Source (www.cvsources.com.cn). The data cover the venture capital events in China from 2000 to 2018 with firm-level data. The data attributes include the name and address of the venture capital institution, name and address of the venture capital receiving enterprises (startups), industry type, investment amount, capital ownership structure of the investment institution, etc. In this study, some data such as detailed investment information and investment institution information were supplemented by consulting “Qichacha (<https://www.Qcc.com/>),” “Tianyancha (<https://www.TianYancha.com/>),” and “ITJuzi (<https://www.itjuzi.com/>)” and searching for news related to investment events on the Internet. Investment events with missing information that could not be supplemented were excluded from the study. Finally, 29,816 data on investment events on the national scale and 2,260 data on investment events at the GBA scale (both the investment institutions and startups were in the GBA during the investment event) were retained. Based on the information of the cities where the investing companies and the invested companies are located, we transform the venture capital between enterprises (with direction) into the venture capital between cities. Furthermore, based on geocoding technology and through the Baidu API interface, the spatial databases of venture capital institutions and startups in the GBA were established, with 5406 and 3167, respectively. Notably, the investment database in this study does not include data from Macao, because it includes gambling and tourism as its pillar industries and does not have a high degree of involvement in the venture capital network in the GBA.

2.3 Method

2.3.1 Distance-based test of spatial concentration (DO approach)

The DO approach was used to identify the aggregation scale of actors related to venture capital in the GBA. The core logic of the DO approach algorithm is to estimate the kernel den-

sity distribution of the bilateral distances between all pairs of points (startups and venture capital institutions), and from the overall points, the counterfactual sample is constructed by random sampling to judge the aggregation scale of points (Duranton *et al.*, 2005; Wang *et al.*, 2016). The estimation of bilateral distances value based on kernel density function can be expressed as the following formula:

$$\hat{\lambda}_s(d) = \frac{1}{n(n-1)h} \sum_{i=1}^{n-1} \sum_{j=i+1}^n f\left(\frac{d-d_{i,j}}{h}\right) \quad (1)$$

where d_{ij} is the distance between enterprise points, h is the bandwidth, $f(*)$ is the Gaussian kernel function, and $\lambda_s(d)$ is the kernel density value of bilateral distances value. Based on this, we can get the kernel density distribution curves of all the values from point-to-point distance. From the kernel density distribution, the largest kernel density value is visible; that is, the points show a concentrated distribution at this distance scale. Only the distance value (Wang *et al.*, 2016) from 0 to 60 km was considered in this study. In order to obtain statistical test information on the scale of this agglomeration, in the DO approach, random sampling was used to extract sample points for the same distance and kernel density calculation process. After sorting the results of kernel density estimation in ascending order, the values below 5% and above 95% of normal values were extracted as the confidence interval. In this study, we used Monte Carlo random sampling to obtain 500 sample points and repeated sampling 500 times (Wang *et al.*, 2016). Based on sorting of the results from these 500 times of sampling, the confidence interval was obtained. We completed the calculation process of distance calculation, matrix operation, kernel density estimation, and random sampling of sample points based on latitude and longitude by programming in MATLAB.

2.3.2 Urban network building based on venture capital flows

Venture capital investment between cities has direction. The main investment entities of capital is enterprises rather than cities (Figure 2). The inter-firm investment is aggregated to the city scale to measure capital linkages between cities. This article examines the inter-city connection of venture capital from two dimensions, namely, the connection of investment events and the connection of total investment capital. The following formula was used to calculate the connection strength of capital flows (Zhang *et al.*, 2021).

$$C_{ij} = \sum_{t=1}^T \sum_{n=1}^N F_{nt:i \rightarrow j} + \sum_{t=1}^T \sum_{n=1}^N F_{nt:j \rightarrow i} \quad (2)$$

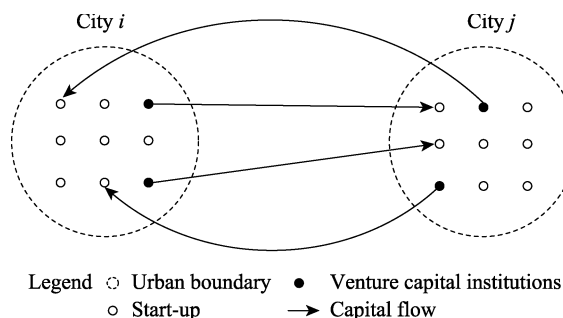


Figure 2 Venture capital connections between cities

where C_{ij} represents the investment connection between city i and city j . $F_{nt:i \rightarrow j}$ represents all investments from enterprises in city i to city j . $F_{nt:j \rightarrow i}$ represents all investments from enterprises in city j to city i . t represents the investment institutions in the city. N represents the investment of enterprise t to other cities (divided into two dimensions, namely total capital and invest-

ment connection events).

2.3.3 Social network analysis

Based on the relevant indicators of social network analysis, this article explores the network structure characteristics of venture capital flows on the city scale in the GBA. Eleven cities in the GBA were included as nodes, constructing the matrix of inter-city connection with data on venture capital flows based on enterprises (in two dimensions, namely total investment amount and investment events), and social network analysis was conducted based on an 11*11 matrix (with direction) to explore the functional structure of the network. It is worth mentioning that the venture capital network matrix is a multi-valued matrix. Three key indicators were used, namely, degree centrality, in-degree, and out-degree (Tahmasebi *et al.*, 2021; Zhang *et al.*, 2021). Degree centrality was used to describe the connection ability of node cities in the network. The larger the value of degree centrality, the stronger the connection function. In-degree and out-degree, respectively, measured the ability to receive capital and produce capital of the node cities. The social network analysis was completed using UCINET 6.

$$C_{out}(i) = \sum_{j=1}^n R_{out}(ij) \quad (3)$$

$$C_{in}(i) = \sum_{j=1}^n R_{in}(ij) \quad (4)$$

$$C'_{RD}(i) = (C_{out} + C_{in}) / (2m - 2) \quad (5)$$

The indicators can be defined as follows: $C_{out}(i)$ denotes the out-degree of node i , $C_{in}(i)$ denotes the in-degree of node i , $R_{out}(ij)$ is the number of investments from node i to node j ; $R_{in}(ij)$ is the number of investments that node i has accepted from node j ; $C'_{RD}(i)$ is the value of degree centrality, and m is the scale of the network. This study used the relative values of the three indicators.

3 The pattern and evolution of GBA venture capital flows

3.1 Location patterns of venture capital actors

Geocoding technology was used to establish the spatial databases of startups and venture capital institutions in the GBA, and the spatial patterns were observed by grid processing (8 km*8 km) of the GBA (Wu *et al.*, 2021a). The result shows that startups are concentrated in cities in the core circle of the GBA (Figure 3), forming high-value areas in Guangzhou and Shenzhen. Venture capital institutions are significantly more concentrated in a few areas, mainly distributed in the core areas of Guangzhou, Shenzhen, and Hong Kong. The differences in aggregation scale between the two were compared by the DO approach (Figure 4). Results show that the agglomeration scale of venture capital institutions is smaller, specifically characterized by startups forming a distance distribution peak at a scale of about 5 km, whereas the agglomeration peak of venture capital institutions is significantly smaller. Therefore, venture capital institutions are more concentrated.

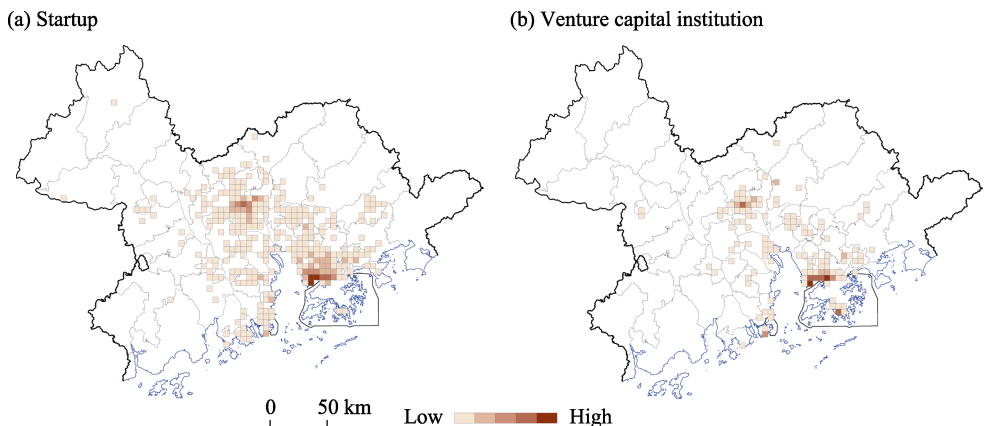


Figure 3 The distribution of the venture capital entity
Note: a and b are the grid-based spatial distributions of startup and venture capital institution, respectively.

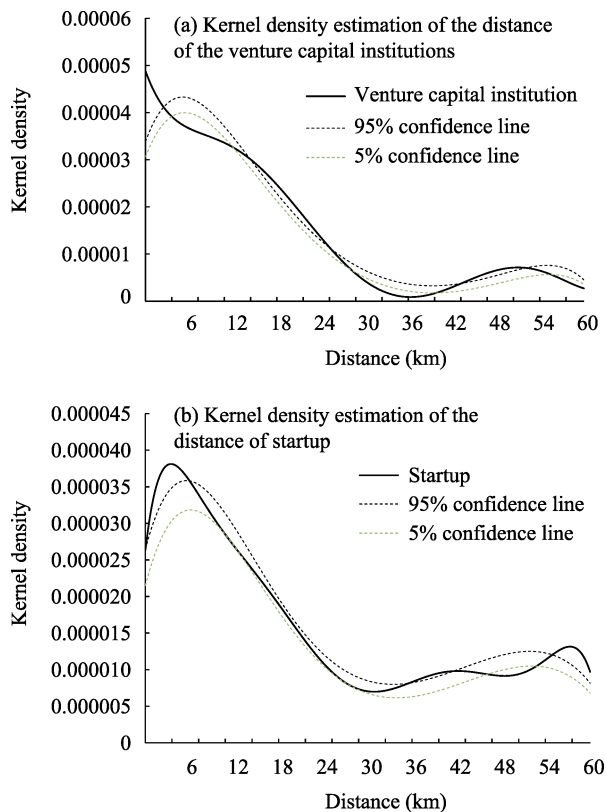


Figure 4 Kernel density estimation of the distance of the venture capital entities
Note: a and b are agglomeration distribution of startup and venture capital based on the DO approach, respectively.

3.2 The growth and evolution of venture capital in the GBA and its network structure

3.2.1 Growth and network structure

According to the overall evolution trend in the past 19 years, although the activity of the venture capital market in the GBA fluctuated in different years, it has maintained an overall

growth trend (Figure 5). China’s Growth Enterprise Market was officially launched in October 2009, which formed an important supplement to the Main-Board Market, greatly stimulated the innovating and entrepreneurial vitality of small and medium-sized enterprises, and formed a strong impetus to the venture capital market. In 2014, the slogan “mass entrepreneurship and innovation” was put forth, which marked the fostering of entrepreneurship to stimulate economic growth as the slogan of the national policy agenda. Since then, venture capital has grown further. Since 2017, there has been a certain decline in the global financial environment with the changes in the initial public offering (IPO) regulatory policy (Pan *et al.*, 2016).

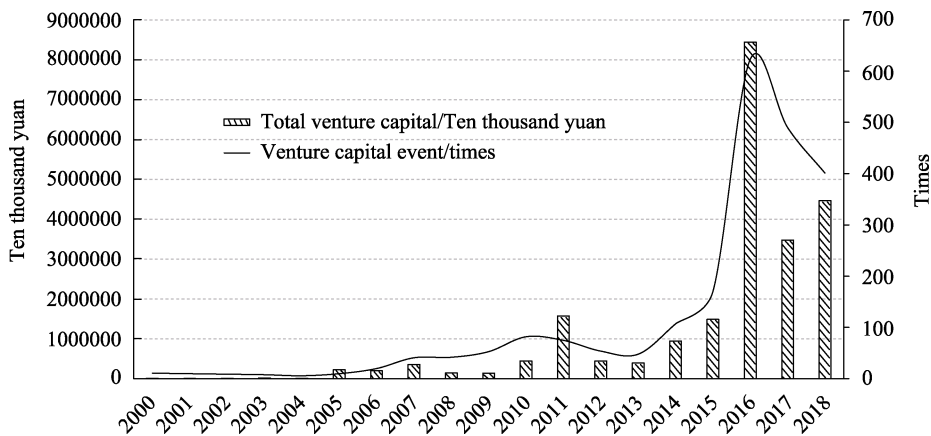


Figure 5 The growth of the venture capital in the GBA from 2000 to 2018

From the perspective of network connection, this article plots the venture capital connection map of investment events and total investment in the GBA. Based on these two key attributes, we determined the degree centrality of 11 cities (Figure 6 and Table 1).

First, in terms of total investment amount, Shenzhen, Guangzhou, and Hong Kong are first-tier cities, and the degree centrality has reached 15.422, 5.062, and 3.194, respectively. As for further distinguishing between in-degree and out-degree, Shenzhen is a venture capital city with high investment and high absorption, Hong Kong is a typical investment-oriented city in the GBA network, and Guangzhou is a typical absorption-oriented city. Zhuhai and Foshan are second-tier cities. From the perspective of network connection, apart from the original close connection between Guangzhou, Shenzhen, and Hong Kong, relatively high capital connection strength has also formed between Hong Kong and Foshan, and Guangzhou and Zhuhai.

Second, from the perspective of investment events, the GBA shows a different spatial pattern from the total capital. Shenzhen and Guangzhou are first-tier cities in the GBA, and their degree of centrality has reached 13.44 and 4.506, respectively. This shows that these two cities are the ones with the highest activity of venture capital in the GBA at present, and from the perspective of degree centrality, they are far ahead of other cities. Zhuhai, Hong Kong, and Dongguan are at the second level, while the capital activity of peripheral cities such as Zhaoqing, Jiangmen, and Huizhou is still not high. From the perspective of network connection, Shenzhen has formed a very strong capital connection with Hong Kong, Guangzhou, Zhuhai and Dongguan.

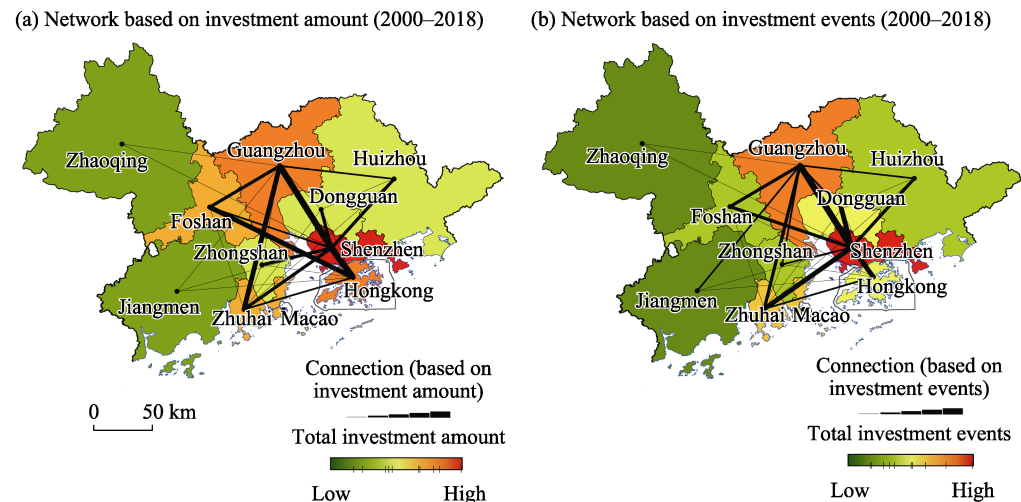


Figure 6 The venture capital network of the GBA from 2000 to 2018
Note: “total investment amount” is defined as the sum of city a and b investing and receiving capital; “investment event” is defined as the sum of the events of city a and b investing and receiving investment; a and b are the urban network structure based on the two links of investment amount and investment event, respectively.

Table 1 The urban centrality of 11 cities in the GBA

	Based on total investment amount			Based on investment events		
	Degree centrality	Out-degree	In-degree	Degree centrality	Out-degree	In-degree
Shenzhen	15.422	13.227	12.195	13.44	13.16	11.175
Guangzhou	5.062	2.663	3.701	4.506	2.708	4.156
Hongkong	3.194	2.905	0.373	0.638	0.638	0.125
Zhuhai	1.464	0.794	1.015	0.7	0.591	0.553
Foshan	1.415	0.256	1.342	0.327	0.117	0.327
Huizhou	0.745	0.357	0.694	0.311	0.047	0.311
Dongguan	0.626	0.134	0.535	0.576	0.249	0.568
Zhongshan	0.474	0.106	0.463	0.21	0.047	0.21
Jiangmen	0.135	0.06	0.131	0.086	0.023	0.086
Zhaoqing	0.053	0.001	0.053	0.078	0.008	0.078

3.2.2 Capital flow direction and structural differentiation

The flow of capital is directional, while the structural differences between capital input and output are ignored from the network connection perspective. This study further spatialized various types of venture capital flows to present the capital flow pattern in the GBA more accurately (owing to the limitation of the spatialization diagram, this article only shows the main venture capital flows that reflects the core structure in the GBA) (Figure 7).

According to the overall capital flow pattern (Figure 7a), the GBA presents a core city-oriented venture capital structure, with Guangzhou, Shenzhen, and Hong Kong being the core capital output and receiving cities. The largest volumes of venture capital output and input come from Shenzhen and Hong Kong, and the largest venture capital flows in the GBA are those from Shenzhen to Guangzhou, from Hong Kong to Shenzhen, and from Hong

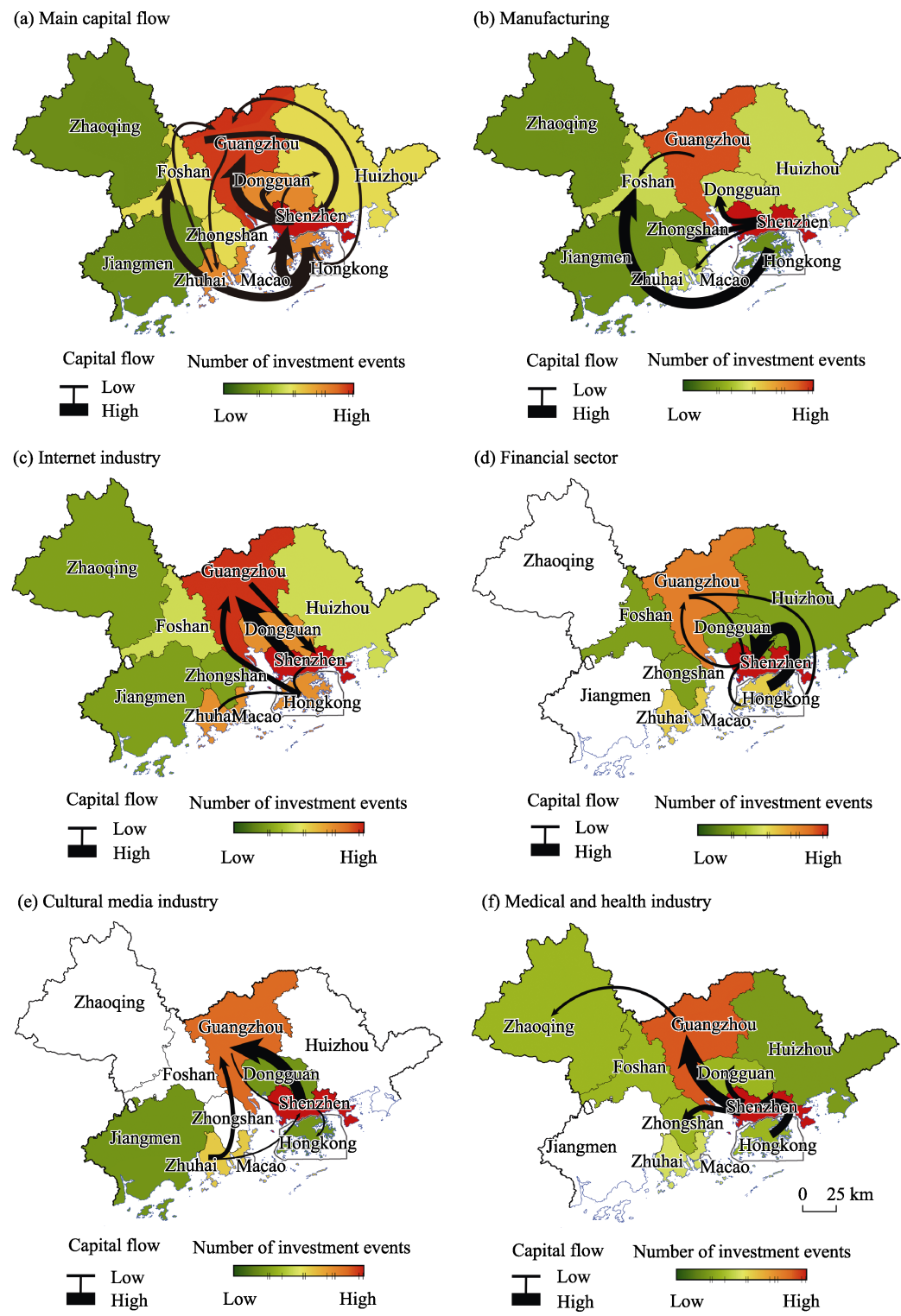


Figure 7 The flow of venture capital in core industries in the GBA

Note: a, b, c, d, e and f are spatial distribution of investment events and the major venture capital flows of the total and the five major industry types, respectively.

Kong to Guangzhou. The results show that the main capital flows in the GBA are concentrated in core cities along the banks of the Pearl River. However, the network participation of peripheral cities is not very high.

This study further subdivided the flow of venture capital according to the differences in industry types and selected the top five industry types in terms of venture capital amount, namely manufacturing, the Internet industry, the financial sector, the cultural media industry, and the medical and health industry¹, to study the industry type differentiation of venture capital flows. The flow directions of venture capital in these five industries were spatialized (Figure 7b, c, d, e, and f).

The flow of venture capital in the GBA shows significant structural differentiation. The capital flow directions of different industry types are closely related to the characteristics of the local industrial structure. According to the flow of venture capital in the manufacturing sector (Figure 7b), as the most typical manufacturing cities in the GBA, Foshan, Zhongshan, and Zhuhai are the three largest receiving cities of venture capital. The largest venture capital flow direction in the manufacturing sector in the GBA is from Hong Kong to Foshan. With respect to the Internet industry (Figure 7c), the flow directions of venture capital are mainly concentrated in Guangzhou and Shenzhen, the two most developed areas of the Internet industry. The largest capital flow at the regional level is the mutual investment between Guangzhou and Shenzhen, and the capital flows from Hong Kong to Guangzhou and from Shenzhen to Zhuhai also occupy a very large proportion in the region. As for the financial industry (Figure 7d), the flow of venture capital is more concentrated in a few cities. Shenzhen is the largest financial capital-receiving place in the GBA. The largest capital flow at the regional level is from Hong Kong to Shenzhen. These two cities are the most important financial cities in the GBA. With regards to the cultural media industry (Figure 7e), Guangzhou has become the largest venture capital receiving city in the GBA, mainly receiving investment from Shenzhen and Zhuhai. The largest capital flow direction in the GBA is from Shenzhen to Guangzhou. Venture capital is active in the cultural media industry in Zhuhai, and the investment from Zhuhai to Guangzhou and Shenzhen is relatively prominent at the regional level. In terms of the medical and health industry (Figure 7f), the major capital flows in the GBA are those from Shenzhen to Guangzhou and from Dongguan to Zhongshan. Besides, a phenomenon in this field is that the peripheral cities in the GBA have also participated in the core investment network. Additionally, the investment amount from Guangzhou to Zhaoqing is prominent at the regional level.

3.3 Capital Hub: The GBA's multi-scale venture capital collaboration pattern

The inter-city capital connection exists not only between cities on the GBA scale. There must be cross-regional capital connections since Hong Kong and Shenzhen are both typical world-class financial cities. It might ignore the capital hub function of the GBA on the national scale by only analyzing the capital network within the region (Li *et al.*, 2017). On the national scale, this article screens the cities closely related to capital in the GBA and integrated several key indicators, such as the number of startups (invested enterprises), number of venture capital institutions, number of venture capital events, and the total amount of

¹ This industry type classification is based on the classification in the venture capital event database.

venture capital. This article takes the selected top 20 cities in China as active cities in the field of venture capital. The total number of investment events in these 20 cities, together with the GBA, accounts for 83% of the total data, which is enough to support the cross-scale analysis of venture capital structure. Furthermore, considering the time of the establishment of the Growth Enterprises Market (2009) as a node, venture capital showed two different growth trends around 2009. This paper built this cross-scale urban capital collaborative network by diving into time periods to further study the evolution of the urban network. Owing to the limitation of the spatialization diagram, we only display the connections between cities with more than 10 mutual investment events instead of all the connections between cities.

Figure 8 shows the cross-scale network structure of venture capital connections in the GBA. The sizes of city nodes shown in the figure represent the total amount of venture capital in the city (invested + received, representing the city's capital activity), and the capital connections between cities are expressed by the number of events of mutual investment between cities. The following conclusions can be drawn from the network structure in Figure 8.

First, on the regional scale, the GBA has formed a network structure of venture capital cities dominated by three core cities, namely Guangzhou, Shenzhen, and Hong Kong, and the periphery of the network structure mainly includes cities such as Dongguan, Zhuhai, Zhongshan, and Foshan. After 2009, the total amount of venture capital in the remaining GBA cities only accounted for 8.74% of the three core cities. The strength of capital's external connection is only 26.27% of that of the three core cities. On the scale of the GBA, big cities tend to be the core of the capital network structure, suggesting that innovations in big cities can obtain capital support more conveniently. Although there are institutional obstacles, the geographical and cultural proximity of Hong Kong to Shenzhen and Guangzhou have also contributed to the formation of intensive capital links between these three cities.

Second, on the national scale, the GBA has formed a more intensive capital connection network with major core cities in China. Beijing, Shanghai, and Hangzhou, together with Guangzhou, Shenzhen, and Hong Kong within the GBA, have formed six national-level capital cities, which are prominent on the national scale. In addition, Nanjing, Tianjin, Suzhou, Chengdu, and other regional capital cities have also formed intensive capital connections with the GBA. Other cities in the GBA have not become capital cores on the regional scale, which indicates that the current venture capital connections still mainly occur between core cities. The national-scale analysis reflects the impact of capital hub cities on the structure of venture capital networks. Although intensive capital linkages have been formed between cities in the GBA, more intensive capital linkages still occur between the GBA and Beijing, Shanghai and Hangzhou. As the city with the highest degree of external ties in the GBA, Shenzhen's capital ties with Guangzhou and Hong Kong before 2009 were only 14.36% of those with Beijing and Shanghai. Although this figure has risen to 16.5% since 2009, it still reflects the impact of national capital hubs such as Beijing and Shanghai on the GBA capital network. This also verifies the importance of cross-scale analysis for venture capital network research. The results of this study elucidate that in the venture capital network, the influence of factors such as institutional proximity, cognitive proximity, and organizational proximity is more important than geographical proximity. In addition to the

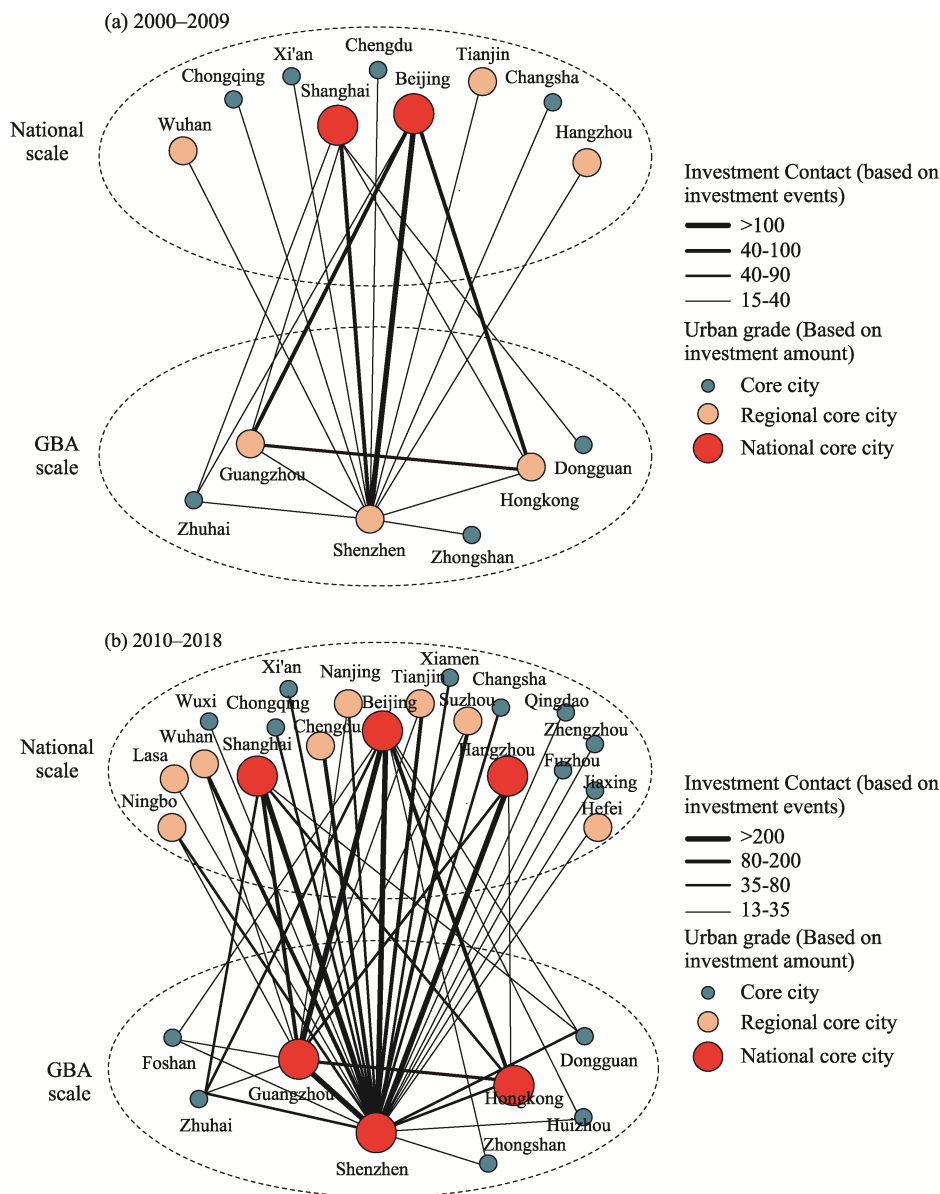


Figure 8 The structure and evolutionary characteristics of the cross-scale capital collaboration network in the GBA

Note: a and b are the cross-scale venture capital network structure of GBA in 2000–2009 and 2010–2018, respectively.

capital hub cities of the GBA, other cities are also obviously affected by the national scale. Foshan and Dongguan are both important manufacturing bases of the GBA. Since 2009, the capital interaction between Foshan, Beijing, and Shanghai accounted for 73.68% of that with Guangzhou and Shenzhen, while the value of Dongguan has reached 150%. The results show that the regional scale network was shaped by the global scale network.

Third, from the perspective of the evolution of the urban network, only Beijing and Shanghai were national-level capital cities on the national scale, which dominated the capital network structure on the national scale before 2009. From 2009 to 2018, the GBA was fully

integrated into the national venture capital connection network. Guangzhou, Shenzhen, and Hong Kong have quickly emerged as the national-level capital cores. Similarly, before 2009, a capital network structure involving only a few cities was formed on the national scale, and regional cities such as Tianjin, Wuhan, and Hangzhou participated in the capital network in the GBA. From 2009 to 2018, with the tide of innovation and entrepreneurship as well as the springing up of venture capital, more regional capital core cities and capital nodes appeared, and the whole network structure became more complex. This also shows that further improvement of the national capital market system as well as innovation and entrepreneurship system promoted the continuous improvement of capital collaboration between cities.

4 The mechanism of the GBA venture capital pattern

4.1 Multi-dimensional proximity

Venture capital behavior has the significant characteristic of “proximity” (Tian *et al.*, 2020). The significant characteristic of high risk means that the selection of investment objects and the protection of investment returns have become core concerns in venture capital behavior (Wray, 2012). Therefore, “pre-assessment” and “post-monitoring” that can narrow the industry information gap have become the core operation mechanism of venture capital (Masucci *et al.*, 2021). One of the strategies to reduce investment risk and improve communication outcomes is to select the investment target based on the criterion of “proximity” (Zook, 2002; Pan *et al.*, 2019). This “proximity” includes not only geographical proximity but also multi-dimensional proximity conceptualized in evolutionary economic geography, including institutional proximity, organizational proximity, cognitive proximity, etc. (Boschma, 2005). Through “proximity”-based investment, venture capitalists can utilize their own social information network to obtain information on the investees and evaluate the transactions, and at the same time provide operational assistance to the invested enterprises based on the industry knowledge accumulation and their own network relationship (Enkel *et al.*, 2020). The mechanism of multi-dimensional proximity explains why there is a clear pattern of collaboration between the core and the periphery in the GBA. At the same time, Guangzhou, Shenzhen, and Hong Kong have formed closer cross-scale capital connections with Beijing, Shanghai, and Hangzhou on the national scale, respectively. China’s rapid development of high-speed railways in recent years has weakened the geographic distance between the GBA’s interior and exterior. The compression of space-time distance promotes the long-distance spread of capital. The promoting effect of space-time compression on the growth of venture capital has also been confirmed by many empirical studies (Dong *et al.*, 2020; Duan *et al.*, 2020; Tian *et al.*, 2020). In the formation mechanism of this mode, while geographical proximity has played a great role and geographical proximity has driven cities such as Dongguan and Foshan to obtain a large amount of manufacturing investment from Hong Kong and Shenzhen. Dimensions such as institutional proximity and cognitive proximity have also played a tremendous role, forming closer capital connections between the major capital centers in the country.

4.2 Institutional factors

With the support of the central government, Shenzhen successfully developed its capital

market after the reform and opening up. Shenzhen Stock Exchange was established in 1990 (Zacharias *et al.*, 2010). In 2009, the Growth Enterprise Market was established to provide a platform for the growth of technological innovation enterprises. In 1991, the Shenzhen Stock Exchange's annual transaction value was RMB 3.56 billion yuan, which has grown to RMB 162.22 trillion yuan in 2020. The transaction value of the ChiNext market also reached 46.67 trillion yuan in 2020, 255 times that of 2009. In 2010, the State Council approved the Qianhai Master Plan, and one of the core objectives of Shenzhen's urban development was to gather offshore RMB outside the Chinese mainland (Chen *et al.*, 2015). Because of a series of special policies, major banking institutions and financial practitioners swarmed into Shenzhen, consolidating its position as an international financial center (Chen *et al.*, 2015). In 2021, Shenzhen ranked fourth in the world in the number of IPOs, making it a financial center that cannot be ignored in the world. Hong Kong has always played a critical role in the overall financial system of the country because of its special history of urban development and the "one country, two systems" policy (Wang *et al.*, 2021). Institutional factors have promoted these two cities to become the core of venture capital for the GBA.

4.3 Urban economy and path dependence

As the national capital hub, the formation mechanism of the GBA also includes two key mechanisms, namely, urban economy and path dependence (Chen *et al.*, 2015). As the unique international financial cities in the GBA, Hong Kong and Shenzhen have gathered the major financial enterprises and financial practitioners in China. This high concentration of financial factors has produced a great Marshallian-localization economy (Marshall, 1890; Florida *et al.*, 2017; Wu *et al.*, 2021b). Through the geocoding of venture capital entities, this study found that 62.47% of startups are located in Shenzhen and Hong Kong, and the proportion of venture capital institutions is 80.04%. This agglomeration effect, strengthened by path dependence (Boschma *et al.*, 2006), has deepened the specialization effect of Hong Kong and Shenzhen on the national and even global scale and has continuously promoted technological spillovers and innovations in the financial service fields of the two places, thereby continuously improving the position of the financial center and development of the capital market. The Gini coefficient of venture capital distribution was as high as 0.8004 in 2000. Although it decreased to 0.7435 in 2018, it can still be seen that the capital distribution is extremely uneven, that is, 69.99% of the GBA venture capital flows are related to Shenzhen and Hong Kong. The degree centrality results based on capital flow also reflect the path-dependent nature of this development. Before 2009, the degree centrality of Hong Kong and Shenzhen were 25.885 and 14.442, respectively. After 2009, they were 12.958 and 26.195, much higher than other cities. These mechanisms have further promoted the formation of the current GBA's complex venture capital network structure.

5 Conclusions and discussion

5.1 Conclusions

As urban agglomeration becomes an important spatial unit of capital accumulation and the innovation transformation of the economic development, as important capital support for innovation, the flow and dynamics of venture capital have become the frontier of research

on urban agglomeration spatial networks. Although existing studies have explored venture capital-based urban network structure, there is still a lack of attention to industry heterogeneity and cross-scale research. In particular, the GBA has rarely been examined as a case study. Combining the DO approach and methods of social network analysis based on a long-term series of venture capital data, the venture capital network structure of the GBA was deeply explored, including its industry heterogeneity characteristics, cross-scale network structure, and evolutionary characteristics.

First, the distribution of venture capital institutions and startups in the GBA shows a remarkably high concentration, with distribution mainly in the core areas of Guangzhou, Shenzhen, and Hong Kong. The network structure of venture capital also presents a core-periphery structure mainly consisting of a few core cities. Additionally, the flow of venture capital shows significant structural differentiation, mainly concentrated in five industries, namely manufacturing, the Internet industry, the financial sector, the cultural media industry, and the medical and health industry. The flow of venture capital in these types of industries is closely related to its local industrial structure background.

Second, a cross-scale analysis of venture capital network structure reveals the hub function of the GBA on the national scale. On the regional scale, the GBA has formed a network structure with Guangzhou, Shenzhen, and Hong Kong as its absolute core. It has formed a dense venture capital connection network on the national scale. In addition, after nearly 20 years of development, a dense venture capital network has been established on a national scale, with Beijing, Shanghai, and Hangzhou, and Guangzhou, Shenzhen, and Hong Kong dominating the network structure.

Thirdly, three key mechanisms, namely, multi-dimensional proximity, institutional factors, urban economy and path dependence, have promoted the network structure of venture capital in the GBA. The “proximity” characteristic of venture capital behavior has promoted the GBA to become a national-scale venture capital hub. The institutional factor is an important reason that Shenzhen and Hong Kong have become the core cities of venture capital. Urban economy and path dependence have promoted the spillover and innovation of financial functions in the GBA core cities, thus, continuously promoting the growth of their financial center status and development of the capital market.

5.2 Discussion

As an important element of innovation flow, the research on the structure of the venture capital network has important theoretical implications in both urban agglomeration network research and innovation network research. The network structure of urban agglomerations from the perspective of capital flow reveals the characteristics of cross-scale capital connections and the status of the GBA as a capital hub in China. In the study of network structure, we found a network structure that is different from traditional flow elements such as traffic flow and logistics, that is, the higher concentration of capital. The formation mechanism of this network structure combines innovation network theory with flow space theory. Urban geography reveals the role of diversity and urbanization economy on local innovation. These key mechanisms promote the agglomeration of capital. The relational turn of economic geography coincides with the perspective of flow space, such as local buzz and global pipelines, global production network reveals the characteristics of local links and cross-scale

links of knowledge, and the research based on venture capital in this paper also responds to these theories.

Our research is one of the few papers that systematically reveals the industry structure differences, cross-scale connections, and evolutionary characteristics of venture capital. Based on the GBA case, Hong Kong is also included in the venture capital network, which forms a case supplement to previous research on venture capital. The analysis based on the spatial data of venture capital entities shows the differences in the distribution of different venture capital entities, and the analysis of the network structure based on the cross-scale urban agglomeration also shows the GBA's status as a national venture capital hub and its growth.

Notably, this research has thrown up many questions in need of further investigation. First, the collection of venture capital data is difficult, coupled with the fact that venture capital events cannot disclose the exact investment amount owing to confidentiality and other reasons, which makes the research of the venture capital network have possible sample bias and cannot fully demonstrate its network structure. Various channels supplement our database, but the construction of the database still needs to be improved. Second, the flow of innovation capital is not limited to regional or national scales, and there is no political boundary to the flow of capital. The research based on the GBA and national scale cannot fully reveal the capital hub function of the GBA. Further in-depth analysis of venture capital data on a global scale is needed. It is believed that Hong Kong's and Shenzhen's capital hub functions will be further highlighted with more comprehensive data. Third, the formation mechanism of the GBA's venture capital network structure has not yet been comprehensively and deeply analyzed. Further in-depth research is needed combining qualitative and quantitative methods to quantify key influencing factors, interviews with venture capitalists, startups, and competent government authorities are also needed for further investigation.

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