Re-examination of Shanghai's construction of a global science and technology innovation center under the great changes: based on the dual perspectives of "knowledge cooperation" and "knowledge combination"

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Abstract: The Shanghai City Master Plan (2017—2035) has set forth the goal of building a Global Science and Technology Innovation Center (GSTIC). However, since the Plan's approval, profound changes not seen in a century have been accelerating. Shanghai faces significant challenges in realizing its GSTIC goal. Drawing on data from global scientific publications, this paper analyzes Shanghai's evolving char - act eristics in the global science and technology (S&T) landscape during this period of great change by constructing models of global network of knowledge collaboration and global network of knowledge combination. The analysis yields several key insights. Firstly, facing external environmental changes, Shanghai's position in the global network of knowledge collaboration has improved significantly, although gaps still exist between the city and top-tier global S&T innovation centers. Secondly, Shanghai ' s 'hinge' function has undergone structural adjustments, showing a marked decrease in outdegree and a notable increase in indegree. Thirdly, Shanghai occupies a pivotal position in the global network of knowledge combination, demonstrating strong comparative advantages in traditional realms of applied engineering while lagging behind in emerging frontier fields. Lastly, the development of Shanghai's S&T innovation capacity exhibits both path dependency and path regeneration while con - fronting a risk of path lock-in.

Keywords: Shanghai; global innovative center; the great change; knowledge collabo - ration networks; knowledge combination networks

Scientific and technological innovation is the first driving force for economic development and social progress, and has become the main battlefield for global competition and strategic games in the 21st century [1]. The arrival of a new round of scientific and technological revolution has overturned the previous paradigm of scientific research and technology research and development: on the one hand, scientific and technological innovation increasingly relies on large-scale open cooperation to realize the continuous updating of the existing knowledge base and share the risks in the innovation process. and cost [2-3]; on the other hand, scientific and technological innovation increasingly relies on exploratory cross-field crossovers. The cross-integration of different cutting-edge disciplines continues to generate new scientific ideas and scientific theories, and the reconstruction and reorganization of different advanced technologies. Continuously create new future scenarios and market space [4,5] . In other words, the process of contemporary scientific and technological innovation is rooted in two different types of networks: one is a " knowledge cooperation network " formed by the collaborative interaction of different innovation subjects, and the other is formed by heterogeneous knowledge in different fields in a specific way. The " knowledge combination network " formed by combination [6] . In the fierce global science and technology competition, occupying the core position of the knowledge cooperation network means having strong control over innovation resources, information channels and relationship assets. Occupying the core position of the knowledge combination network means having strong control over knowledge combination opportunities and cross-field potential. Strong control ability. Cities are incubators of innovation, providing necessary agglomeration economies, scale effects, environmental protection and policy support for innovation [7,8] . Building a " global science and technology innovation center " has become an important starting point for all countries to actively participate in the new wave of scientific and technological revolution, promote national competitiveness, and transform old and new driving forces [9] . In 2015 , in order to adapt to the new trends of global scientific and technological competition and economic development, and to face the national innovation-driven development strategy, the Shanghai Municipal Party Committee and Municipal Government issued the "Opinions on Accelerating the Construction of a Globally Influential Science and Technology Innovation Center", which kicked off Shanghai's promotion of globalization. The curtain on the construction of the Science and Technology Innovation Center. In 2017 , the "Shanghai Urban Master Plan (2017-2035)" (hereinafter referred to as the " Shanghai 2035 Master Plan ") was approved by the State Council. The Shanghai 2035 Master Plan proposes the overall goal of Shanghai becoming an " excellent global city " , and expands the four central functions of international economy, finance, trade and shipping and adds the function of " global science and technology innovation center " [10-11] . Building Shanghai into a global science and technology innovation center is not only a major task and strategic mission entrusted to Shanghai by the Party Central Committee, but also the only way for Shanghai to move forward in high-quality development and move the city's energy level and core competitiveness closer to the top global cities. It is also the only way for China to move towards world science and technology. An important support for the advancement of powerful countries [12] . However, since Shanghai officially established itself as a global science and technology innovation center, drastic changes have taken place in both the external and internal development environment: major changes unseen in a century have been combined with the global pandemic of the century, the competition between major powers has intensified significantly, and the international political and economic situation has The landscape is complex and ever-changing; unilateralism, protectionism, and hegemonism are on the rise, posing a threat to world peace and development. Globalization has encountered countercurrents, and economic recovery momentum has been weak [13] . In 2018 , the United States unilaterally provoked a " trade war " against China in an attempt to curb China's rapid rise in international status, and Sino-US economic and trade frictions heated up sharply. Subsequently, the United States' containment of China quickly spread from the economic and trade fields to the field of scientific and technological innovation. Through administrative controls, judicial proceedings, diplomatic pressure, and alliances, it suppressed China's scientific and technological development in all aspects, unilaterally cut off transnational scientific and technological cooperation, and China and The trend of " technological decoupling " between the United States and its allies has intensified, and some key technological fields are " stuck " . In May 2022 , "Nature" magazine published a relevant report on Sino-US scientific and technological cooperation, pointing out that under the influence of the " technological decoupling " between China and the United States, the total amount of Sino-US scientific research cooperation showed a " cliff-like " decline from 2019 to 2021 . As an important strategic fulcrum for the country to build a scientific and technological power, Shanghai is first faced with major challenges brought about by profound changes in the internal and external environment. While unswervingly adhering to

Shanghai's goal of promoting the construction of a global science and technology innovation center, it is necessary to conduct an in-depth analysis of Shanghai's evolution and development trends in the global science and technology innovation landscape during the period of great changes. This is essential for accurately judging Shanghai's strategy for building a global science and technology innovation center. It is crucial to implement the effect and adjust strategic deployment based on the situation. In view of this, this study starts from the scientific research dimension, uses Clarivate Analytics (Essential Science Indicators , ESI) highly cited paper data, and targets 700 major cities around the world to build a " global knowledge cooperation network " and a " global knowledge combination network " ” , analyzing the evolving characteristics of Shanghai' s position in the global science and technology innovation map during the period of great change (2017-2022) from the two dimensions of knowledge cooperation and knowledge combination, analyzing current challenges and future trends against top science and technology innovation centers, and helping Shanghai to advance Construction of a global science and technology innovation center .

1Theoretical review

1.1Global science and technology innovation center: connotation and extension

The concept of "global science and technology innovation center" first originated from the study of the history of science, and is used to refer to those countries that ignited the fuse of technological explosions and set off a wave of scientific and technological changes in the history of human civilization [14] . Since the 1980s, some economic geographers have noticed that cutting-edge science and key technologies are often concentrated in a very small number of cities in developed countries. These cities are the main driving force for national economic development and aggravate the differentiation of the world pattern [15] . Since then, the discussion and research on global science and technology innovation centers has moved from the national level to the city level, and many results have emerged in terms of connotation definition, evaluation system and international comparison, which have had a wide impact on the formulation of national and urban innovation policies [16].

In terms of connotation definition: Du Debin et al. [16] believe that a global science and technology innovation center is a city with concentrated scientific and technological innovation resources and a wide range of scientific and technological achievements, leading the transformation of the world's science and technology-industrial paradigm, and occupying a dominant position in the global science and technology innovation map; Global Science and Technology The innovation center has two basic functions of scientific research and technology research and development, and two derived functions of industry driving and cultural leadership. It shows functional dominance, structural hierarchy, spatial agglomeration, industrial high-end and cultural inclusiveness in the global science and technology innovation landscape. [9,17] . In terms of evaluation systems and international comparisons , relevant results mainly come from think tanks or business consulting organizations, such as the "Global Innovation Index (GlobalInnovationIndex)" of the World Intellectual Property Organization (WIPO) , and the "Urban Innovation Index" released by the Australian think tank "2thinknow" (InnovationCityIndex)", the "International Science and Technology Innovation Center Index" released by Tsinghua University and the "Global Science and Technology Innovation Center Development Index" released by East China Normal University. These studies have important reference value for clarifying the connotation of global science and technology innovation centers, tracking the geographical process of the evolution of the global science and technology innovation landscape, and for countries and cities to formulate science and technology innovation policies.

The above studies mainly focus on the city's resource element endowment, environmental institutional support and scientific and technological knowledge production, and can generally be regarded as a research and evaluation paradigm based on the "input-output" linear logic. Although the dimensional indicators refined under this paradigm have important implications for relevant policies. It is easier to find the starting point for action in terms of formulation and launch, but they are only necessary conditions for innovation but not sufficient conditions. To a certain extent, they ignore the complexity and non-linear characteristics of contemporary scientific and technological innovation. In today's ever-changing era of technological explosion, any cutting-edge or cutting-edge technology will inevitably become obsolete and eliminated at some point in the future [18-19] . Therefore, for an in-depth analysis of the connotation of global science and technology innovation centers, we can break through the basic logic of "input-output" and conduct extended discussions based on the changes and trends in contemporary science and technology innovation paradigms. As mentioned at the beginning of this article, the two most prominent features of contemporary scientific and technological innovation are large-scale open collaboration and cross-domain knowledge crossover. Therefore, for global scientific and technological innovation center cities, in addition to resource endowment and institutional support, embedding into the global knowledge cooperation network and occupying the core position of the network are also effective ways to continuously acquire new knowledge and avoid path lock-in [20] . At the same time, in addition to paying attention to knowledge production, we need to pay more attention to the way of knowledge production. Compared with the incremental innovation formed by the combination of homogeneous knowledge in the same field, the breakthrough innovation formed by the combination of heterogeneous knowledge in different fields is more critical [21] .

1.2 Dual network perspective: " knowledge cooperation network " and " knowledge combination network "

" Knowledge Cooperation Network " emphasizes the important role of open interaction and external resources in the development of urban innovation. Contemporary scientific and technological innovation presents unprecedented system complexity, deeper and broader interdisciplinary nature, and more significant risks and uncertainties. Therefore, it increasingly relies on the establishment of multi-scale and multi-dimensional cooperation networks [2] . The resources of urban local technology base are limited. Actively participating in cross-border innovation cooperation and forming a collaborative network are inevitable choices to maintain and enhance innovation competitiveness and avoid path dependence and technology lock-in [22] . By establishing and accessing external cooperation networks, cities can obtain new external knowledge and information, and achieve self-renewal and optimization and adjustment [20] . Therefore, the open innovation strategy has been greatly praised [23] . In terms of empirical research: Mat - thiessen et al . [24] used WoS data to study the structural characteristics, hierarchies and evolution processes of global city knowledge cooperation networks. However, the samples they focused on were mainly European and American cities, making it difficult to fully depict the global science and technology innovation landscape. and the rapid growth of cities in new economies; Gui Qinchang et al. [25] used WoS data to construct and analyze scientific research cooperation networks in more than 900 cities around the world, and further explored the impact of multi-dimensional proximity on network structure, but did not develop a historical Sexual analysis; Cao Zhan et al. [3] used WoS data to analyze the evolutionary characteristics of scientific research cooperation networks in more than 500 cities around the world from 2006 to 2018 , and focused on analyzing the rise of Chinese cities.

" knowledge combination network " emphasizes the decisive role of the endogenous dynamics of knowledge evolution in urban innovation development. The birth of new knowledge comes from the combination and reconstruction of existing knowledge [26] . For example, in 2021 , the AlphaFold artificial intelligence system developed by DeepMind was able to predict 214 million protein structures from more than 1 million species , covering almost all known proteins on the earth, achieving unprecedented and huge progress in the field of protein structure prediction. . This innovative breakthrough comes from the cross-fusion of relevant knowledge in the field of artificial intelligence and knowledge in the field of structural biology. This process can also be regarded as the process of different knowledge combinations being reconstructed into a knowledge combination network. The formation of knowledge networks is not random. Whether different knowledge can form valuable and meaningful combinations and form effective innovations depends not only on the understanding, absorption and application of it by the innovation subject, but also on the objective internal self-organization between these knowledges. logic [27] . Due to the limited rationality of innovative subjects, local search characteristics and the uncertainty of knowledge combination, the combination and reconstruction of knowledge are often limited to mature scientific and technological fields in cities [28] . In other words, the success of knowledge combination depends on the correlation (relatedness) between different knowledges. A higher correlation indicates that the innovative subjects in the city have a similar cognitive basis for these different knowledges, and the related industries have a similar cognitive basis for these different knowledges. The utilization and processing have similar infrastructure and management methods [29] . This law is called the " law of association " by economic geographers [30] . The correlation law explains the dynamic mechanism of the formation and evolution of knowledge combination networks from a micro level. The direct result is that urban innovation shows significant path dependence characteristics, that is, the generation of new urban knowledge is constrained by its existing knowledge base [29] .

However, there is heterogeneity between different knowledge. For some very complex knowledge, even if it has a high correlation with the existing knowledge of the city, it is difficult for all cities to master it skillfully and freely combine it. For example, in 2022 , one of the top ten scientific breakthroughs selected by Science magazine was the in-depth research and breakthrough innovation of Chinese scientists on perennial hybrid rice. Although many countries and regions around the world possess knowledge related to rice cultivation and production, it is extremely difficult to develop and cultivate high-quality, high-yielding, and specific hybrid rice, which requires a huge amount of knowledge accumulation, scientific equipment, and scientific talents. High requirements are often only mastered by a few countries and places. In other words, what determines the competitiveness of urban technological innovation is highly complex cutting-edge knowledge, but it is often difficult to copy and imitate, and is only mastered by a few cities [31] . Although it is extremely difficult to study and develop this kind of complex knowledge, it also has high benefits [32] .

Therefore, by superimposing the knowledge complexity dimension on the basis of the knowledge relevance dimension, an analytical framework can be constructed to explain and judge urban knowledge combination opportunities and innovative development paths [33] . As shown in Figure 1 , the Highly relevant to the local knowledge base, with low risk of recombination and exploitation (high relevance); the lower right quadrant indicates that the city possesses knowledge with lower returns (low complexity) and lower risk of recombination and exploitation (high relevance) , but there is the possibility of falling into path dependence; the upper left quadrant indicates that although the knowledge owned by the city can bring higher returns (high complexity), it is less relevant to the local knowledge base, requires a lot of investment, and has the risk of failure (low Relevance); the lower left quadrant indicates that the knowledge possessed by the city not only has low returns (low complexity), but also has high risks of reorganization and utilization (low relevance), and is prone to path locking.

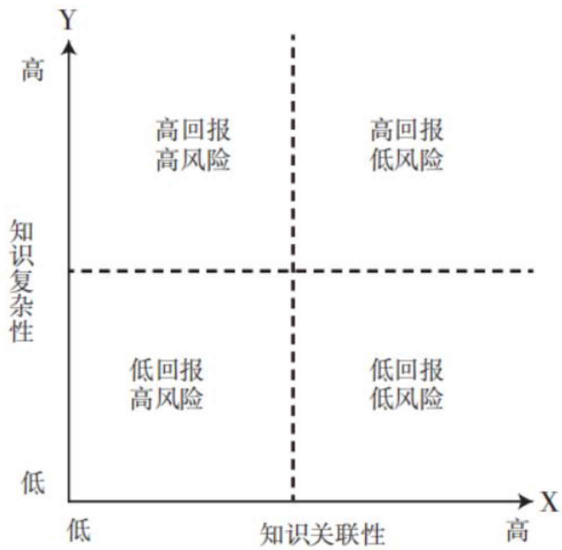

Figure 1 Analysis framework of knowledge combination opportunities and innovative development paths

2Data and methods

Scientific papers are an important output form of scientific and technological innovation. This study uses Clarivate Analytics ESI highly cited paper data, selects 700 major cities around the world with reference to the GaWC series of studies, and uses the address co-occurrence information of research institutions in the paper and the co-occurrence information of the subject field to which the paper belongs to construct a "global Knowledge collaboration network" and "global knowledge portfolio network". At the end of 2017, General Secretary Xi Jinping made the important judgment of "a major change unseen in a century." In early 2018, the United States launched a comprehensive "trade war" and "technology war" against China. This study uses 2018 as the watershed between the period before and after the great changes, and considering the "time lag" between the research process and the publication of the paper, two time windows of 2015-2017 and 2020-2022 are selected to aggregate the original data. , comparatively analyze the changing characteristics of Shanghai in the global science and technology innovation landscape before and after the great changes.

2.1 Construction and analysis of global knowledge cooperation network

First, data on highly cited papers are obtained in batches from the WoS database, the address information of the research institutions of each paper is summarized to the city scale, and papers containing two or more different cities are screened out. Then, construct a city science and technology cooperation connection matrix: if the research institutions of a collaborative science and technology paper are located in n different cities, then there are $n \times (n-1)/2$ cross-city cooperations in the paper, and the cooperation connections between any two cities Strength is 1. By summarizing and superimposing all collaborative papers, a knowledge cooperation network between cities can be constructed. The connectivity degree of a city in the network is the sum of all cross-city cooperative connections during the study period. The higher the connectivity degree, the stronger the resource control and spillover capabilities it has in the network.

This study conducts analysis from two dimensions: nodes (city individuals) and edges (city pairs). For the node dimension, in order to facilitate horizontal comparison between cities, the network connectivity is treated as a percentage (ratio to the maximum network connectivity). In order to examine diachronic changes, the "standardized connectivity change" (hereinafter referred to as "standardized change") indicator was used for reference from the methods of Derudder et al. [34] and Cao Zhan et al. [3] . The specific calculation method will not be described again. Using this method, we focus on observing the changes in cooperation connectivity between Shanghai and other cities at home and abroad during the study period, and judge the changes in Shanghai's connection center in the global knowledge cooperation network.

2.2 Construction and analysis of global knowledge portfolio network

The construction of the knowledge combination network uses the subject classification information in the WoS paper data. WoS has developed a set of subject classification standards for all included academic journals and monographs, covering 254 subject categories. When a paper is included, it will be classified into one or more subject areas based on this standard. In this study, if a paper is divided into different subject areas at the same time, it is considered that the research results involve heterogeneous knowledge combinations in different subject areas and form a knowledge combination network. As pointed out above, correlation is the main driving force for the formation and evolution of knowledge combination networks. By calculating the correlation between different knowledge, the weight of the edges in the network can be determined and the knowledge network can be further constructed. This study mainly focused on the natural sciences, without considering the humanities, arts, and social sciences, and ultimately included 194 subject areas in the computational analysis. The specific operation refers to the minimum co-occurrence probability method proposed by Hidalgo et al. [35] to identify the subject knowledge that each city has a revealed comparative advantage and construct a city-knowledge two-model 0-1 matrix [3 5] .

$$RCA_{c,i} = \frac{paper_{c,i}/\sum_i paper_{c,i}}{\sum_c paper_{c,i} / \sum_e \sum_i paper_{c,i}} \quad (1)$$

$$M_{c,i} = \begin{cases} 1, RCA_{c,i} \geq 1 \\ 0, RCA_{c,i} < 1 \end{cases} \quad (2)$$

The formula is heavy, Paper $_{c,i}$ is the number of papers published by city c in subject field i. Binarize all RCA calculation results and construct the city's relative comparative advantage technology matrix M $_{c,i}$. Then, based on the minimum conditional probability that two different fields have comparative advantages in the same city at the same time, calculate the correlation $\Phi_{i,j}$ between different subject fields. With $\Phi_{i,j}$ as the weighted edge and the scientific field as the node, it can be constructed Knowledge combination network:

$$\phi i, j = \min\{ P\ (RCA c, i\ RCA c, j\ ), P\ (RCA c, j\ RCA c, I\ ) \} \quad (3)$$

To compare different cities in knowledge portfolio networks The structural heterogeneity in the city is placed in the analytical framework of Figure 1 to examine the combination of knowledge possessed by the city. meeting and development model, further calculation knowledge is needed Association density and complexity. Knowledge correlation density is mainly It is used to measure the degree of correlation between a certain knowledge in the city and the overall knowledge structure of the city. This study adopts the correlation density calculation method proposed by Bal-land et al. [33] , mainly focusing on knowledge with relative comparative advantages in cities:

$$RD c, i = \frac{\sum_{j \in c, j \neq i} \phi i,j \times M C,j}{\sum_{j \neq i} \phi i,j} \times 100 \quad (4)$$

Hidalgo et al. [32] pioneered a complexity algorithm based on eigenvector matrix iteration. Its core assumption is that products or technologies with high complexity are only owned by a few regions, while products or technologies with low complexity can be owned by most regions. have. Tacchella et al. [36] improved this method and proposed a complexity algorithm based on nonlinear iteration. This project uses Tacchella et al.' s method to calculate the technical complexity of the city. The expression is as follows:

$$\begin{cases} \widetilde{KCI}_c^{(n)} = \sum_i MC,j \, KCI_c^{(n-1)} \\ \widetilde{KCI}_c^{(n)} = \frac{1}{\sum_i MC,j \frac{1}{KCI_c^{(n-1)}}} \end{cases} \rightarrow \begin{cases} KCI_c^{(n)} = \frac{\widetilde{KCI}_c^{(n)}}{\langle \widetilde{KCI}_c^{(n)} \rangle_c} \\ KCI_i^{(n)} = \frac{\widetilde{KCI}_i^{(n)}}{\langle \widetilde{KCI}_i^{(n)} \rangle_i} \end{cases} \quad (5)$$

In the formula, the initial value of urban technical complexity is set to $\widetilde{KCI}_c^{(n)}$1, and the initial value of complexity in a certain technical field is set $\widetilde{KCI}_i^{(n)}$to 1. $M_{c,j}$ represents whether city c' s technology i has a relative comparative advantage. After each iteration is completed, the $\widetilde{KCI}_c^{(n)}$sum $\widetilde{KCI}_i^{(n)}$is normalized to obtain $\widetilde{KCI}_c^{(n)}$the sum $\widetilde{KCI}_i^{(n)}$. $\widetilde{KCI}_c^{(n)}$and are $\widetilde{KCI}_i^{(n)}$the urban and technological complexity after n iterations respectively.

3Research results

3.1Shanghai in the global " knowledge cooperation network " under the great changes

3.1.1 Changing characteristics of Shanghai' s connectivity

Table 1 shows the top 30 cities in the global knowledge cooperation network . Among them, European and American cities have always had an obvious " monopoly " status, and their number is significantly higher than that of cities in other regions. For Shanghai, its ranking improved from 28th to 11th during the study period , with a connectivity growth rate of 55.7% . Although Shanghai still lags far behind the world's top innovation centers such as London, New York, and Boston, this gap is gradually narrowing. During the study period, Shanghai's social investment intensity in research and experimental development has increased significantly, from 104.9 billion yuan in 2016 to 187.5 billion yuan in 2022 , and its proportion in GDP has also increased from 3.95% to 4.20% , much higher than the national level. Average. Shanghai has also rapidly improved in the transformation of scientific and technological achievements. The number of scientific and technological contract transactions has increased from 11,837 in 2017 to 27,241 in 2022, and the total transaction volume has also increased from 5 billion yuan to 15.1 billion yuan. In terms of top talents, according to statistics from the "Nature Index" high-level scientists, Shanghai has 11,215 high-level scientists in 2021, ranking second among the 20 major cities in the world (second only to Beijing and higher than London and In terms of major scientific facilities in New York, Shanghai is building a "1+7+X" major scientific facility led by the hard X-ray free electron laser device, based on 7 large photon science facilities

表1 全球城市知识合作网络中连接度排名前30的城市

Tab.1 The 30 most connected cities in the global network of interurban knowledge collaboration

排名	城市	相对连接度(2015—2017年)	城市	相对连接度(2020—2022年)
1	波士顿	100.00	伦敦	100.00
2	纽约	87.57	波士顿	98.11
3	伦敦	83.79	北京	97.83
4	北京	73.03	纽约	96.98
5	巴黎	70.59	巴黎	68.60
6	巴塞罗那	62.13	巴塞罗那	66.35
7	多伦多	60.95	多伦多	60.58
8	西雅图	60.55	米兰	59.95
9	马德里	58.97	西雅图	57.00
10	巴尔的摩	54.60	马德里	56.44
11	首尔	51.82	上海	54.27
12	罗马	50.62	阿姆斯特丹	52.21
13	芝加哥	50.02	巴尔的摩	51.86
14	米兰	49.49	墨尔本	51.72
15	海德尔堡	49.41	芝加哥	50.81
16	休斯敦	48.24	休斯敦	49.66
17	墨尔本	46.90	悉尼	49.55
18	柏林	46.86	费城	49.21
19	哥本哈根	46.43	罗马	49.13
20	斯德哥尔摩	45.97	首尔	48.56
21	费城	45.82	香港	46.71
22	东京	45.62	东京	44.89
23	悉尼	45.24	柏林	42.94
24	莫斯科	44.90	旧金山	41.89
25	阿姆斯特丹	44.27	罗彻斯特	41.86
26	罗彻斯特	42.54	亚特兰大	40.94
27	亚特兰大	42.43	斯德哥尔摩	39.82
28	上海	41.18	莫斯科	39.76
29	旧金山	41.12	武汉	38.53
30	华盛顿	40.92	蒙特利尔	38.34

such as the Shanghai Light Source, and supported by facilities in other fields. system, forming the world's largest scientific facility cluster with the most comprehensive types and the strongest comprehensive service functions. The above shows that since the goal and vision of "an outstanding global city" was clarified in 2017, despite the background of great changes and complex In the ever-changing international political and economic landscape, Shanghai has still effectively integrated into the global knowledge cooperation network, with significantly improved connectivity, increasing R&D investment and output, continuous optimization of scientific and technological talents and scientific equipment, and significantly improved innovation capabilities. However, On a national scale, there is still a big gap between Shanghai and Beijing.

top 30 cities in the global city knowledge cooperation network in terms of connectivity

3.1.2 Changing characteristics of Shanghai connection dimension

Figure 2 is a histogram comparing introversion and extroversion based on the proportion of domestic and international knowledge cooperation to total cooperation in global cities such as Shanghai. Comparing the two time windows, Shanghai's outward agglomeration degree significantly decreased and its inward radiation degree increased significantly. Its "two sectors" role has undergone significant changes during the period of great changes. Beijing has a similar trend of change as Shanghai. In comparison, the inward and outward orientations of London and New York have not changed significantly, indicating that "technological decoupling" has an insignificant impact on the spatial dimension of their cooperative connections, and that China, as their collaborator, is to some extent replaceable. of.

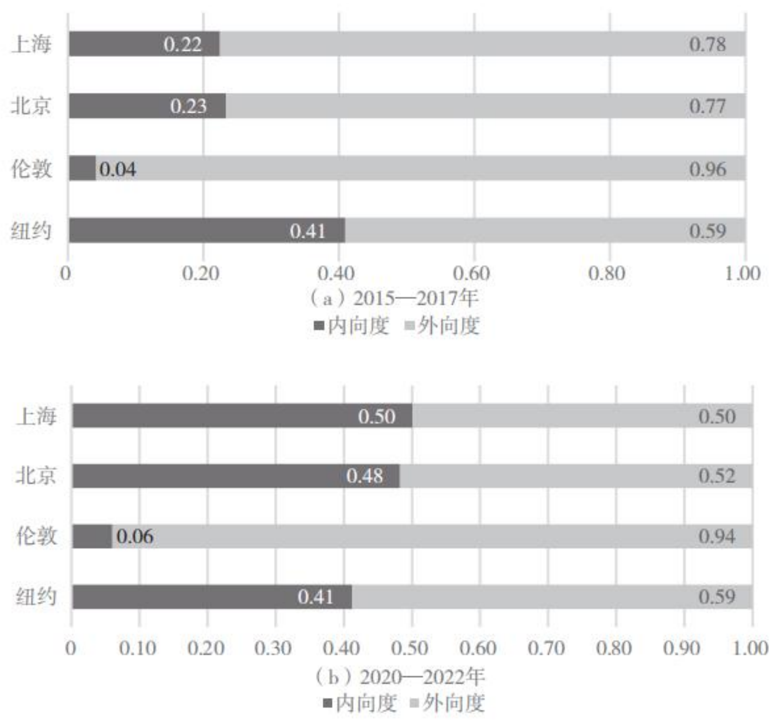

Figure 2 Introversion and extroversion in Shanghai, Beijing, London and New York

Table 2 shows the standardized change values of the cooperation intensity of the top 20 domestic and foreign cities with cross-city cooperation intensity with Shanghai during the two time periods. The calculation logic is as follows: First, select the top 20 domestic and foreign cities with cross-city connection strength with Shanghai from 2015 to 2017 and 2020 to 2022, and perform union processing, thus obtaining 24 Chinese cities and 30 foreign cities. Then, the method of Cao Zhan et al. [3] was used to calculate the standardized change value of the cross-city cooperation intensity between these cities and Shanghai in the two periods. If the standardized change value is positive, it means that the growth of cross-city cooperation intensity exceeds the overall expectation; if the standardized change value is close to 0, it means that the change of cross-city cooperation intensity tends to be consistent with the overall expectation; if the standardized change value is negative, it means that the cross-city cooperation intensity Cooperation intensity is increasing at a slower rate than overall expectations. It can be seen from the results that: on the one hand, affected by the "technological decoupling" between China and the United States, the focus of Shanghai's transnational knowledge cooperation has shifted from North America to Europe. On the other hand, Shanghai’ s domestic knowledge cooperation hinterland continues to expand, gradually extending to the west, north and southwest regions. In general, although Shanghai’ s connection dimension in the global knowledge cooperation network has been profoundly affected by the “technological decoupling” between China and the United States, from another perspective, it also shows a high level of resilience and endogenous power, and cooperation and connection The degree of cooperation is generally increasing steadily, and the focus of cooperation has shifted from North America to Europe, and from foreign countries to domestic countries.

表2　两个时段内与上海跨城合作强度排名前20城市的合作强度标准化变化值

Tab.2　Changes in standardized network connectivity between the 20 most connected Chinese/foreign cities and Shanghai during the two periods

中国城市	与上海合作强度的标准化变化值	外国城市	与上海的合作强度的标准化变化值
天津	2.43	柏林	1.98
西安	2.06	赫尔辛基	1.63
南京	0.86	诺丁汉	1.56
徐州	0.85	圣路易斯	1.41
广州	0.75	新西伯利亚	1.32
桂林	0.70	图森	1.17
哈尔滨	0.65	伦敦	0.96
南通	0.64	鹿特丹	0.84
青岛	0.50	华盛顿	0.60
南京	0.46	纽约	0.56
长春	0.07	都灵	0.39
武汉	−0.34	海德堡	−0.07
济南	−0.50	芝加哥	−0.10
合肥	−0.56	那不勒斯	−0.15
福州	−0.57	费城	−0.16
香港	−0.58	莫斯科	−0.30
成都	−0.62	休斯敦	−0.39
苏州	−0.64	巴尔的摩	−0.43
深圳	−0.68	蒙特利尔	−0.48
北京	−0.70	米兰	−0.57
重庆	−0.97	斯德哥尔摩	−0.67
郑州	−1.12	慕尼黑	−0.72
杭州	−1.20	罗马	−0.72
长沙	−1.51	马德里	−0.74
—	—	巴黎	−0.77
—	—	阿姆斯特丹	−0.78
—	—	巴塞罗那	−0.81
—	—	西雅图	−1.09
—	—	多伦多	−1.32
—	—	波士顿	−2.15

Table 2 Standardized changes in cooperation intensity with the top 20 cities in cross-city cooperation with Shanghai during the two periods

3.2 Shanghai in the global “knowledge combination network” under the great changes

3.2.1 Changing characteristics of Shanghai' s relevance and complexity

Figure 3 shows the global knowledge combination network drawn based on the calculation results of knowledge correlation. The edges in the figure are the correlations between different subject areas, which are calculated according to formula (3). In order to facilitate visual expression, only knowledge combinations with correlations greater than 0.4 are retained. The nodes in the figure represent different WoS scientific fields, the color of the node represents the ESI subject classification⑧ to which the scientific field belongs , and the node size represents the total number of highly cited papers published in the subject field. Overall, the global knowledge combination network shows an obvious " core – periphery " structure, including two closely related knowledge cores (shown in the red dotted box in the figure): one is based on clinical medicine, molecular biology and genetics , immunology, etc.; the second is the traditional engineering applied science core consisting of engineering science, materials science, chemistry, etc. There is a dense interdisciplinary and heterogeneous combination of knowledge within these two cores. Comparing the two periods, it can be found that the density and correlation strength of the global knowledge combination network have increased significantly. The network density has increased from 0.057 in 2015-2017 to 0.105 in 2020-2022 . The average correlation strength between knowledge in different fields has increased from 2015-2017 . It rose from 0.46 in 2017 to 0.47 in 2020-2022 , which shows that the breadth and depth of global knowledge combinations and disciplinary intersections are constantly increasing.

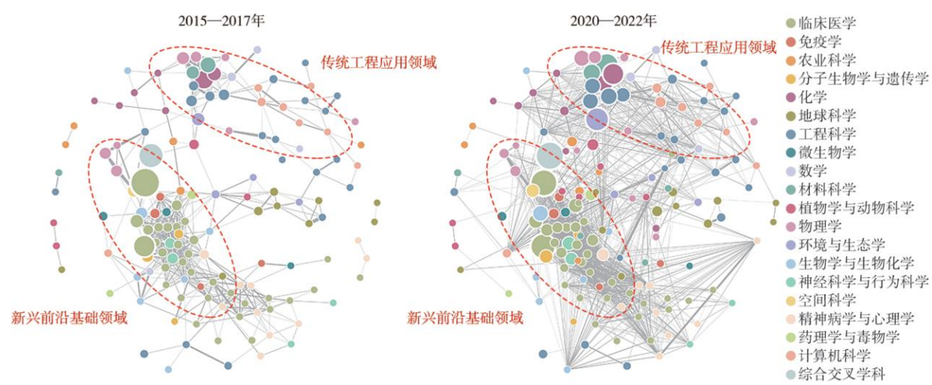

图3 全球知识组合网络的总体结构

Fig.3 The overall structure of the global network of knowledge combination

Figure 3 The overall structure of the global knowledge portfolio network

According to formula (1) and formula (2), the changes in disciplines with explicit comparative advantages in Shanghai during the two periods are calculated. The results show that there are 57 disciplines with comparative advantages in Shanghai from 2015 to 2017 , and the number will increase to 65 from 2020 to 2022. . Taking Figure 3 as the basis and superimposing the disciplines with comparative advantages in Shanghai, we can obtain the Shanghai knowledge combination network as shown in Figure 4. It is mainly used to examine the position characteristics of the dominant disciplines in different cities in the global knowledge combination network to reflect different The heterogeneity of urban scientific and technological innovation development paths. It is easy to see from Figure 4 that the dominant subject areas in Shanghai from 2015 to 2017 are mainly concentrated in the core of traditional engineering applied sciences, including materials science (nanoscience and nanotechnology, interdisciplinary materials science), engineering science (environmental engineering, chemical engineering, electrical and electronic engineering, energy and fuel engineering), physics (applied physics, optical physics, condensed matter physics) and computer science (information systems, artificial intelligence, software engineering, etc.). From 2020 to 2022 , a total of 38 advantageous disciplines will remain stable, 19 advantageous disciplines will withdraw, and 27 advantageous disciplines will enter. Among them, the dominant disciplines that remain stable are mainly concentrated in some fields of chemistry, engineering machinery, materials science, and physics, the dominant disciplines that have withdrawn are mainly concentrated in some fields of computer science, physics, and mathematics, and the dominant disciplines that have entered are mainly concentrated in life sciences. Some areas of science, chemistry, engineering machinery, and materials science. Overall, the development model of Shanghai's knowledge structure shows significant coexistence characteristics of " path dependence " and " path update " . While the traditional engineering application field continues to deepen, it also continues to undergo succession ; in addition , Shanghai There is also a local trend of " path breakthroughs " , and some comparative advantages are gradually emerging in emerging frontier fields such as molecular biology and genetics, biology and biochemistry.

Figure 4 shows the distribution characteristics of the comparative advantage disciplines of other top global science and technology innovation centers (Beijing, London and New York) in the global knowledge portfolio network. The distribution of dominant disciplines and knowledge combination patterns in Beijing and Shanghai are relatively similar, with both being concentrated in traditional engineering application fields. The dominant disciplines in London and New York show completely different distribution characteristics in the global knowledge portfolio network. They are more specialized in life sciences, including clinical medicine, neuroscience and behavioral science, psychiatry and psychology, molecular biology and genetics. Basic cutting-edge sciences such as biology and biochemistry. This result is consistent with the research findings of Miao et al . [37] . The uneven distribution of technological innovation on a global scale is closely related to the socio-economic development stages, resource endowment factors and geo-historical evolution of different regions. Since the founding of the People's Republic of China, China has gradually formed a national science and technology system in which " science and technology serve national defense and economic construction " , with particular emphasis on using science and technology development to drive the country's strategic line of transformation from an agricultural country to an industrial power. Long-term policy promotion has enabled China to Comparative advantages have gradually been established in scientific fields such as engineering, materials and chemical engineering. Developed countries such as the United Kingdom and the United States have entered the post-industrial era since the mid -20th century. The proportion of industrial production and traditional manufacturing in the economic structure of these countries has continued to decline, creating and leading the fourth era of science and technology marked by systems biology. A technological revolution.

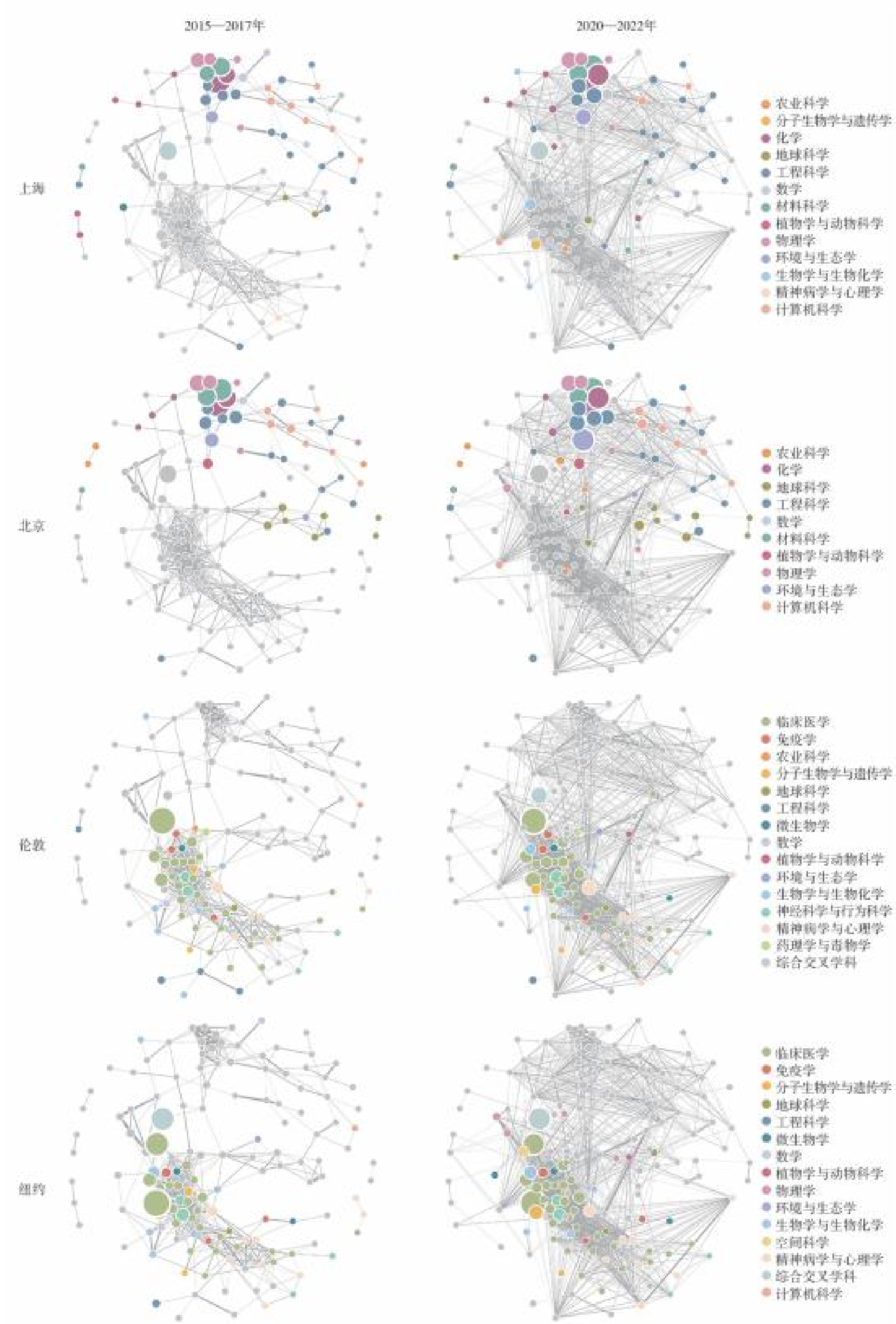

Figure 4 Distribution characteristics of comparative advantage disciplines in Shanghai, Beijing, London and New York in the global knowledge combination network

Table 3 shows the top 10 and bottom 10 cities in terms of complexity , calculated according to formula (5). Comparing the two time windows, it can be clearly seen that the complexity of many cities in China has increased rapidly, largely because they generally have comparative advantages in engineering application fields such as computers, chemistry, physics, etc., and these fields are relatively unpopular in the cities covered by the study The sample is more concentrated in Chinese cities and generally shows higher spatial specificity, so it also shows a higher ranking in the complexity calculation results. From 2015 to 2017 , Shanghai's complexity was 1.53 , ranking 4th ; from 2020 to 2022 , Shanghai's complexity increased to 1.88 , but dropped to 12th . This result needs to be interpreted dialectically. The decrease in Shanghai ' s ranking does not completely mean that Shanghai ' s scientific and technological innovation level has declined. Rather, it is largely because the diversity of disciplines in which Shanghai has comparative advantages has increased. In some fields with relatively low complexity, There are new breakthroughs such that its overall complexity has been reduced. Conversely, for Chinese cities such as Chengdu, Wuhan, and Hangzhou, where the complexity is rapidly rising, the increasing comparative advantages in traditional application fields such as computers, chemistry, physics, and engineering may not necessarily be a good thing. Such a specialized development model It may continue to strengthen the " path dependence " of urban technological innovation and create the risk of falling into " path lock " .

3.2.2 Changing characteristics of Shanghai ' s knowledge portfolio opportunities and development paths

Figure 5 shows the knowledge combination opportunities and innovation development paths in Shanghai, Beijing, New York, and London. Among them : _ _ _ _ The mean value is calculated according to formula (5). The size of the midpoint in Figure (5) represents the total number of papers published by the city in different subject areas. Based on the analysis framework shown in Figure 1 , it is not difficult to find through observation that Shanghai and Beijing have more advantageous knowledge in the upper right quadrant, and they are mainly in disciplines in traditional application fields such as computers, chemistry, physics and engineering, indicating that Shanghai and Beijing The knowledge combination model and development path belong to the "high-yield, low-risk" type, but this low-risk development model can easily strengthen "path dependence" and there is also the possibility of "path locking". At the same time, Shanghai and Beijing do not have many advantageous disciplines ("high-yield, high-risk") in the upper left quadrant, which shows that compared with London and New York, Shanghai still has the ability to seize the opportunity of "path breakthrough" and tap the potential of new advantageous disciplines. Lots of space. Comparing the two time windows, it is easy to see that from 2015 to 2017, Shanghai had a small number of advantageous disciplines in the upper left quadrant, mainly concentrated in life sciences and clinical medicine; but by 2020-2022, the advantageous disciplines in the upper left quadrant no longer exist. . Through further data analysis, it can be seen that in the fields of life sciences and clinical medicine, although the total number of cooperation in Shanghai has increased, from 4295 cooperations in 2015-2017 to 5256 cooperations in 2020-2022, the increase mainly comes from Shanghai and Chinese cities In terms of internal cooperation between Shanghai and European and American cities, the amount of cooperation between Shanghai and European and American cities has shown a downward trend, from 1,837 cooperations in 2015 to 2017 to 1,677 cooperations in 2020 to 2022. Before the "technological decoupling", the total amount of cooperation between China and Europe and the United States in this field was increasing year by year. In recent years, this growth momentum has shown a downward trend, resulting in Shanghai's potential growth space for the output of scientific papers in this field being compressed to a certain extent. . This further illustrates that the "technological decoupling" between China and the United States has had a greater impact on Shanghai's innovative exploration in basic frontier fields.

表3 全球复杂性排名前10位与后10位的城市

Tab.4 The top 10 and bottom 10 cities in terms of complexity

		复杂性（2015—2017年）	城市	复杂性（2020—2022年）
城市（前10位）	悉尼	1.74	成都	2.56
	香港	1.66	北京	2.42
	北京	1.58	武汉	2.42
	上海	1.53	杭州	2.38
	布里斯班	1.52	南京	2.36
	南京	1.52	西安	2.34
	蒙特利尔	1.48	首尔	2.27
	武汉	1.46	长沙	2.23
	广州	1.43	广州	2.04
	新加坡	1.43	香港	2.02
城市（后10位）	阿雷格里港	0.50	日内瓦	0.52
	利物浦	0.49	巴塞尔	0.52
	基辅	0.43	鹿特丹	0.5
	利马	0.42	马赛	0.47
	马尼拉	0.41	罗切斯特	0.47
	斋浦尔	0.39	伯明翰	0.41
	德班	0.38	纳什维尔	0.39
	亚的斯亚贝巴	0.33	开普敦	0.37
	库埃纳瓦卡	0.29	达拉斯	0.35
	第比利斯	0.25	休斯敦	0.33

Table 3 The top 10 and bottom 10 cities in the country in terms of complexity

4.Conclusion and discussion

4.1 Main conclusions

Accelerating the construction of a scientific and technological innovation center with global influence is a major task and strategic mission entrusted to Shanghai by the Party Central Committee with Comrade Xi Jinping at its core. It is a key driver for Shanghai to accelerate high-quality economic and social development and enhance the city's energy level and core competitiveness. Strength is an important support for our country to build a world power in science and technology. Since the Shanghai 2035 Master Plan in 2017 clarified the construction of a technological innovation center with global influence, Shanghai has faced the impact of changing innovation development paradigms and a sharp increase in internal and external risk challenges. Against this background, this article uses the data of highly cited scientific research papers from 2015 to 2017 and 2020 to 2022 to examine Shanghai's role in global science and technology during the period of great change from the two dimensions of "global knowledge cooperation network " and " global knowledge combination network " Evolutionary dynamics and development trends in the innovation landscape. The study found that: ① In the face of changes in the external environment, Shanghai' s status in the global knowledge cooperation network has significantly improved, but compared with the top global science and technology innovation center (London, New York, Boston, etc.) There is still a big gap; in addition, on a national scale, the gap between Shanghai and Beijing is still significant. ② As the " technological decoupling " between China and the United States intensifies, Shanghai's spatial connectivity in the global knowledge cooperation network has been greatly affected, but it has also shown considerable resilience. Shanghai's " two sectors " function of undertaking knowledge spillover externally and instigating knowledge radiation internally has undergone structural adjustments: the degree of outward agglomeration has been significantly reduced, while the degree of inward radiation has been significantly increased. At the same time, Shanghai's connection center of gravity in the global knowledge cooperation network has shifted from North America to Europe, and its connection center of gravity in the national knowledge cooperation network has expanded from the east to the north and west. ③Shanghai occupies a core position in the global knowledge combination network and has significant comparative advantages in traditional application fields such as computers, chemistry, physics and engineering, and has made some breakthroughs in the fields of life sciences and molecular genetics. ④ Shanghai' s innovative development path is characterized by a "high-yield, low-risk" model, which exhibits the coexistence of "path dependence" and "path update" development characteristics in traditional application fields, but there is also the risk of "path lock-in"; at the same time, affected by Affected by the "technological decoupling" between China and the United States, Shanghai's "pathway breakthroughs" in emerging basic fields are relatively lagging behind, and there is still a lot of room for exploration.

4.2 Extended discussion

In the article "The Rising Global Innovation Center: The Evolutionary Characteristics of Chinese Cities in the Global Urban Scientific Research Cooperation Network", the author analyzed the evolution of the global urban scientific research cooperation network from 2002 to 2006 and 2014 to 2018, focusing on the analysis of Chinese cities. The development trend of the overall rise in the Internet has also raised concerns about whether Chinese cities can maintain and improve their status in the global scientific and technological innovation map in an uncertain international environment. Through this article' s tracking study of the global science and technology innovation landscape and Shanghai' s development path during the period of great changes, it is clear that the drastic changes in the external environment have not had a destructive impact on Shanghai' s further rise in the global science and technology innovation landscape, but they have The "two sectors" functional structure, knowledge combination opportunities and innovative development paths have varying degrees of impact.

Many scholars believe that although the result of "technological decoupling" can only be a lose-lose situation, judging from the current trend direction, until the US government truly realizes that decoupling will bring serious negative effects to the United States, the pace of decoupling will not Stop[38]. From the research results on the knowledge cooperation network, we can see that the status of Shanghai and other cities in China in the network is still rapidly improving under the influence of the external environment, which shows that after years of accumulation, China's scientific and technological innovation strength has achieved considerable development and has considerable Resilience against external disturbances, the blockade and containment by the United States and its allies has a limited impact on the development of China's independent innovation system and key core scientific and technological breakthroughs. Even so, it is necessary to realize that there is still a clear gap between Shanghai and other top global science and technology innovation centers. It is also necessary to realize that in the national science and technology innovation landscape, Beijing's dominance will be difficult to shake in the short term. Shanghai should be based on the region, take the construction of the "Yangtze River Delta Science and Technology Innovation Community" and the "G60 Science and Technology Innovation Corridor" as practical starting points, further leverage the advantages of international opening up to the outside world, deepen multi-dimensional cooperation in science and technology innovation, and give full play to Shanghai's leading role as a core city in the Yangtze River Delta region , strengthen all-round, multi-level, and wide-ranging domestic and international scientific and technological innovation exchanges and cooperation, give full play to Shanghai's role as a central node of the domestic macrocycle and a strategic link between domestic and international dual cycles, and help Shanghai become an important hub of the global innovation network.

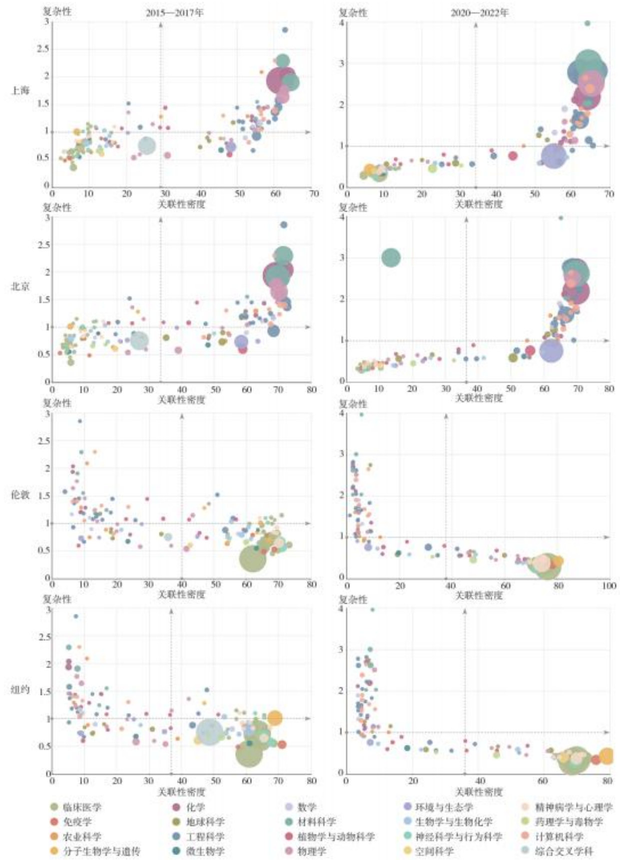

图5 上海、北京、伦敦和纽约的知识组合机会与创新发展路径

Fig.5 The knowledge combination opportunities and innovative development paths of Shanghai, Beijing, London,

Figure 5 Knowledge portfolio opportunities and innovation development paths in Shanghai, Beijing, London and New York

At the same time, it can be seen from the research results on the knowledge combination network that Shanghai's scientific and technological innovation development model still has the problem of "path dependence" and the risk of "path locking". The scientific and technological development paths of Shanghai, London and New York are completely different. Shanghai has significant comparative advantages in traditional engineering application fields, while London and New York have leading positions in emerging frontier fields. This comparison of obviously different development paths has at least two possible implications: On the one hand, it is necessary for Shanghai to gradually shift the development focus of scientific and technological innovation from traditional application fields to emerging basic fields, and further strengthen the guidance and investment in life sciences and biomedicine. , insisting on equal emphasis on free exploration and strategic demand, giving full play to the source supply and leading role of emerging basic research in scientific and technological innovation, targeting major scientific issues in global basic frontier fields and key core technologies, strengthening deployment in key areas, and forming latecomers in emerging basic fields. Advantage. On the other hand, under the trend of "technological decoupling", the differences in advantageous fields and development paths between Shanghai and even China and European and American technological powers can be regarded to a certain extent as a "peer-to-peer game" pattern of mutual constraints and interdependence [38]. In other words, for Shanghai and even other cities in China, there is currently neither the ability nor the need to deliberately pursue comprehensive breakthroughs and independent controllability of core technologies in all scientific and technological fields. Instead, it needs to be in the global innovation chain under the background of "decoupling". Seeking a balance between "independent controllability" and "opening up to the outside world", while striving to solve the "stuck" areas of shortcomings, further strengthen the advantages of being "the leader" in longboarding areas, and enhance mutual understanding between China and Europe and the United States in the high-tech field. Dependent relationships, expanding the intersection of economic interests and symbiotic relationships.

This study also has shortcomings and limitations: First, scientific and technological innovation includes not only scientific research, but also technology research and development. Patents are the main form of achievement of technology research and development. In the future, cooperative patent data can be used to conduct relevant research on global urban knowledge cooperation networks and explore the evolving characteristics of Shanghai in the global technology cooperation network. However, it should be noted that the process of patent application and authorization is significantly different from the publication of scientific research papers. There are many differences in the patent application and review systems of different countries. Cross-border patent application is only a game for a few leading innovative entities. Second, in the study of the global knowledge combination network, since most of the selected city samples are national capitals and more economically developed cities, their innovation capabilities are in a leading position in the national innovation system where they are located, representing the national innovation Therefore, there is a relatively obvious homogeneity phenomenon in its innovation field, which may be quite different from the research results using the country as the basic unit. In the future, more in-depth comparative research is needed. Third, this study analyzes the evolving characteristics of Shanghai's position in the global science and technology innovation landscape during the period of great changes from the two dimensions of "knowledge cooperation" and "knowledge combination", focusing on the analysis and description of the network structure. In the future, we can pay more attention to the interactive effect of knowledge cooperation network and knowledge combination network, and analyze their joint impact on urban innovation performance; we can also pay attention to the coupling relationship between knowledge cooperation network and knowledge combination network, and analyze the co-evolution process of the two. association mechanism.

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