BCAS Vol.36 No.3 2022

China Is Changing the Global Scientific Landscape – Based on Science Structure Maps[1]

WANG Xiaomei, LI Guopeng, CHEN Ting

Institutes of Science and Development, Chinese Academy of Sciences

This report examines China's basic research achievements and challenges in the 12th and 13th Five-Year Plan periods using a science structure map. Our aim was to gain a deeper understanding of China's scientific achievements. The findings reveal that China's basic research has undergone rapid development, resulting in a significant impact on the global scientific landscape. Through comparison and analysis of research output, cooperation, and strengths in global hot research fronts and various subjects, we aimed to identify the gaps between China and developed countries and provide guidance for identifying priority research fields, strategic focus, and science and technology policies in China.

I. Methods and Data

The science structure map is a tool to visualize highly abstract science, especially to visualize the macrostructure of the basic research in natural science, which can reveal the correlation and development process among the hot frontier areas of science. Since 2007, the Research Group of Science Structure Map (RGSSM) at the Institutes of Science and Development of the Chinese Academy of Sciences has been conducting related research. RGSSM has been producing a science structure map every two years to periodically monitor the structure of scientific research and its evolution pattern.

The principle of mapping science structure is to form research areas by clustering the co-citations of highly cited papers (referring to the Essential Science Indicators database of Clarivate Analytics), revealing hot research fronts. These hot research fronts are naturally, objectively, and dynamically developed during scientific practices (primarily through interdisciplinary integration), and are of great interest to the world. As mutual citations indicate, these research areas go beyond traditional subject categories and reflect specific shared nature among different fields of study.

To analyze larger data and to make the clustering and visualization algorithms more accurate and comprehensive, RGSSM has fully upgraded its algorithms since 2018. For detailed methods, please refer to the book entitled "Mapping Science Structure 2021".

Figure 1 shows two science structure maps in 2010~2015 and 2014~2019. It shows that the layout of the science structure remains relatively stable during these periods, visually reflecting the current science

[1] This is an authorized translation of a piece from Chapter 6 in the *2021 Science Development Report* (in Chinese) drafted and released by the Chinese Academy of Sciences (CAS). This chapter focuses on the overview of scientific development in China. BCAS thanks the authors for their kind permit and support for the translation.

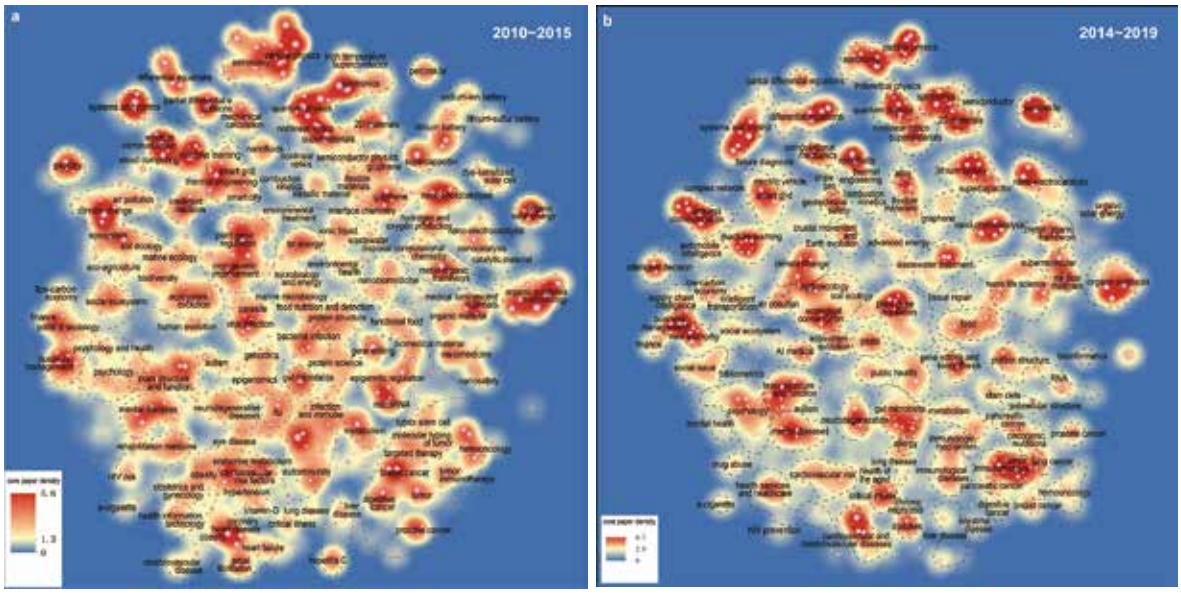

Figure 1. Science structure maps based on clusters of highly cited papers in 2010~2015 (a) and 2014~2019 (b). The higher the volume of papers there are in a research field group, the higher the density and the warmer the color (red); Conversely, the lower the volume of papers, the lower the density and the colder the color (blue). The research field groups form clusters (the islands) that are circled and tagged by major research field groups to show the landmarks on the global scientific landscape.

structure and scientific research activities of the world.

We termed the highly cited papers for science structure mapping as "core papers", and papers that cite these core papers in subsequent research as "cited papers". Core papers from 2014 to 2019 fall into 1333 research areas. On this basis, we further classify these research areas into numerous research area groups according to the scientific problems they investigated or according to their similarities or shared concepts.

At the top of Figure 1(b) is astronomy and particle physics, and at its lower right is physics and optics, where reads "quantum physics", "spintronics", "nonlinear optics", "semiconductor physics" (semiconductor for short), "supermaterials" and "2D materials". The "2D materials" also belong to nanotechnology.

The lower right of physics is dominated by the subject of chemistry and materials science, most of which also belong to nanotechnology, including "lithium battery", "nano-electrocatalysis", "nano-photocatalysis" and "nano life science". In chemistry, there are "organic synthesis methodology" (organic synthesis for short), "supramolecular self-assembly materials" (supramolecular for short), "medical luminescent materials" (medical materials for short), "metal-organic framework," and others.

Mathematics, computer science, and engineering take the upper left of the figure, including "systems and control", "wireless communication", "machine learning", "smart grid" and other research areas. Engineering science covers a wide range, intersecting with earth science, chemistry, etc. The center-left part of the map is taken by earth science and ecological environment, including "crustal movement and Earth evolution", "climate change", "ecological conservation", "wastewater treatment", and others.

Botany and zoology, and biology take the center of the map. Their major research area groups include "plant gene regulation", "gene editing and biosynthesis", "protein structure", "stem cells", "RNA", "public hygiene and health" (public health for short), "food nutrition and health" (food for short), and others. Medicine is located below biology and also at the bottom of the whole map, which includes "tumor immunotherapy", "cardiovascular and cerebrovascular diseases", "neurological and psychiatric diseases" (mental diseases for short in the figure), "neurodegenerative diseases", "diabetes", "immunological diseases", "gut microbiota" and others. The bottom left shows social sciences.

The highly cited papers and research fronts were

Table 1. The data used for mapping science structure

Item	Detail	
Time period	2010~2015	2014~2019
Retrieval time	March 2016	March 2020
Number of research fields	969	1,333
Number of core papers	44,495	50,767
Number of cited papers	1,801,996	2,504,043

collected from the ESI database of Clarivate over six years. Table 1 shows the data we retrieved for mapping the science structure.

II. The Overall Scientific Research Trends in China

China is rapidly rising to the forefront in hot research areas, quickly narrowing the gap with technologically advanced countries. Comparing the science structure map between the two periods reveals that China's core paper volume has rapidly increased. The coverage rate and intensity of core papers in all research areas show a clear trend of growing and strengthening. All indicate that China's scientific research structure is gradually improving. Although there is still an imbalance between different subjects, the balance gradually improves.

2.1. China's research activity is rapidly increasing

China's scientific activity in the world's hot frontier areas is developing rapidly. As you can see from the science structure maps of the two time periods, China's share of core papers steadily ranks second, rising from 11.5% to 21.0%, an increase of 82.6%. Since 2018,

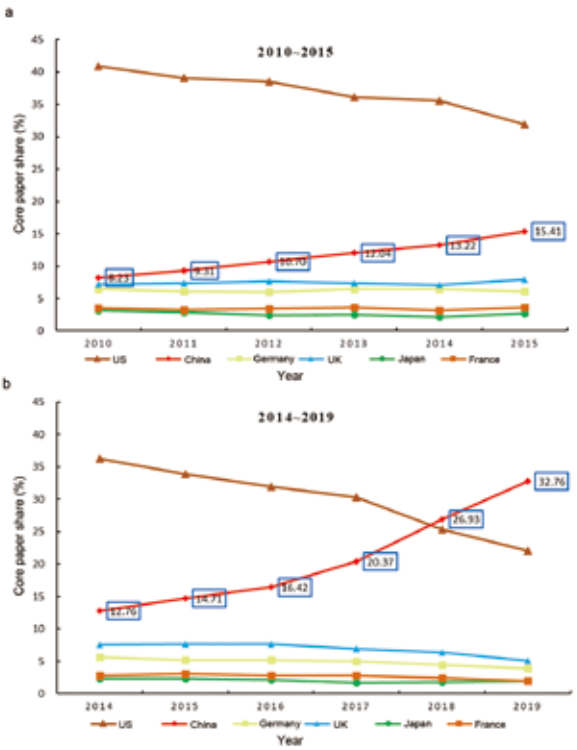

Figure 2. The world share of China's and developed countries' core paper in 2010~2015 (a) and 2014~2019 (b).

Table 2. The world share and ranking of core papers for China and developed countries

Time Period	Item	Country					
		US	China	Germany	UK	Japan	France
2010~2015	Core paper share (%)	37.1	11.5	6.3	7.4	2.6	3.4
	Core paper ranking	1	2	4	3	9	5
2014~2019	Core paper share (%)	29.7	21	4.9	6.9	2	2.6
	Core paper ranking	1	2	4	3	10	8
Between two periods	Change of core paper share (%)	-19.9	82.6	-22.2	-6.8	-23.1	-23.5

Note: This report uses the fractional counting method (count by the proportion of the number of authors of each country or institution in each paper to the total number of authors, the count of one paper is 1) to calculate the number of core papers of a country.

Table 3. The share and ranking of cited papers for China and developed countries in the two periods

Time Period	Item	Country					
		US	China	Germany	UK	Japan	France
2010～2015	Cited paper share (%)	27.1	14.8	5.8	5.6	4.0	3.6
	Cited paper ranking	1	2	3	4	5	6
2014～2019	Cited paper share (%)	22.7	22.2	4.9	5.1	3.3	2.9
	Cited paper ranking	1	2	4	3	5	8
Between two periods	Change of cited paper share (%)	-16.2	50.0	-15.5	-8.9	-17.5	-19.4

China's share of core papers has surpassed the US, as indicated by Table 2 and Figure 2. In the science structure map from 2014 to 2019, China's share of core papers has significantly exceeded that of Germany, the UK, Japan, and France combined. As listed, the world shares of core papers from developed countries showed a decreasing trend. The decrease in the US, Germany, Japan, and France is around 20%.

The cited papers reflect the following-up research in these hot frontiers. China also ranks second in the world in the number of cited papers, exceeding its world share of core papers, with a solid upward momentum (Table 3), while the US, Germany, the UK, Japan, and France showed a downward trend.

2.2 China's scientific research structure is gradually improving, while performance in various subjects still suffers from serious imbalance.

China's scientific research structure layout is gradually improving, and the disciplinary structure layout is progressively stable, judging from the coverage rate and intensity in all research areas. However, there is still room for improvement in balancing the research level in different subjects.

(1) The coverage rate of research areas in China has increased significantly. The coverage rate and intensity of China's core papers in all research areas showed a noticeable trend of growing and strengthening. China's global ranking of coverage rate rose from fifth to third place, from 66.7% to 78.6%. It is close to the UK (80.3%), but there is still a gap with the US (94.8%). The coverage rate of new fields of study also increased significantly, from 48.3% to 66.7%. At the same time, the coverage rate of research areas in developed

Table 4. The research coverage rate in China and developed countries

Time Period	Item	Country					
		US	China	Germany	UK	Japan	France
2010～2015	Research fields with publications (total of 1,084)	1,051	723	857	901	562	746
	Research fields with publications count (%)	97.0	66.7	79.1	83.1	51.9	68.8
	New fields with publications (total of 87)	71	42	40	47	18	27
	New fields with publications count (%)	81.6	48.3	46.0	54.0	20.7	31.0
2014～2019	Research fields with publications (total of 1,333)	1,263	1,048	955	1,070	639	826
	Research fields with publications count (%)	94.8	78.6	71.6	80.3	47.9	62.0
	New fields with publications (total of 180)	147	120	65	97	34	51
	New fields with publications count (%)	81.7	66.7	36.1	53.9	18.9	28.3

countries decreased slightly, among which the decrease in France and Germany was over 5% (Table 4).

(2) China's dominant research areas have been strengthened, and the disciplinary structure and layout have been steadily stabilized. The share of core papers in different countries superposed with each research area forms the distribution diagram of the number of core papers in countries. As revealed in Figure 3 and Figure 4, we find that the coverage area and density of the core papers of China in the research area significantly increase, forming many highly dense dark red regions. After five years of intensive effort, China has taken a dominant position in these research areas.

China's dominant research areas gradually stabilized over the two periods. They are mainly located in the top half of the map, covering nanotechnology, systems and control, wireless communication, machine learning, geotechnical safety, and wastewater treatment, among other research areas. The bottom of China's science structure map is mainly blue, showing insufficiency in many research areas, including medicine, biology, social sciences, astronomy and particle physics, earth science, and ecology. The dominant research areas of the US and China show a complementary pattern.

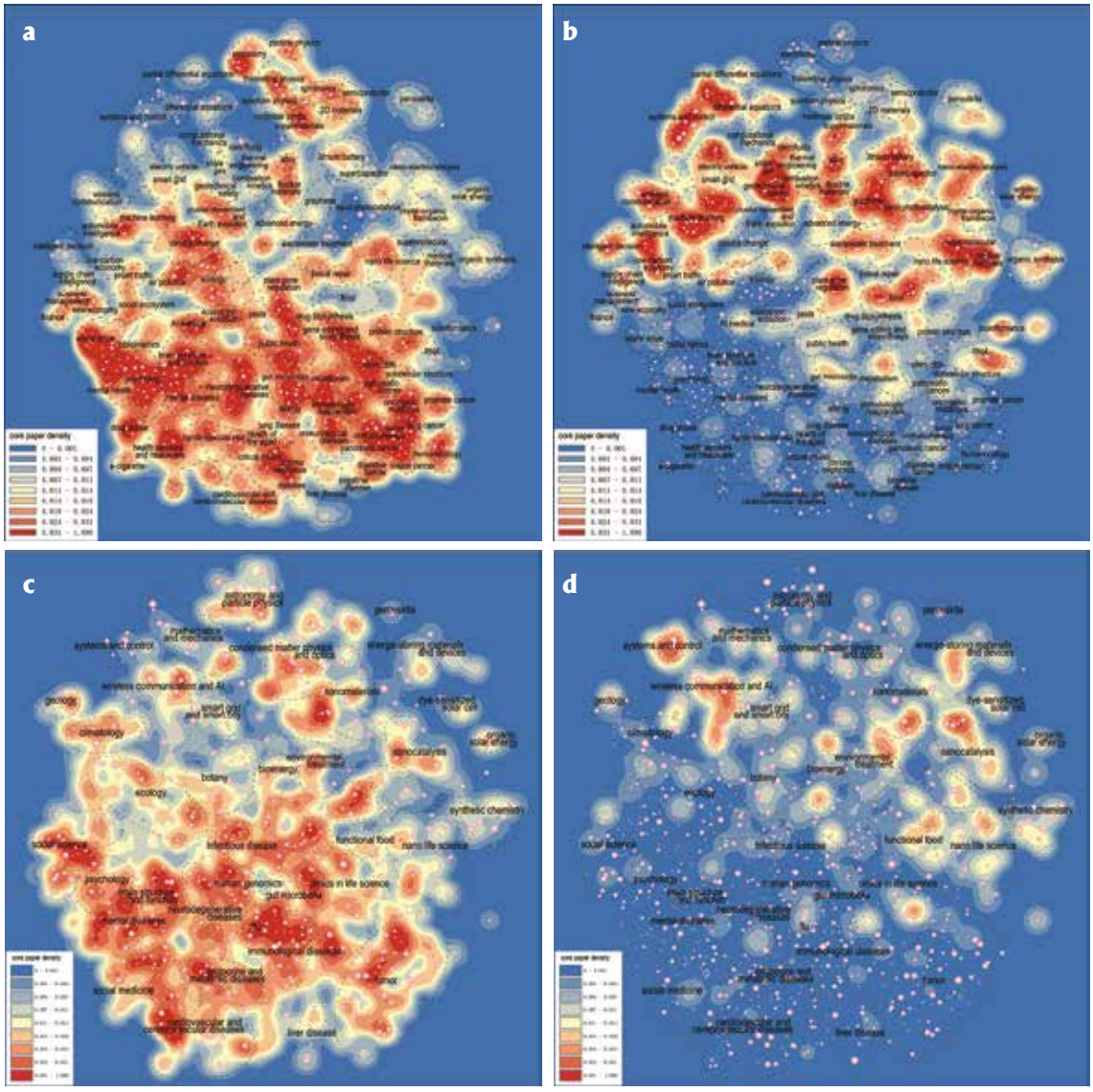

Figure 3. The distribution of the share of core papers in China and the United States in the two periods.

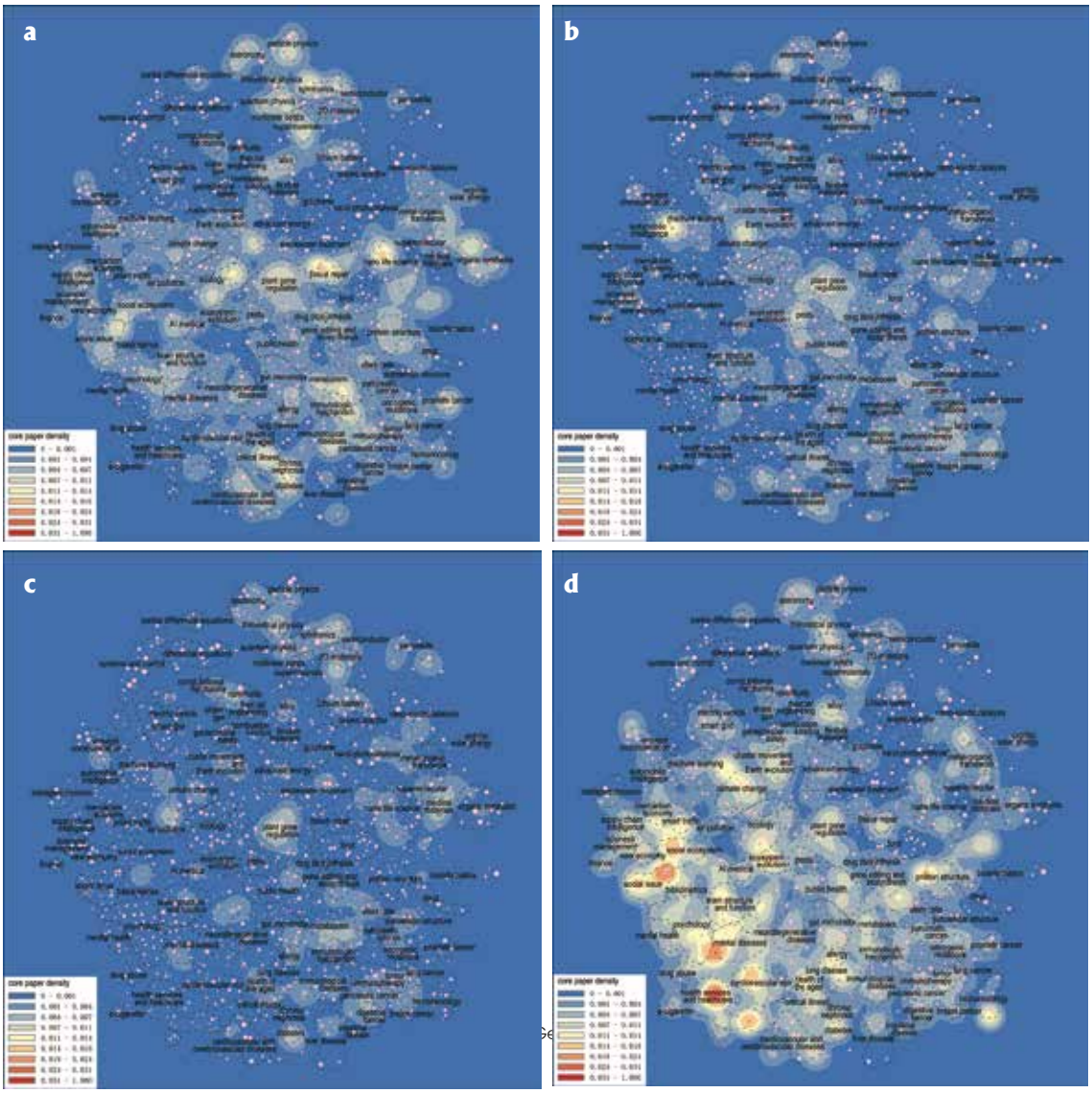

Figure 4. The distribution of the share of core papers in Germany, the UK, Japan, and France from 2014 to 2019.

As seen from the science structure map, the research level of various subjects in China remains quite uneven. The relatively weak subjects, such as medicine and biology, developed rapidly. The relatively strong subjects like engineering, computer science, chemistry, and materials science progressed even faster. In contrast, the developed countries, as listed, have relatively balanced research in various research areas.

2.3. The coverage rate and intensity of China's international cooperation have increased significantly

The comparison of the international coauthorship rates in two different periods, as indicated by the science structure map (Figure 5), shows that global cooperation in scientific research is rising and strengthening.

China's coverage rate and intensity of international coauthorship in various research areas show a noticeable trend of increasing and strengthening (Table 5). Its leading degree in international cooperation is growing annually, with the proportion of corresponding authors increasing substantially. From 2014 to 2019, the ratio of Chinese authors listed as corresponding authors in

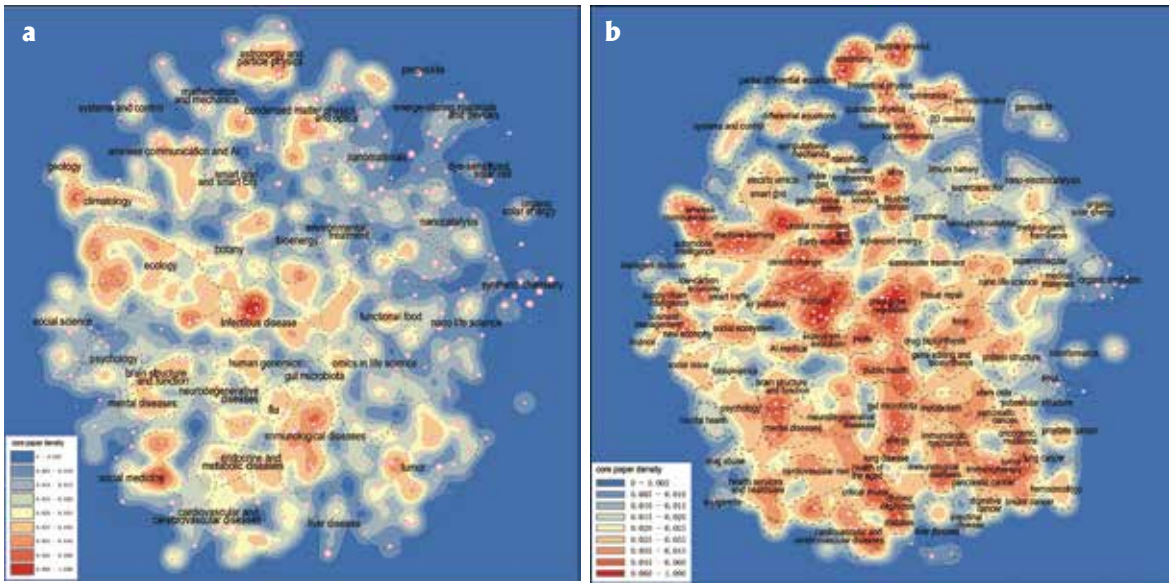

Figure 5. Comparison of international coauthorship rates based on the science structure map in the two periods.

Table 5. The international coauthorship rate in China and the developed countries

Item		Country					
		US	China	Germany	UK	Japan	France
International coauthorship rate (Mean, %)	2010~2015	52.3	50.1	79.7	78.8	66.8	85.1
	2014~2019	62.0	52.1	85.8	83.7	78.8	89.0
	Change rate (%)	18.5	3.9	7.6	6.2	17.9	4.6
Research fields with 100% International coauthorship count (%)	2010~2015	7.0	39.4	44.9	38.3	51.1	56.3
	2014~2019	17.0	36.0	57.7	48.1	65.3	64.9
Research fields with 0% International coauthorship count (%)	2010~2015	4.2	10.4	6.7	6.0	16.9	6.6
	2014~2019	3.6	7.7	4.2	5.2	8.0	5.1

Table 6. The ratio of corresponding-author papers in China and developed countries

Item	Country					
	US	China	Germany	UK	Japan	France
Corresponding-author papers count in 2010~2015 (%)	50.5	48.3	29.2	31.8	21.3	25.8
Corresponding-author papers count in 2014~2019 (%)	51.6	63.7	31	33.5	21.6	22.8
Change rate (%)	2.2	32	6.4	5.2	1.4	-11.7

internationally co-authored papers reached 63.7%, ranking first among the US, China, Germany, France, the UK, and Japan. The ratio of corresponding authors of co-authored papers in the US, Germany, the UK, and Japan also showed an increasing trend. As listed, the increase in China was much higher than in other countries, reaching 32.0% (Table 6). Among the six countries, the international co-authorization rate of Chinese papers is the lowest (mean). Still, the ratio of the research areas utterly dependent on international cooperation (international co-authorization rate is equal to 100%), and the lack of international

collaboration (international co-authorization rate is equal to 0) has declined. It indicates that the scope of China's participation in international cooperative research activities has increased. The dependence on international coauthorship has reduced gradually, and the scientific research strength is strengthening.

2.4 China's performance in the research areas that impact technological innovation

A scientific paper cited by a patent indicates its specific impact on technological innovation. In this study, we analyzed the scientific performance of China and the developed countries in the research areas that impact technological innovation (innovation research area for short). From the science structure map from 2014 to 2019, we found that the core papers cited by patents fall into 864 research areas. Due to the low ratio of core papers cited by patents in some research areas, we selected the research areas with at least ten core papers cited by patents for further analysis, yielding 267 innovation research areas. There is no significant difference in the coverage rate of innovation research areas among different countries (Table 7), with the US slightly higher than the others.

However, regarding the world share of core papers cited by patents, the US has a clear advantage and reads at 58%, much higher than the others. For China, the global share of core papers cited by patents reads 20%, ranking second, close to the world share of China's core papers at 21% (Table 2). However, the world share of core papers cited by patents in developed countries such as the US is much higher than that of the core papers.

Figure 6 shows the research activity in the research areas in which scientific papers are cited by patents from 2014 to 2019. As can be seen from this figure, the number of research areas cited by patents in the US

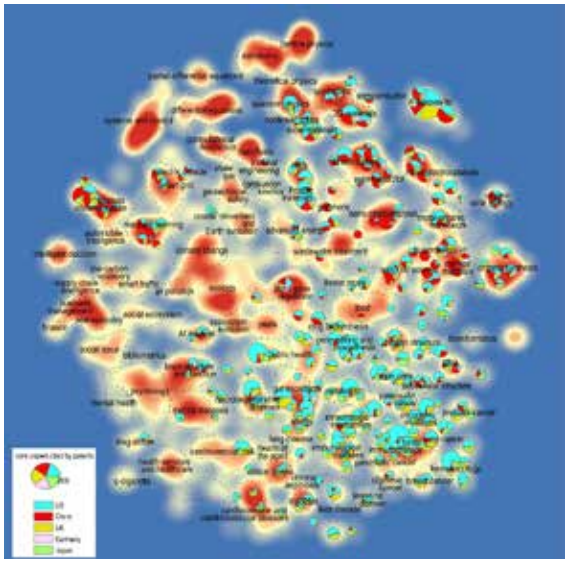

Figure 6. The research activity of five countries in the research areas in which papers are cited by patents. The pie chart shows the share; the pie size is proportional to the number of papers cited by patents, with different countries distinguished by color.

and China is far higher than that in the UK, Germany and Japan, and the difference in coverage rate is more pronounced. The US leads mainly in biology, medicine and a few in the material and device research area group, with obvious advantages. The UK and Germany occupy a particular share in the medicine group. On the contrary, patents rarely cite China's scientific papers in most medical and biological research areas. Hence, China only occupies a limited share in several research areas with limited research directions, such as protein structure, RNA, and stem cells.

China's performance in the innovation research areas is similar to China's overall status of scientific research. China still has its edge in chemistry and materials science, mathematics, computer science and engineering, and wastewater treatment. However,

Table 7. The coverage rate of the innovation research areas in China and developed countries

Item	Country					
	US	China	Germany	UK	Japan	France
Number of innovation research areas	264	214	215	216	200	169
Core papers cited by patents share (%)	57.8	20.4	15.9	14.6	5.6	9.2

Note: Only the research areas in which at least ten core papers are cited by patents are enrolled for analysis.

China's advantage is less evident across the whole research area. In addition, in the research areas where China gets the upper hand, the US still takes a larger share in the number of core papers with patent citations and exceeds China in the areas such as machine learning and lithium battery.

III. China's Performance over Different Subjects

By comparing the structural differences in scientific research between China and developed countries, we can better understand the features of China's research activities and then describe the layout of China's science structures.

Table 8 shows the world share of the corresponding-author papers for China and developed countries in the two periods. Due to the ever-growing interdisciplinary integration, it is challenging to achieve subject division in a strict sense. We listed the ratios of the core papers from each research area group according to the subjects they belong to and classified the research area group as the subjects with the top ratio.

Compared with 2010~2015, the number of corresponding-author papers in China during 2014~2019 increased significantly in each research area group, approaching or more than doubling. China's world share of corresponding-author papers in chemistry and materials science, mathematics, computer science and engineering far exceeds that of the US. However, China lags behind the US, Germany, and the UK in astronomy, particle physics, and medicine.

The following is a comparative analysis of the scientific research structure of China and the developed countries in each subject.

3.1. Astronomy and particle physics

In astronomy and particle physics, China's number of corresponding-author papers is higher than Japan, ranking fifth among the six countries (Table 9).

In astronomy, China's share of the corresponding-author papers is the smallest (2.4%), much lower than

Table 8. The share of corresponding-author papers in different subjects for China and developed countries (%)

Subject	2010~2015						2014~2019					
	US	China	Germany	UK	Japan	France	US	China	Germany	UK	Japan	France
Astronomy and Particle Physics	39.3	2.1	10.4	7.9	3.8	5.9	37.7	4.4	10.1	8.6	4.3	6.9
Condensed Matter Physics and Optics	38.3	13.0	9.3	4.6	4.8	3.8	36.1	21.2	8.7	5.2	4.2	3.4
Chemistry and Materials Science	29.0	29.7	6.1	3.9	3.5	2.0	24.1	47.8	5.6	3.3	2.6	1.3
Mathematics, Computer Science and Engineering	19.1	27.6	3.5	2.8	1.2	1.9	9.6	51.7	2.1	3.1	1.0	1.5
Earth Science and Ecological environment	39.9	8.6	7.1	9.2	4.1	4.0	27.5	21.4	6.1	8.0	1.9	3.0
Biology	36.8	11.2	6.3	7.5	2.2	4.1	33.4	20.4	5.8	7.2	1.9	3.6
Medicine	49.3	1.5	5.9	10.3	1.3	3.9	48.8	3.5	6.1	9.9	1.9	3.3
Social Science	49.3	1.5	5.9	10.3	1.3	3.9	35.7	9.9	3.7	15.3	0.2	1.9

Note: The red font refers to a subject with a high increase in the share of corresponding-author papers, while the blue font refers to a large decrease. Social science is not the focus of this report and hence is not discussed.

Table 9. The share of corresponding-author papers of China and developed countries in astronomy and particle physics (%)

Research Area Group	Number of Research Areas	US	China	Germany	UK	Japan	France
Astronomy	15	44.0	2.4	9.8	10.2	5.2	5.8
Particle physics	5	19.8	8.2	12.2	4.8	2.9	9.5
Theoretical physics	4	56.4	5.3	4.5	10.5	2.3	5.3

Note: A color scale of red-yellow-green stands for the maximum, midpoint, and minimum thresholds of the values. The color scale is applicable for the following tables.

that of the US (44%). Still, there is an improvement, compared with 1.9% in 2010~2015.

In particle physics, China's share of corresponding-author papers ranked fourth among the six countries, lower than that of the US, Germany and France. Compared with the 2.5% back in 2010~2015, China rapidly advanced. From 2010 to 2015, the relevant research papers in theoretical physics did not form a prominent cluster or island in China's science structure map.

In the research group of astronomy, particle physics and optics, Germany has a relatively balanced development in various research areas, among which its advantage in particle physics is more prominent. In contrast, the UK has a better performance in astronomy.

3.2 Condensed matter physics and optics

In the fields of condensed matter physics and optics, China's number of corresponding-author papers ranked second among the six countries (Table 10), with an increase of 8.2% compared with the previous period, second only to the 36.1% of the US, and far ahead of the UK, Germany, France and Japan.

China's share of corresponding-author papers in supermaterials, semiconductor physics and nonlinear optics groups has risen rapidly, comparable with the US. China ranks third in the quantum physics group regarding the number of corresponding-author papers. Compared with 2010~2015, China's number of corresponding-author papers in all the research areas of condensed matter physics and optics has significantly increased, especially in quantum mechanics, spintronics, supermaterials and nonlinear optics. Germany is outstanding in quantum physics and nonlinear optics, while the UK performs well in quantum physics.

3.3 Chemistry and materials science

China's chemistry and materials science ranks first (Table 11), with corresponding-author papers reaching 47.8%, an increase of 18.1% over the previous period (2010~2015). China's share of corresponding-author papers is much higher than that of the US (24.1%) and far ahead of the UK, Germany, France and Japan.

Except for flexible materials and devices, nanosafety and nanomaterials preparation, China takes the biggest shares of the corresponding-author papers in the other 13 research area groups. Among them, the shares of corresponding-author papers in eight research area groups, including electrochemical energy storage materials and devices, ceramic materials, interface chemistry, nanomedicine, organic solar cells, nanocarbon materials, medical luminescent materials, and nanobiomedicine were close to or more than 50%.

Chemistry and materials science have always been well-performing subjects in China. Compared to 2010~2015, China's share of corresponding-author papers for most research areas in this area has continued to increase. Notably, from 2014 to 2019, the growth of three research area groups where China did not rank first was especially significant. Flexible materials and devices increased from 20.6% to 25.5%, nanosafety increased from 1.8% to 13.6%, and nanomaterials preparation rose from 26.4% to 35.3%.

Table 10. The share of the corresponding-author papers in condensed matter physics and optics for China and developed countries (%)

Research Area Group	Number of Research Areas	US	China	Germany	UK	Japan	France
Quantum physics	9	29.9	10.8	12.6	10.0	1.9	3.3
Spintronics	8	40.0	17.9	9.3	4.3	9.3	5.2
2D materials	6	42.9	26.9	4.6	2.5	3.4	2.3
Semiconductor physics	5	34.0	29.2	8.3	3.5	7.6	2.1
Nonlinear optics	8	36.1	22.6	12.3	2.7	1.8	3.6
Supermaterials	11	30.6	30.6	3.8	5.9	1.6	2.5

Note: A color scale of red-yellow-green stands for the maximum, midpoint, and minimum thresholds of the values.

Table 11. The share of the corresponding-author papers in chemistry and materials science for China and developed countries (%)

Research Area Group	Number of Research Areas	US	China	Germany	UK	Japan	France
Electrochemical energy storage materials and devices	18	24.3	57.0	4.4	2.0	3.3	1.1
Perovskite materials and devices	4	29.2	34.3	2.3	9.0	2.5	0.2
Ceramic materials	3	20.0	51.0	2.0	7.0	0.0	0.0
Interface chemistry	3	8.0	70.5	2.3	2.3	0.0	4.5
Nanomedicine	8	28.7	46.2	4.1	0.5	1.1	2.5
Alloy materials	6	32.6	32.6	8.4	6.7	0.6	1.7
Flexible materials and devices	6	51.1	25.5	2.6	1.5	0.7	1.1
Organic solar cells	21	25.4	61.9	8.1	2.5	1.5	0.5
Nanocarbon materials	3	27.5	68.2	0.9	3.8	0.0	0.9
Metal-organic frameworks	8	32.2	35.9	5.1	6.3	2.7	4.1
Organic synthesis methodology	9	22.9	35.0	14.9	4.8	4.0	2.1
Supramolecular self-assembly	16	15.7	38.5	7.7	9.8	11.9	2.4
Medical luminescent materials	5	5.6	68.0	0.8	1.6	6.4	0.4
Nanomaterials preparation	5	41.2	35.3	5.9	0.0	2.9	0.0
Nanobiomedicine	3	21.4	47.9	4.6	2.2	1.7	1.7
Nanosafety	13	21.8	13.6	2.7	1.8	3.6	1.8

Note: A color scale of red-yellow-green stands for the maximum, midpoint, and minimum thresholds of the values.

3.4 Mathematics, computer science and engineering

China ranked first in the share of corresponding-author papers in mathematics, computer science and engineering (Table 12). China took 51.7% in 2014~2019, an increase of 24.1% over the number in 2010-2015, far higher than the other five countries.

Except for advanced energy, China's other seven research area groups ranked first among the six countries regarding the number of corresponding-author papers. The numbers of corresponding-author papers in the research area groups of differential/partial differential equations, systems and control, wireless communication, and artificial intelligence were close to or over 50%.

Mathematics, computer science and engineering are the best-performing subjects in China in 2014~2019. Compared with 2010~2015, the number of corresponding-author papers in differential/partial differential equations, wireless communication and artificial intelligence in China increased significantly. In 2010~2015, the share of the corresponding-author papers in differential/partial differential equations was 21%; the share in wireless communication was 20.6%, and that in artificial intelligence was 37.9%.

Table 12. The share of corresponding-author papers in mathematics, computer science and engineering for China and developed countries (%)

Research Area Group	Number of Research Areas	US	China	Germany	UK	Japan	France
Differential/partial differential equations	20	7.9	48.2	2.3	2.8	0.8	1.5
Computational mechanics	6	11.4	20.1	4.7	2.0	2.5	3.5
Systems and control	21	1.4	81.1	1.2	1.4	0.2	0.8
Wireless communication	15	12.4	55.1	2.2	2.5	1.8	0.9
Artificial intelligence	33	12.5	60.0	2.4	2.9	0.8	2.1
Energy network	17	14.5	32.0	2.0	6.6	0.5	0.8
Thermal engineering	13	6.7	25.1	0.9	3.0	0.7	1.9
Advanced energy	14	21.8	17.8	4.0	7.6	2.4	2.1

Note: A color scale of red-yellow-green stands for the maximum, midpoint, and minimum thresholds of the values.

3.5 Earth science and ecological environment

In earth science and ecological environment, China's share of corresponding-author papers ranks second among the six countries (Table 13), reaching 21.4%, second only to the US. There was an increment of 12.8%, compared with the previous period (2010~2015).

In geotechnical mining and pollution control, China's number of corresponding-author papers ranked first among the six countries. China ranked second, second only to the US, in the other five research area groups: crustal movement and Earth evolution, air pollution, hydrology, soil ecology, and environment and health. In climate change and ecological conservation, the number of corresponding-author papers in China was relatively small, accounting for 9.2% and 1%, ranking third and fifth, respectively.

Compared with 2010~2015, China's number of corresponding-author papers in earth sciences and ecological environment increased significantly in 2014~2019. In 2010~2015, China's share of corresponding-author papers in the climate change research group was 3.5%, that in air pollution was 1.5%, and that in pollution control was 23.4%. China's number of corresponding-author papers in the hydrological and ecological research area group was only 0.5%.

The UK has an outstanding performance in climate change. The US, Germany, and the UK are relatively balanced in all research area groups, except for their limited share of corresponding-author papers in geotechnical mining and pollution control, which are China's strengths.

3.6 Biology

In biology, China's number of corresponding-author papers ranked second in 2014~2019 (Table 14), reaching 20.4%, with a significant increase of 14.1% compared with 2010-2015. China's share of corresponding-author papers is second only to that of the US (33.4%) and is far ahead of the UK, Germany, France and Japan.

In the research area groups of food nutrition and health, RNA, and bioinformatics methods, China ranked first regarding the number of corresponding-author papers. In plant gene regulation, animal and plant diseases and pests (pests for short), stem cells, and public hygiene and health (public health for short), China ranked second only to the US. In ecosystem evolution, gene editing and biosynthesis, and protein structure, China's share of corresponding-author papers was small, ranking fourth, third, and fourth, respectively.

Compared with 2010~2015, China's number of corresponding-author papers in all research area groups of biology increased significantly in 2014~2019.

Table 13. The share of corresponding-author papers in earth science and ecological environment for China and developed countries (%)

Research Area Group	Number of Research Areas	US	China	Germany	UK	Japan	France
Geotechnical mining	19	8.2	71.2	0.6	1.8	0.8	1.0
Crustal movement and Earth evolution	11	29.9	26.5	7.0	8.6	3.2	3.7
Climate change	17	42.0	9.2	6.9	15.4	1.0	4.4
Air pollution	7	41.7	33.5	5.5	4.7	0.4	0.0
Ecological	15	30.7	1.0	7.5	9.8	0.3	3.5
Hydroecology	6	31.7	16.7	3.3	10.0	0.0	6.7
Soil ecology	5	26.5	21.2	10.6	6.6	0.0	4.0
Pollution control	20	6.9	42.3	3.6	1.7	4.4	1.4
Environment and health	5	33.3	25.4	7.9	0.0	0.0	1.6

Note: A color scale of red-yellow-green stands for the maximum, midpoint, and minimum thresholds of the values.

Table 14. The share of corresponding-author papers in biology for China and developed countries (%)

Research Area Group	Number of Research Areas	US	China	Germany	UK	Japan	France
Ecosystem evolution	8	42.3	4.5	5.5	17.5	0.3	3.8
Plant gene regulation	39	26.2	21.5	8.4	9.0	4.9	6.1
Pests	9	25.3	15.8	5.0	6.9	0.0	5.3
Food nutrition and health	23	6.5	30.8	0.5	0.4	0.1	2.1
Gene editing and biosynthesis	19	56.6	7.6	6.9	8.2	3.6	2.0
Protein structure	10	53.1	6.5	12.6	11.9	0.4	1.9
RNA	7	27.4	52.1	5.3	2.2	1.3	0.7
Stem cells	6	58.2	7.2	4.6	5.7	2.7	2.3
Bioinformatics	3	27.4	76.9	0.9	0.0	0.0	0.0
Health services and healthcare	21	35.5	12.4	3.6	8.5	0.1	5.7

Note: A color scale of red-yellow-green stands for the maximum, midpoint, and minimum thresholds of the values.

In 2010~2015, China took the share in ecosystem evolution at 2.5%, food nutrition and health at 13%, and omics in life science at 8.4%.

Germany performed well in protein structure, and the UK was strong in the ecosystem evolution research area group. In food nutrition and health, which is China's strength, the US, Germany, and the UK took small shares of corresponding-author papers.

3.7 Medicine

In medicine, China ranked fourth in 2014~2019, with 3.5% regarding the share of corresponding-author papers (Table 15), an increment of 2% compared to that in 2010~2015. Its share in medicine is lower than the US (48.8%), the UK (9.9%), and Germany (6.1%), yet higher than France (1.9%) and Japan (0.2%). China's share of corresponding-author papers was minor in most research groups, except for the emerging AI medical and gut microbiota, in which China ranked second. There are two research area groups in which China took more than 5% shares, namely metabolism and immunity and liver disease.

Compared with other subjects, China's number of corresponding-author papers in medicine has not increased significantly. The US has an absolute advantage in medical research. The UK excels in many research groups, such as health services and healthcare, brain structure and function, mental diseases, and psychology.

IV. China's Strengths and Weaknesses

The science structure map shows China's research strengths in nanotechnology, mathematics, computer science and engineering science, and environmental governance. In this section, we deduced research areas that are China's strengths by ranking the number of corresponding-author papers. Meanwhile, we obtained the research areas that are China's weaknesses when core papers are scarce in the research area.

Our analysis shows that China's output of core papers is growing rapidly. China leads in many research area groups, including geotechnical mining, systems and control, nanocatalysis, artificial intelligence, wireless communication, wastewater treatment, etc., and has begun to influence the global scientific landscape profoundly.

4.1 China's strengths

When China ranks first in the number of corresponding-author papers in most of the research areas in a research area group, we consider this group represents China's strength. As can be seen from Table 16, China's research strengths mainly lie in such fields as engineering, mathematics, computer science, materials science, and chemistry.

China ranks first in the number of corresponding-author papers in more than 80% of the research areas

Table 15. The share of corresponding-author papers in medicine for China and developed countries (%)

Research Area Group	Number of Research Areas	US	China	Germany	UK	Japan	France
Psychology	39	51.5	1.8	3.6	12.5	0.1	0.7
Brain structure and function	20	53.6	2.5	6.6	13.1	1.5	2.7
Neurodegenerative diseases	12	53.4	2.7	6.4	10.0	2.1	2.1
Mental diseases	19	42.1	1.6	3.9	19.3	1.4	0.7
AI medical	9	42.9	15.3	5.2	7.0	3.8	2.8
Gut microbiota	19	45.3	9.6	4.3	5.8	1.7	3.3
Metabolism and immunity	32	48.7	5.4	10.0	7.6	1.9	2.3
Immunological diseases	19	53.1	1.4	7.3	9.2	1.6	5.8
Tumor	75	54.1	3.4	6.3	7.1	2.9	4.6
Cardiovascular and cerebrovascular diseases	34	42.1	1.8	6.1	11.7	0.9	3.0
Liver disease	8	38.7	6.4	7.5	8.5	3.9	6.2
Diabetes	6	43.9	0.3	12.0	12.3	1.3	2.3
Critical illness	8	34.6	0.6	6.6	6.6	2.2	6.3
Health services and healthcare	27	38.7	1.6	1.8	20.7	0.0	1.5

Note: A color scale of red-yellow-green stands for the maximum, midpoint, and minimum thresholds of the values.

in eight research area groups (in colors warmer than yellow), namely geotechnical mining, medical luminescent materials, systems and control, nanocatalysis, artificial intelligence, electrochemical energy storage materials and devices, nanobiomedicine, and wireless communication. In the other two research area groups (yellowish green), namely differential/partial differential equations and energy network, China ranks first in the number of corresponding-author papers in more than 60% of their research areas.

4.2 China's weaknesses

In the science structure map of 2014~2019, the number of research areas without Chinese corresponding authors was 494, accounting for 37% of the total number of research areas. Table 17 shows the number of research areas in 2014~2019 with no corresponding authors from China. The result indicates that medicine and social sciences are China's weaknesses.

There are six research area groups in which more than 70% of the research areas (colored in green) bear

Table 16. The research area groups that are China's strengths

Geotechnical Mining	Systems and Control	Nanocatalysis	Artificial Intelligence	Electrochemical energy storage materials and devices
12(12)	16(17)	8(9)	25(29)	15(18)
Nanobiomedicine	**Wireless communication**	**Differential/Partial Differential Equations**	**Energy network**	**Metal-organic frameworks**
10(12)	12(15)	10(15)	10(15)	5(9)
Food nutrition and health	**Wastewater treatment**	**Organic synthesis methodology**	**Medical luminescent materials**	**Alloy materials**
12(23)	7(16)	7(16)	5(5)	3(6)

Note: The numbers outside the brackets are the number of research areas ranked first regarding the corresponding-author paper count in China, and the numbers inside the brackets are the number of research areas in the research area group; a color scale of red-yellow-green stands for maximum, midpoint, and minimum thresholds of the values of the number outside the bracket divided by the number within.

Table 17. The research area groups that are China's weaknesses

Tumor	Cardiovascular and cerebrovascular diseases	Health services and healthcare	Critical illnesses	Social issue research
72(75)	31(33)	23(27)	6(8)	15(20)
Social ecosystem	Brain structure and function	Neurodegenerative diseases	Psychology	Ecological conservation
8(11)	16(24)	8(12)	20(31)	9(15)
Mental diseases	Metabolism and immunity	Astronomy	Gut microbiota	Climate change
9(17)	14(30)	7(15)	7(19)	5(17)

Note: the numbers outside brackets refer to the number of research areas in which no Chinese corresponding authors has been seen in a paper, while the numbers inside brackets refer to the number of research areas in the research area group; a color scale of green-yellow-red stands for maximum, midpoint, and minimum thresholds of the values of the number outside the bracket divided by the number within.

no sign of Chinese corresponding authors in the papers, namely tumor, cardiovascular and cerebrovascular diseases, health services and healthcare, critical illnesses, social issue research, and social ecosystem.

In addition, there are four research area groups in which more than 60% of the research areas (colored in yellowish green) bear no sign of Chinese corresponding authors in the papers, namely brain structure and function, neurodegenerative diseases, psychology, and ecological conservation.

V. Conclusion

The analysis of the science structure maps from the 12th Five-Year Plan and the 13th Five-Year Plan periods shows that China's basic research has made remarkable progress. Regarding the overall status of scientific research, China's share of the core papers has increased significantly. It has stably ranked second worldwide; since 2018, it has surpassed the US.

In 2014~2019, China greatly exceeded Germany, the UK, Japan and France combined regarding the number of core papers. Meanwhile, the number of core papers in other developed countries showed a downward trend. China was rapidly progressing in research coverage and international coauthorship, gradually narrowing the gap with the US, the UK, Germany, and other countries. However, China's coverage rate and the share of corresponding-author papers in the research areas that impact technological innovation are not as prominent as in all the research areas. In the scientific research status in various disciplines, China's progress is also relatively rapid. While China's structure and layout of disciplinary structure is gradually stabilising, a number of Chinese-dominated research area groups have emerged and are influencing the world's scientific landscape.

Meanwhile, we noticed that, compared with the developed countries, China's research level is still very uneven in different fields of study; 494 research areas bear none of the Chinese corresponding authors in the published papers. In the newly advanced research area groups dominated by China, the overall participation of developed countries is limited. This may be related to China's unique problems in the development process or incentives for Chinese scientists to publish particular papers. The differences in the structure of scientific research between China and the developed countries may imply the differences in the layout of scientific research, the focus of innovation, and innovation ability, among many other hidden forces waiting to be revealed.

China is facing a new starting point for high-quality development. In addition to growing in scale, it is more important to improve the quality of research, focus on the crucial core scientific problems, promote interdisciplinary integration, and highlight theoretical innovations.

References

[1] Wang Xiaomei, Li Guopeng, Chen Ting, Mapping Science Structure 2021. http://sciencemap.casaid.cn/dist/[2022-01-27]
[2] Wang Xiaomei, Han Tao, Li Guopeng, et al. Atlas of Science Structure 2017, Beijing: Science Press, 2017.
[3] Wang Xiaomei, Han Tao, Wang Jun, et al. Science Structure Map 2015. Beijing: Science Press, 2015.
[4] Pan Jiaofeng, Zhang Xiaolin, Wang Xiaomei, et al. Science Structure Map 2012. Beijing: Science Press, 2013
[5] Pan Jiaofeng, Zhang Xiaolin, Wang Xiaomei, et al. Science Structure Map 2009. Beijing: Science Press, 2010