Global Innovation Hubs Index 2024

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Executive Summary

2024 has witnessed generative artificial intelligence (AI) breaking new frontiers in science, driving a new wave of industrial innovation and increasing the level of human-machine interaction in daily lives. Although the global economy is recovering after the COVID-19 pandemic, it faces risk from geopolitical conflicts and natural disasters. In this climate, scientific and technological innovations are much needed to address global problems and drive health improvements. The Global Innovation Hubs Index (GIHI) developed by the Center for Industrial Development and Environmental Governance (CIDEG) at Tsinghua University, with data services and translation support from Nature Research Intelligence, has been tracking and analysing year-on-year changes and the latest trends in global innovation since 2020. GIHI2024 continues to apply scientific, objective, independent and impartial principles to evaluate global innovation hubs (GIHs) using three indicators — research innovation, innovation economy and innovation ecosystem — providing a reference for policymakers, entrepreneurs and practitioners.

The GIHI2024 top 20 cities/metropolitan areas overall are San Francisco-San Jose, New York MA, Beijing, Boston MA, London MA, Guangdong-Hong Kong-Macao Greater Bay Area, Shanghai, Paris MA, Tokyo MA, Baltimore-Washington, Seoul MA, Singapore, Los Angeles-Long Beach-Anaheim, Munich, Seattle-Tacoma-Bellevue, Chicago-Naperville-Elgin, Chapel Hill-Durham-Raleigh, San Diego MA, Amsterdam MA and Dublin.

The following conclusions have been made using the GIHI2024:

First, GIHs have provided strong support for the global economic recovery, with cities/metropolitan areas in Europe and the United States still taking the lead and Asian cities catching up rapidly. The innovation landscape of the top cities/metropolitan areas remains competitive and the development of bay areas and mini-hubs show distinct characteristics:

• The innovation capability of Asian cities continues to improve rapidly, especially in the innovation ecosystem category. Seven Asian cities have moved up in overall ranking among the top 50 cities although Europe and the United States still take the lead in innovation and have 14 cities/metropolitan areas ranking in the overall top 20.

• Bay area cities hold prominent advantages in integration of innovation resources, with four of the top five cities/metropolitan areas in the innovation economy ranking being bay areas. These cities show strong strengths in innovation enterprises and emerging industries.

• Cambridge, Basel and Oxford are the top three mini-hubs with a population of less than one million. These cities drive innovation by leveraging distinct strengths in specific fields, for example, Ithaca's top universities and scientific research talent resources, Eindhoven's technological innovation capabilities, and Oslo's booming innovation ecosystem.

Second, the top 20 cities can be clustered into four development patterns as revealed by their scores, highlighting the key role of sourcing capability for original innovation in scientific and technological innovation:

• Innovation economy-oriented cities, such as San Francisco-San Jose, Tokyo MA, Seoul MA and Dublin have demonstrated strong industrial competitiveness by driving the rapid growth of emerging industries and technological innovations. For example, San Francisco-San Jose which is leading in the innovation economy for its strong performance and continuous innovation in emerging fields, and Tokyo MA with its solid innovation capabilities and a large number of established leading companies.

• Research innovation-oriented cities, such as New York MA, Beijing, Boston MA and Guangdong-Hong Kong-Macao Greater Bay Area, have become important global innovation hubs with their leading research strength and academic resources. For example, New York MA is home to abundant research talent and leads the world in knowledge creation.

• The development pattern of research innovation plus innovation ecosystem implies that the research and innovation environment develop simultaneously, offering huge potential for the industrial use of scientific and technological achievements. Seven cities demonstrate this pattern, including London MA, Baltimore-Washington and Shanghai.

• Cities with a balanced development pattern include Munich, Seattle-Tacoma-Bellevue, San Diego, Singapore and Amsterdam MA. These cities are relatively balanced in research innovation, innovation-driven industrialization and ecosystems, and have maintained their edge through openness and cooperation as well as resource integration.

Third, in research innovation, cities in the United States continue to dominate with solid foundations, with cities in China being on the rise. Cities/metropolitan areas in the United States not only outperform in the overall ranking of research innovation, but also have great advantages in knowledge creation, maintaining the lead in academic research. For example, New York MA, Boston MA and Baltimore-Washington are among the top five for the number of highly cited papers and the total citations from patents, policy reports and clinical trials. New York MA ranks first in research innovation, followed closely by Beijing. Wuhan, Hangzhou, Changsha, Tianjin and other Chinese cities have moved up significantly in the overall ranking. Chinese cities are strong performers in the research institutions sub-indicator, with Beijing and Guangdong-Hong Kong-Macao Greater Bay Area having the most top 200 research institutions and world-leading universities. Chinese cities also have strong potential for scientific infrastructure with several large scientific facilities in construction.

Fourth, in the innovation economy indicator, the driving forces for the global economy have changed significantly and the rise of AI has enabled the rapid growth of GIHs. GIHs have shown strong innovation momentum. The market values of high-tech manufacturing enterprises have generally recorded positive growth. San Francisco-San Jose is not only the absolute leader in technological innovation capabilities, innovative enterprises and emerging industries, but it has also outperformed in incremental growth. In the post-COVID era, there has been a major change in the drivers of the global economy. The market value of high-tech manufacturing enterprises in information technology has increased rapidly. Leading innovation enterprises and unicorn companies (privately owned start-up companies valued at more than US$1 billion) keep springing up and the biopharma sector has entered a temporary period of dormancy. Gross domestic product growth rates indicate that the impact of the COVID-19 pandemic is dissipating and the global economy is on its way to a stable recovery.

Fifth, in the innovation ecosystem indicator, cities in Europe and the United States lead the world with their well-established infrastructure, public services and innovation culture, while Asian cities are gaining momentum with their strong growth in overseas investment and financing. In the post-COVID era, the demand for air travel continues to rebound and GIHs have seen a significant growth in talent inflow. Growing international exchanges have injected new momentum into the cities' innovation ecosystems and facilitated the exchange of knowledge and technology. Despite the sustained decline in global capital flows and venture capital investment, capital flows in emerging markets are more resilient. For example, the foreign direct investment (FDI) of Kuala Lumpur has doubled, and the FDI of Mumbai, Bangalore and the Central National Capital Region (Delhi) have increased by 49%, 25% and 54%, respectively. Multinational companies are shifting more investment and resources to southeast Asia for a more diversified and stable supply chain.

The GIHI2024 also features two special focus sections. First, the global trend of international collaboration in academic co-authorship. As research is increasingly taking the form of 'big science', enhanced worldwide cooperation has become a major force for scientific and technological innovation. The most influential cities/metropolitan areas are leading in academic cooperation. However, the COVID-19 pandemic affected global research output and had negative effects on international cooperation. In this context, Beijing and the Guangdong-Hong Kong-Macao Greater Bay Area have maintained growth in the number of internationally co-authored papers that originate from these areas, which goes against the trend. In 2022, Beijing ranked first in the number of internationally co-authored papers in eight disciplines across science, technology, engineering and medicine. Biomedical and clinical sciences is one of the hot fields for international cooperation. Physical sciences, earth sciences and environmental sciences are the three disciplines with the highest level of internationalization for the elite cities. Expanding the boundaries of human knowledge, jointly addressing global challenges and achieving sustainable development are important cornerstones of global academic cooperation.

Second, the global landscape of patents in biomedicine. The COVID-19 pandemic has raised people's awareness of biomedical innovation, which has led to explosive growth in the field since 2020. For patent output, the United States, Europe, Japan and China are superior players. As AI and materials science grow at a faster pace, these countries are leading the interdisciplinary development of biomedicine. For innovation organizations, GIHs, including Paris MA, New York MA and Beijing, are developing their innovation sourcing capabilities by having a large number of national research institutions. GIHs, such as Boston MA, San Francisco-San Jose and Shanghai, are fostering biomedical start-ups and promoting interdisciplinary integration with their leading innovation ecosystems. GIHs such as Tokyo MA, Seoul MA and Basel are accelerating biomedical innovation with a global collaboration network led by multinational companies. In the future, major breakthroughs in biomedicine will rely more heavily on large scientific facilities, integration of interdisciplinary technologies and the support of venture capital.

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Introduction

In 2024, cutting-edge technologies, such as generative artificial intelligence (AI), have continued to drive change and foster innovation. Industries remain committed to pursue a more digital, intelligent and green future. At the same time, investors in innovation capital are taking a cautious view due to uncertainties arising from political, environmental and technological factors. In this landscape, the need for technology to be harnessed for good, and for effective global governance of technology has become more important than ever.

The Global Innovation Hubs Index (GIHI) uses objective data to trace the performance and rankings of leading global innovation hubs (GIHs) in areas such as scientific research, technological innovation and support for start-ups. It explores the key drivers behind innovative transformation, revealing key elements and strategies for cities to deliver valuable global innovation and provides information for policymakers about the development of GIHs.

In line with the tradition established from the first GIHI report in 2020, we have continued to apply scientific, objective, independent and impartial principles in evaluating 108 GIHs and 12 mini-hubs for GIHI2024 (see Appendix IV for details of the GIH selection process), while taking into account the feedback and suggestions of industry experts, media and the public. Some adjustments have been made to the assessment metrics and focus sections as follows.

First, to improve its scientific rigour, the index system has been optimized for GIHI2024. As China has not taken part in the ranking of top 500 supercomputers since 2022, China's top 100 supercomputers have been included in our analysis alongside the global number of top 500 supercomputers. This adjustment ensures that GIHI2024's top 500 supercomputers indicator is comprehensive. For patent-related indicators, patents in biomedicine have been added and the integrated circuit has been replaced by the smart chip. The patents in four areas are classified with reference to the Patent Classification System for Key Digital Technologies (2023) and the Reference Table for Strategic Emerging Industries Classification and International Patent Classification (2021) issued by the China National Intellectual Property Administration. The number of patent cooperation treaty (PCT) patents is collated on an annual basis after adjustments. These changes are intended to further ensure the authority, objectivity, comprehensiveness and immediacy of the indicators. See Appendix I for a more detailed explanation of these adjustments.

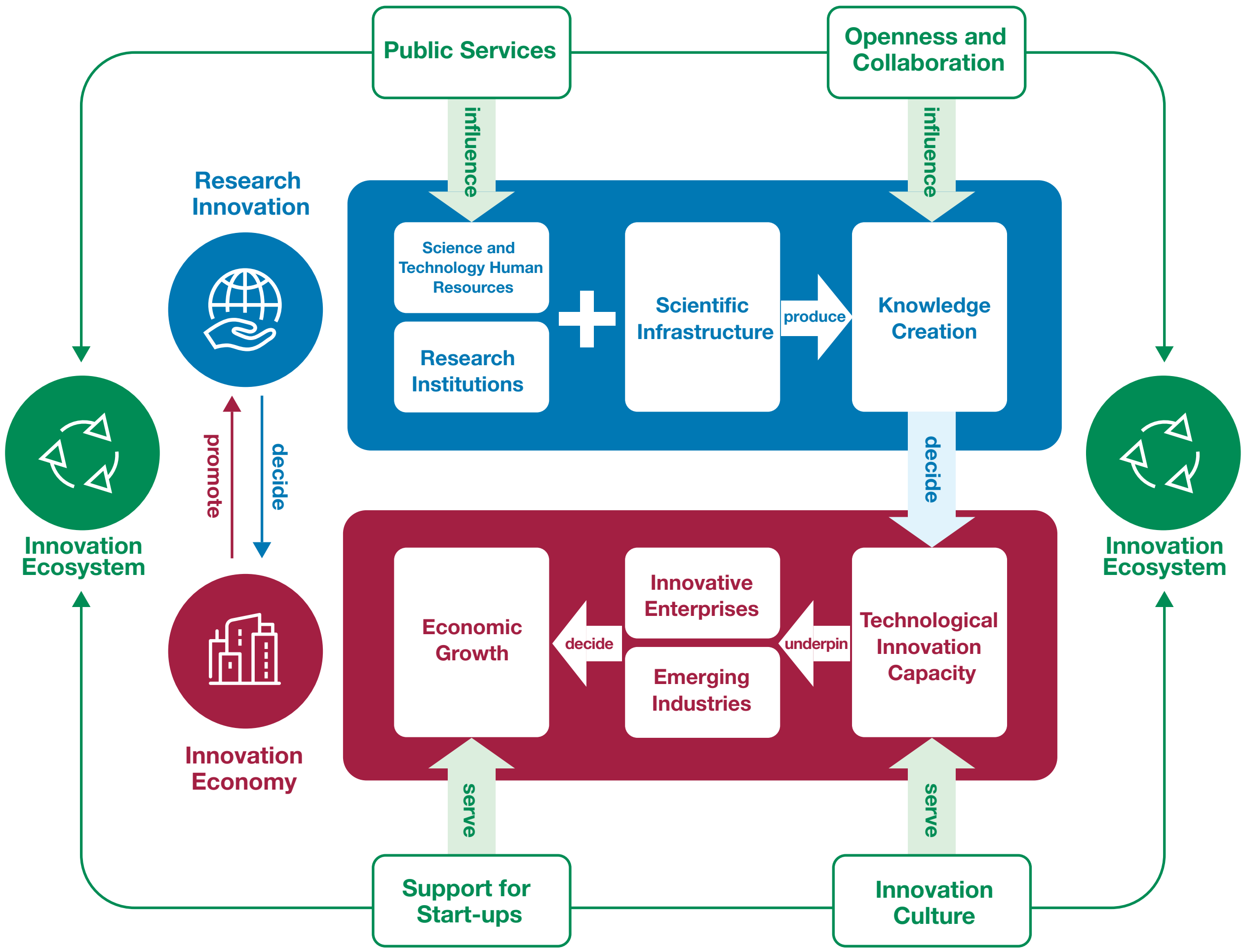
Second, the GIHI2024 have added two focus sections to track the dynamics of GIHs in global scientific and technological innovation. The first focus section is on international collaboration in academic co-authorship, which reveals the trends of internationally co-authored papers of GIHs and identifies the global cooperation pattern and evolution for the top ten cities ranked by the number of internationally co-authored papers. The second focus section examines patents for biomedicine, which investigates GIHs' innovation capability in biomedicine by total numbers of patents, innovation entities and future prospects.

1.1
A conceptual model for GIHI

Global innovation hubs (GIHs) are defined as cities or metropolitan areas that lead the flow of global innovation elements and influence the efficiency of resource allocation, drawing on their unique advantages in science and technology innovation. With advanced technological and innovative resources, GIHs are also hubs of scientific and innovative activities. They boast good innovation ecosystems and play an important role in the global innovation landscape. The GIHI assesses the development of GIHs in three dimensions — research innovation, innovation economy and innovation ecosystem. The conceptual model for GIH assessment is shown in Figure 1.

FIGURE 1

A conceptual model for GIH assessment



1.The index system

1.2
The index system

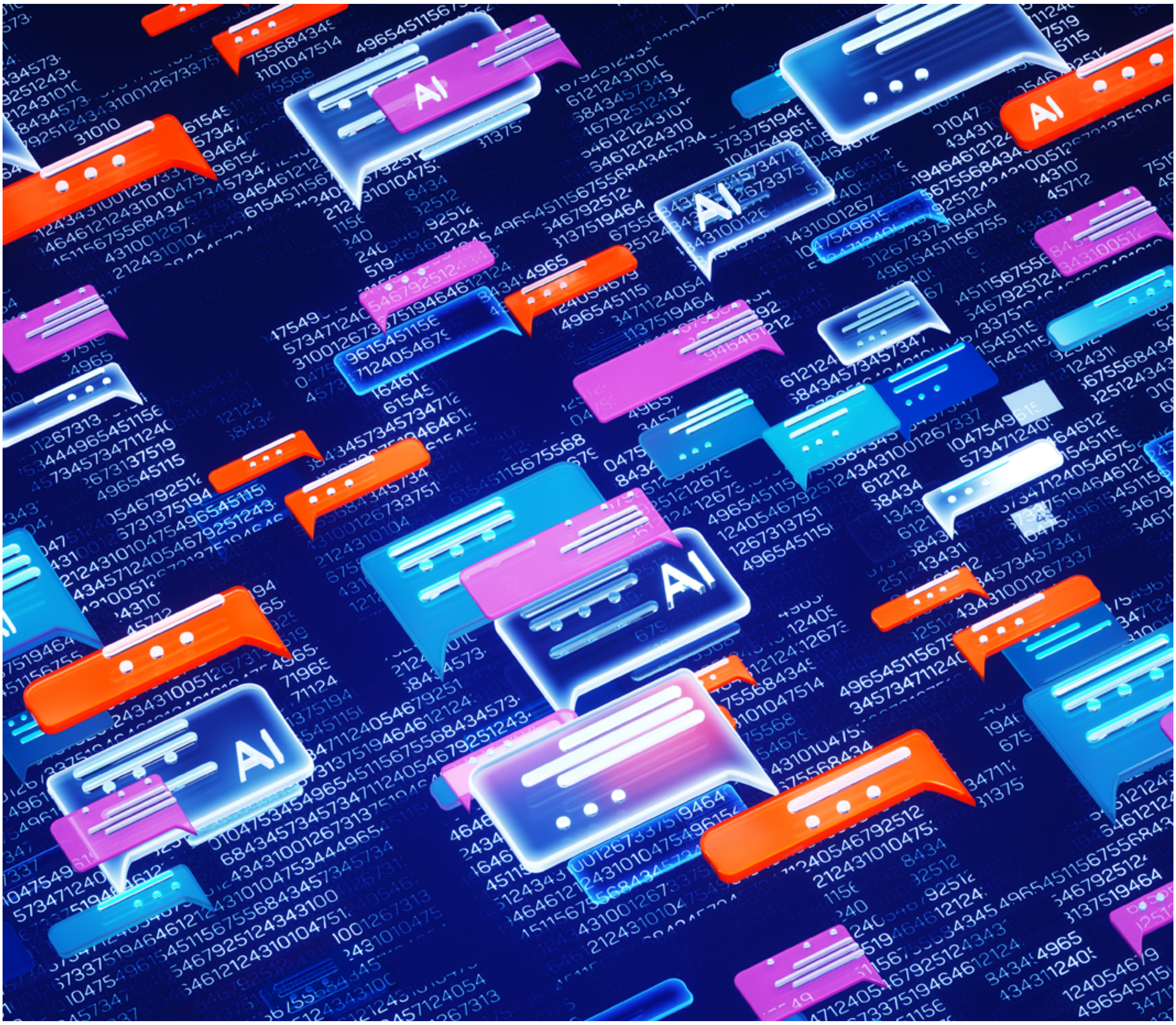
The GIHI system is shown in Table 1.

TABLE 1

Global Innovation Hubs Index (GIHI) System

Level-1 indicator	Level-1 indicator weight	Level-2 indicator	Level-2 indicator weight	Level-3 indicator
A Research Innovation	30%	A1.Science and Technology Human Resources	30%	01. Number of active researchers (per million people)
				02. Number of winners of top scientific awards
		A2. Research Institutions	30%	03. Number of world-leading universities
				04. Number of top 200 world-class research institutions
		A3. Scientific Infrastructure	10%	05. Number of large scientific facilities
				06. Number of top 500 supercomputers
		A4. Knowledge Creation	30%	07. Number of highly cited papers
				08. Total citations from patents, policy reports and clinical trials
B Innovation Economy	30%	B1. Technological Innovation Capacity	25%	09. Total number of valid patents (per million people)
				10. Number of patent cooperation treaty (PCT) patents
		B2. Innovative Enterprises	25%	11. Number of leading innovative companies
				12. Number of unicorn companies
		B3. Emerging Industries	25%	13. Market value of high-tech manufacturing companies
				14. Revenue of listed companies in new economy industries
		B4. Economic Growth	25%	15. GDP growth rate
				16. Labour productivity
C Innovation Ecosystem	40%	C1. Openness and Collaboration	25%	17. Paper co-authorship network centrality
				18. Patent collaboration network centrality
				19. Foreign direct investment (FDI)
				20. Outward foreign direct investment (OFDI)
		C2. Support for Start-ups	25%	21. Venture capital investment (VC)
				22. Private equity (PE)
				23. Number of registered lawyers (per million people)
		C3.Public Services	25%	24. Number of data centres (public clouds)
				25. Broadband connection speed
				26. Number of international flights (per million people)
				27. E-governance level
		C4. Innovation Culture	25%	28. Professional talent inflow (per million people)
				29. Residents' average years of schooling
				30. Number of public libraries and museums (per million people)

Research innovation, innovation economy and innovation ecosystem constitute level-1 indicators of the GIHI system and the key elements of each area make up level-2 indicators. The weight of GIHI is allocated as follows: the total weight for level-1 indicators is 100%, with 30% for research innovation, 30% for innovation economy and 40% for innovation ecosystem, respectively. The linear-weighted-sum method is used to calculate the overall scores. See Appendix II for the definitions and data sources of GIHI indicators and see Appendix III for information about data standardization.



1.3
Subjects of evaluation

This report uses four international city rankings — the Nature Index 2023 Science Cities, the 2023 Global Cities Index by Kearney, the Global Innovation Index by WIPO and the Innovation Cities™ Index 2023 by 2ThinkNow. Cities/metropolitan areas with strong innovation capabilities were evaluated, which totaled 120 cities/metropolitan areas. Among these, 12 cities/metropolitan areas with a population of less than one million were evaluated separately as mini-hubs. The evaluation assessed the other 108 cities/metropolitan areas and selected the top 100 cities/metropolitan areas (see Appendix IV for the GIH selection process).

These 120 cities/metropolitan areas are from 38 countries/regions in six continents, covering 374 major administrative divisions. Among them, there are 44 Asian cities, 38 European cities, 31 North American cities, four Oceanian cities, two South American cities and one African city. These cities/metropolitan areas are home to the top innovation resources and output in the world, and they stand out in the research innovation, innovation economy and innovation ecosystem indicators. Accounting for only 11.3% of the world's total population, these cities/metropolitan areas boast 138 world-leading universities, 149 of the top 200 world-class research institutions, 1,453 unicorn companies valued at more than US$1 billion and 1,888 leading innovative enterprises. They have attracted 279 winners of top scientific awards, including Nobel prizes, the Turing Award or the Fields Medal.

2. Overall GIHI ranking

2.1 Ranking results

The GIHI2024 ranking is shown in Table 2.

TABLE 2

Overall ranking of the top 100 Global Innovation Hubs (GIHs)

City/metropolitan area	Overall		Research Innovation		Innovation Economy		Innovation Ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
San Francisco - San Jose	100.00	1	95.55	4	100.00	1	97.13	2
New York MA	91.88	2	100.00	1	79.48	3	95.88	3
Beijing	89.28	3	99.75	2	84.07	2	80.71	9
Boston MA	83.73	4	97.02	3	72.38	8	82.91	7
London MA	83.52	5	86.16	7	68.75	13	100.00	1
Guangdong - Hong Kong - Macao Greater Bay Area	82.39	6	88.27	5	74.95	5	84.63	6
Shanghai	77.90	7	78.81	9	70.00	10	87.93	4
Paris MA	77.02	8	80.76	8	69.99	11	82.81	8
Tokyo MA	76.49	9	75.62	12	75.63	4	78.51	14
Baltimore - Washington	76.27	10	86.84	6	66.08	29	79.28	11
Seoul MA	74.64	11	71.87	17	74.85	6	77.79	17
Singapore	73.31	12	70.34	21	68.44	15	84.75	5
Los Angeles - Long Beach - Anaheim	72.14	13	76.41	10	66.26	27	77.22	18
Munich	71.60	14	71.55	19	68.16	19	78.11	15
Seattle - Tacoma - Bellevue	71.34	15	69.30	28	70.15	9	76.84	21
Chicago - Naperville - Elgin	71.08	16	74.59	13	66.35	25	75.65	23
Chapel Hill - Durham - Raleigh	70.46	17	75.91	11	64.86	47	74.33	28
San Diego MA	70.18	18	69.20	30	68.46	14	75.66	22
Amsterdam MA	69.96	19	68.25	34	66.01	30	79.65	10
Dublin	69.89	20	64.29	66	73.65	7	72.52	38
Zurich	69.61	21	73.16	14	64.73	53	74.82	26
Dallas - Fort Worth	69.50	22	65.35	57	68.37	17	77.91	16
Copenhagen	69.30	23	70.63	20	65.91	31	74.91	25
Stockholm	69.15	24	69.76	26	66.34	26	74.78	27
Toronto MA	68.79	25	69.09	31	63.27	88	78.92	12
Kyoto - Osaka - Kobe	68.28	26	70.24	23	68.39	16	68.29	58
Austin	68.25	27	65.30	58	67.26	21	75.51	24
Madrid	67.93	28	65.96	52	65.12	37	76.89	20
Houston MA	67.87	29	69.37	27	66.13	28	71.32	46
Atlanta MA	67.78	30	70.28	22	64.92	43	71.75	43

City/metropolitan area	Overall		Research Innovation		Innovation Economy		Innovation Ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Taipei	**67.48**	31	**66.72**	47	**68.25**	18	**69.86**	54
Nanjing	**67.43**	32	**72.48**	15	**65.47**	34	**67.29**	70
Abu Dhabi	**67.37**	33	**60.40**	106	**67.99**	20	**77.07**	19
Philadelphia MA	**67.32**	34	**70.06**	25	**64.85**	48	**70.61**	51
Milan	**67.31**	35	**67.10**	43	**66.91**	23	**70.85**	48
Rome	**66.95**	36	**68.61**	33	**64.14**	71	**72.09**	41
Berlin MA	**66.92**	37	**67.31**	40	**64.60**	58	**72.77**	35
Melbourne	**66.89**	38	**72.04**	16	**62.60**	95	**70.29**	52
Daejeon	**66.83**	39	**68.15**	36	**69.19**	12	**64.68**	86
Sydney	**66.81**	40	**70.24**	24	**61.78**	106	**73.31**	34
Helsinki	**66.79**	41	**65.68**	55	**64.68**	56	**74.08**	32
Hangzhou	**66.77**	42	**67.84**	37	**66.48**	24	**68.90**	55
Pittsburgh	**66.69**	43	**69.29**	29	**63.89**	77	**70.82**	49
Barcelona MA	**66.66**	44	**67.34**	39	**64.29**	65	**72.34**	39
Hamburg	**66.55**	45	**64.52**	63	**64.94**	41	**74.23**	30
Denver MA	**66.44**	46	**63.93**	67	**65.67**	32	**73.44**	33
Wuhan	**66.31**	47	**71.60**	18	**64.88**	45	**65.47**	82
Phoenix MA	**66.27**	48	**64.47**	64	**65.66**	33	**72.30**	40
Vancouver MA	**66.21**	49	**67.30**	41	**63.04**	90	**72.77**	36
Frankfurt	**65.99**	50	**63.34**	77	**64.59**	60	**74.26**	29
Manchester	**65.89**	51	**66.30**	50	**63.91**	76	**71.57**	45
Nagoya MA	**65.89**	52	**66.07**	51	**67.23**	22	**66.86**	73
Lyon - Grenoble	**65.86**	53	**66.31**	49	**64.89**	44	**70.01**	53
Montreal MA	**65.81**	54	**68.21**	35	**62.20**	98	**71.68**	44
Miami MA	**65.80**	55	**62.28**	89	**65.06**	39	**74.11**	31
Minneapolis - Saint Paul	**65.76**	56	**65.61**	56	**64.71**	54	**70.72**	50
Tel Aviv	**65.26**	57	**63.29**	79	**65.29**	35	**70.86**	47
Dubai	**65.22**	58	**60.00**	108	**62.47**	97	**78.65**	13
Moscow	**64.84**	59	**67.48**	38	**63.45**	87	**67.44**	66
Vienna	**64.82**	60	**65.94**	53	**64.50**	62	**67.54**	63
Dusseldorf	**64.70**	61	**61.32**	100	**64.75**	52	**72.06**	42
St. Louis	**64.70**	62	**65.82**	54	**64.06**	72	**67.94**	62
Sao Paulo	**64.70**	63	**64.91**	60	**61.63**	107	**72.59**	37
Xi'an	**64.47**	64	**68.77**	32	**63.84**	78	**64.17**	89
Hefei	**64.44**	65	**66.54**	48	**64.29**	66	**65.93**	78

2.Overall GIHI ranking

City/metropolitan area	Overall		Research Innovation		Innovation Economy		Innovation Ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Rotterdam	64.42	66	63.83	68	64.94	42	67.99	61
Brisbane	64.36	67	67.14	42	62.15	99	68.18	60
Lisbon	64.34	68	63.66	71	64.75	51	68.20	59
Perth	64.04	69	64.57	62	63.91	75	67.41	67
Bengaluru	63.86	70	61.55	98	65.14	36	68.41	56
Warsaw	63.78	71	62.93	81	64.82	49	67.07	71
Göteborg	63.77	72	63.81	69	64.49	63	66.50	74
Chengdu	63.76	73	66.97	45	63.61	84	64.21	88
Brussels	63.76	74	63.63	73	64.86	46	66.12	76
Cologne	63.74	75	63.57	74	64.05	73	67.35	68
Tianjin	63.47	76	66.96	46	62.83	94	64.44	87
Cincinnati	63.37	77	62.30	88	64.22	69	67.32	69
Portland	63.36	78	62.14	90	63.66	83	68.30	57
Central National Capital Region (Delhi)	63.19	79	61.90	93	64.70	55	66.48	75
Suzhou	63.19	80	62.67	84	64.95	40	65.20	83
Changsha	63.14	81	67.09	44	63.76	81	61.81	99
Mumbai MA	62.92	82	60.65	104	64.65	57	67.06	72
Buenos Aires	62.89	83	62.47	85	64.24	67	65.52	81
Doha	62.87	84	62.34	87	62.97	92	67.48	65
Las Vegas	62.85	85	60.10	107	64.59	59	67.54	64
Stuttgart	62.71	86	61.76	95	64.81	50	64.86	84
Prague	62.60	87	63.37	76	64.24	68	63.53	91
Jinan	62.51	88	64.35	65	63.78	79	62.81	95
Detroit MA	62.38	89	61.56	97	63.49	86	65.96	77
Kuala Lumpur	62.36	90	62.44	86	63.02	91	65.61	80
Xiamen	62.34	91	63.45	75	65.07	38	61.33	101
Mexico City	62.25	92	61.75	96	63.15	89	65.85	79
Qingdao	62.17	93	62.81	83	64.01	74	63.08	93
Dalian	62.05	94	63.65	72	63.73	82	62.14	98
Budapest	61.96	95	62.07	91	64.54	61	62.43	96
Istanbul	61.83	96	61.17	101	64.34	64	63.34	92
Busan	61.78	97	61.10	103	63.77	80	64.10	90
Fuzhou	61.41	98	63.02	80	64.21	70	60.04	107
Bangkok	61.40	99	61.91	92	61.87	104	64.76	85
Harbin	61.39	100	65.07	59	61.79	105	61.26	103

2.2
Overall analysis

San Francisco-San Jose has been named the top ranked GIH for the fifth consecutive year, scoring much higher than other GIHs; New York MA ranks second again with a score of 91.88; Beijing comes in third place with a score of 89.28; Boston MA and London MA rank fourth and fifth, respectively and have swapped position since 2023. Other cities/metropolitan areas in the top 20 are Guangdong-Hong Kong-Macao Greater Bay Area, Shanghai, Paris MA, Tokyo MA, Baltimore-Washington, Seoul MA, Singapore, Los Angeles-Long Beach-Anaheim, Munich, Seattle-Tacoma-Bellevue, Chicago-Naperville-Elgin, Chapel Hill-Durham-Raleigh, San Diego MA, Amsterdam MA and Dublin.

Overall, competition in global innovation continues to intensify. The rankings in research innovation are relatively stable while those in innovation economy and innovation ecosystem are fiercely competitive. Comparing the top 20 GIHs between 2022 and 2024 (Table 3), San Francisco-San Jose, New York MA and Beijing continue to lead, demonstrating their strong innovation capabilities. Among the top 20, seven cities/metropolitan areas have improved upon their 2023 position, namely Boston MA (↑1), Shanghai (↑3), Paris MA (↑1), Munich (↑3), Chapel Hill-Durham-Raleigh (↑2), Amsterdam MA (↑4) and Dublin (↑5). By the changes to the ranking in innovation factors, the top 20 spots in research innovation show less volatility as they involve a commitment to long-term strategic development. Only six cities have changed their ranking since 2023. By comparison, the top 20 cities in innovation economy and innovation ecosystem have shown more movement, with 16 cities/metropolitan areas in each category ranking differently to 2023.

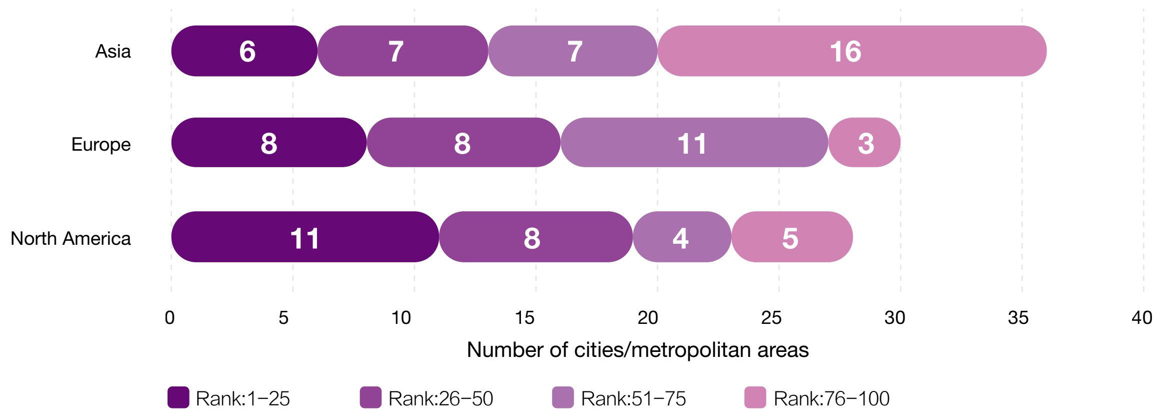
TABLE 3 A comparison of the top 20 GIHs in overall ranking between 2022-2024

City/metropolitan area	Rank 2024	Rank 2023	Rank 2022
San Francisco - San Jose	1	1	1
New York MA	2	2	2
Beijing	3	3	3
Boston MA	4	5	5
London MA	5	4	4
Guangdong - Hong Kong - Macao Greater Bay Area	6	6	6
Shanghai	7	10	10
Paris MA	8	9	9
Tokyo MA	9	7	7
Baltimore - Washington	10	8	15
Seoul MA	11	11	12
Singapore	12	12	13
Los Angeles - Long Beach - Anaheim	13	13	16
Munich	14	17	14
Seattle - Tacoma - Bellevue	15	15	11
Chicago - Naperville - Elgin	16	14	24
Chapel Hill - Durham - Raleigh	17	19	27
San Diego MA	18	18	18
Amsterdam MA	19	23	17
Dublin	20	25	28

2.Overall GIHI ranking

FIGURE 2

Quartile graph of overall ranking for cities/metropolitan areas in Asia, Europe, and North America



Innovation competition continues to deepen

Geographically, the global innovation landscape has evolved towards multi-polarity and competition has deepened. As shown in Figure 2, cities in North America and Europe possess well-established innovation systems and Asian cities are rising significantly. Among the top 50 cities/metropolitan areas, 19 are in North America, 16 are in Europe and 13 are in Asia. Among Asian cities/metropolitan areas, Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, Shanghai, Tokyo MA, Seoul MA and Singapore have made it to the top 20 and have become some of the most active areas for technological innovation in the world. By comparing the progress of cities/metropolitan areas in different regions, 23 European cities have risen up in the top 100 overall ranking and their performance in the innovation economy has shown greater resilience against the impact of the COVID-19 pandemic. Eighteen Asian cities have moved up in the overall ranking, supported by their steady growth in research innovation and innovation ecosystem. For example, 11 Chinese cities have ranked higher in research innovation compared to 2023; Abu Dhabi has surpassed several other cities thanks to its improvements in innovation ecosystem, rising 26 places to number 33 in the overall ranking.

A total of 19 Chinese cities are in the top 100 overall ranking in 2024 and the collaborative innovation capacity of city clusters in China has strengthened. The overall technological innovation capacity of Chinese cities keeps improving, with Beijing (third), Guangdong-Hong Kong-Macao Greater Bay Area (sixth) and Shanghai (seventh) remaining among the top ten GIHs. While Beijing maintains its existing strength, its gap with New York MA (second) in overall scores has narrowed. Beijing ranks second in both research innovation and innovation economy, and has moved up two places in innovation ecosystem. It ranks third (↑3) in openness and collaboration and it has performed well in public services (↑19). Guangdong-Hong Kong-Macao Greater Bay Area has made significant progress in the introduction and training of science and technology human resources (↑29). Shanghai's overall ranking has risen by three places, performing remarkably well in innovation economy (↑5). Shanghai has also caught up significantly in innovation ecosystem (↑9) and is among the top three globally in its support for start-ups. It has also made significant progress in openness and cooperation and public services. In general, Beijing, Shanghai and Guangdong-Hong Kong-Macao Greater Bay Area have emerged as three key innovation hubs. Chinese cities are making accelerated progress, especially in research innovation and innovation ecosystem.

Development patterns

The top 20 cities/metropolitan areas are clustered into four development patterns — innovation economy-oriented, research innovation-oriented, research innovation + innovation ecosystem-oriented, and balanced type — based on their scores in development patterns (see Appendix VI for measurement details).

For the innovation economy-oriented pattern, urban development is driven by cutting-edge technologies and a vibrant innovation economy. Four cities/metropolitan areas fall into this category: San Francisco-San Jose, Tokyo MA, Seoul MA and Dublin. San Francisco-San Jose, with its superior innovation economy, is growing rapidly in emerging industries such as next-generation information technology. Tokyo MA has excellent technological innovation capability and is home to a number of established innovation enterprises. Seoul MA stands out in emerging industries with remarkable innovation output.

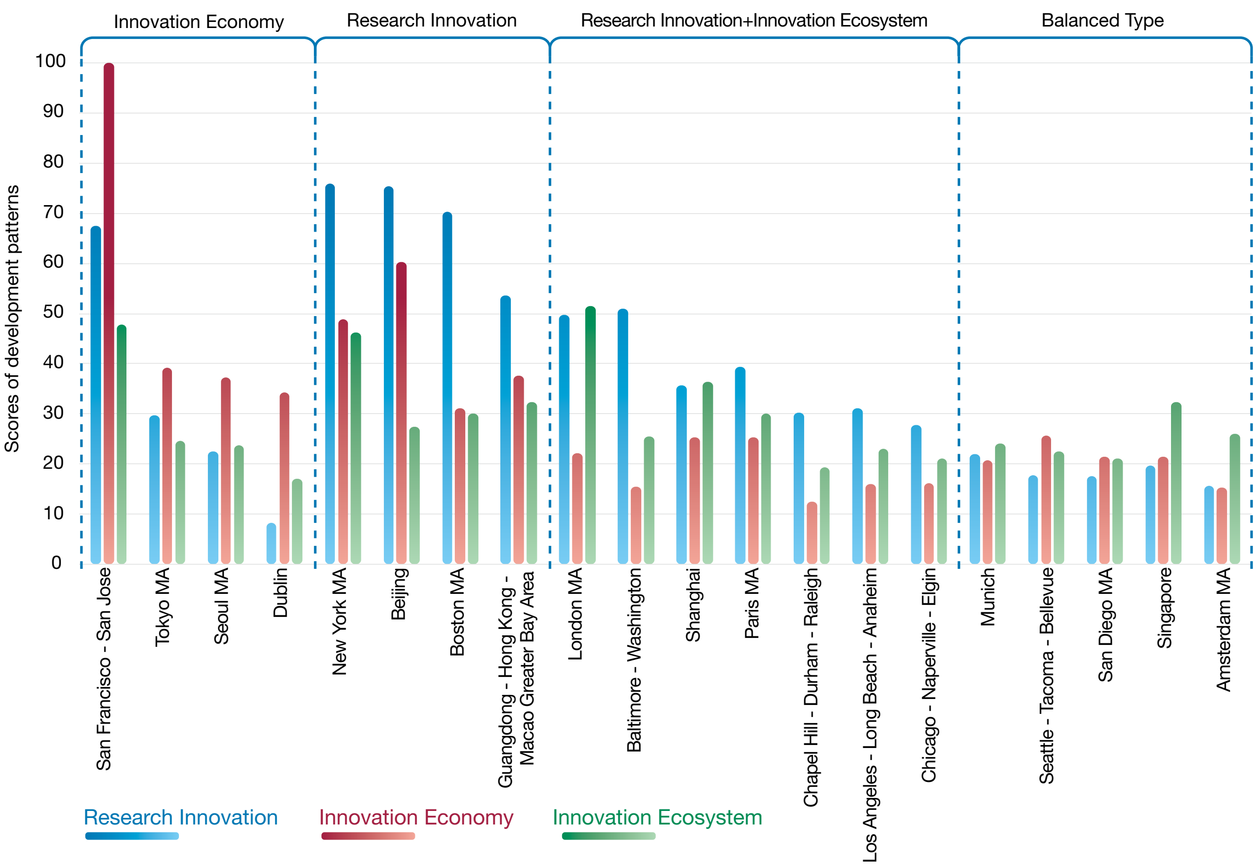
For the research innovation-oriented development pattern, scientific and technological innovation is supported by strong fundamental innovation capabilities. Four cities/metropolitan areas fall into this category — New York MA, Beijing, Boston MA and Guangdong-Hong Kong-Macao Greater Bay Area. New York MA, home to seven world-leading universities, abounds with science and technology human resources, taking the lead in knowledge creation. Beijing boasts 13 world-class research institutions (from the top 200) and ranks second in scientific infrastructure, it is also actively building up word-class large scientific facilities and supercomputers.

For the research innovation + innovation ecosystem-oriented development pattern, fundamental innovation and the innovation ecosystem are progressing simultaneously, indicating significant potential in the industrialization of scientific and technological achievements and technology transfer. Seven cities/metropolitan areas fall into this category — London MA, Baltimore-Washington, Shanghai, Paris MA, Chapel Hill-Durham-Raleigh, Los Angeles-Long Beach-Anaheim and Chicago-Naperville-Elgin. London, home to world-renowned research institutions with much academic talent, has an open and diversified innovation ecosystem. Its strong global interconnectivity helps incubate innovation activities and its well-established legal system and high-quality infrastructure are necessary to facilitate innovation.

The balanced-type development pattern strikes a balance among fundamental research, innovation industrialization and innovation ecosystem. This pattern drives global competitiveness through continuous opening up and resource integration, and five cities/metropolitan areas fall into this category — Munich, Seattle-Tacoma-Bellevue, San Diego, Singapore and Amsterdam MA. Munich has excellent researchers and research institutions to support the application and translation of basic research and to improve its technological innovation capabilities. Meanwhile, its solid support for start-ups and strong innovation culture provides a good ecosystem for scientific and technological innovation. Amsterdam MA and Singapore are known for their international business environments, which compensate for their comparatively low level of local research output and technology resources by enhancing global cooperation, forming a balanced development pattern.

FIGURE 3

The development patterns of the top 20 GIHs



2.Overall GIHI ranking

2.3 Mini-hubs

In GIHI2024, we continue to evaluate mini-hubs separately to larger cities/metropolitan areas as the GIHI indicator system assesses the innovation of cities primarily on scale indicators. Mini-hubs feature small populations (less than one million) but strong innovation, which makes them significantly different from most of the other cities in this report and therefore unsuitable for inclusion in the overall ranking. A total of 12 mini-hubs are included in the GIHI, with Oslo a new addition in 2024. All mini-hubs except for Jerusalem are in Europe and the United States. Specifically, they are in the United States, Switzerland, Germany, the Netherlands, the United Kingdom and Norway. Table 4 shows their rankings and scores.

TABLE 4 The GIHI2024 ranking of mini-hubs

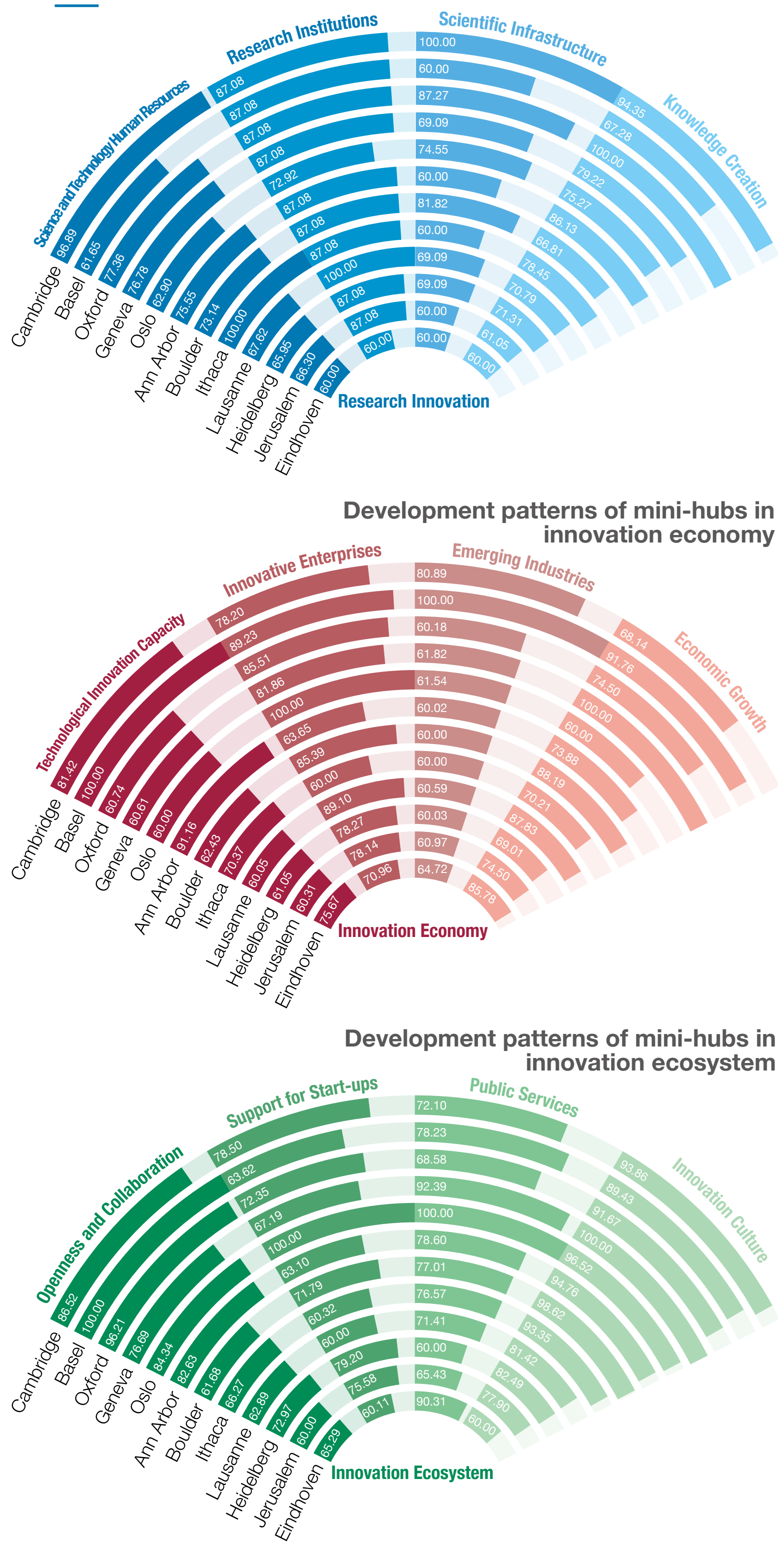
City/metropolitan area	Overall		Research Innovation		Innovation Economy		Innovation Ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Cambridge	100.00	1	100.00	1	76.88	2	80.82	3
Basel	95.31	2	75.53	9	100.00	1	78.73	5
Oxford	90.01	3	95.27	2	65.94	9	78.95	4
Geneva	88.61	4	85.40	5	72.26	3	82.39	2
Oslo	86.77	5	73.93	11	66.77	8	100.00	1
Ann Arbor	84.13	6	86.87	4	68.39	7	75.63	6
Boulder	80.23	7	80.73	7	69.98	6	74.23	7
Ithaca	78.80	8	91.07	3	60.00	12	68.46	9
Lausanne	76.99	9	85.31	6	70.52	5	61.00	11
Heidelberg	72.32	10	79.18	8	62.34	11	68.70	8
Jerusalem	67.48	11	74.48	10	63.93	10	63.48	10
Eindhoven	60.00	12	60.00	12	70.98	4	60.00	12

Cambridge, Basel and Oxford are the top three mini-hubs in the overall ranking. Cambridge and Oxford excel in research innovation. Cambridge and Oxford, as home to the University of Cambridge and the University of Oxford, respectively, benefit from an abundance of excellent human resources in science and technology, a large number of research institutions, well-developed scientific infrastructure and remarkable knowledge creation. Moreover, their favourable geographical locations mean they are able to have a close innovation network with London. Cambridge also has a vibrant innovation economy and a thriving innovation ecosystem, with excellent technological development capabilities and emerging industries. Basel ranks second in the overall mini-hubs ranking and leads in the innovation economy indicator. It is also a global powerhouse for pharmaceuticals and life sciences and stays ahead in emerging industries. The city is located at the junction of Switzerland, France and Germany in the Upper Rhine region. The cross-border flow of the elements needed for innovation has supported its multinational enterprise clusters.

For development patterns (Figure 4), Cambridge, as the top mini-hub, is a ‘straight A’ city with balanced development, ranking among the top three in research innovation, innovation economy and innovation ecosystem. There are also other mini-hubs that outperform in other sub-indicators. For example, Ithaca excels in research innovation, ranking first in the number of active researchers (per million people) and the number of top 500 world-class research institutions. Home to Cornell University, Ithaca attracts top researchers who contribute to fundamental innovation. Eindhoven, which outperforms in innovation economy, used to house the Philips headquarters and has a long history of industrialization and innovation. Driven by the presence of Philips, Eindhoven has grown into a city that integrates technology, design and innovation. Its total number of valid patents (per million people) and the number of PCT patents stand out, and its High Tech Campus Eindhoven (HTCE) is dubbed ‘the smartest square kilometre in Europe’. Oslo outperforms in innovation ecosystem by providing strong support for start-ups, offering high-quality public services and creating a good environment for entrepreneurs. The city set out its strategy to become a knowledge capital in 2019. Oslo Science City is the first innovation district in Norway and plays an important role in nurturing and expanding start-ups.

FIGURE 4

Development patterns of mini-hubs in research innovation



3. Research innovation

Cities/metropolitan areas in Europe and the United States remain leaders in research innovation supported by their solid foundations. Those in the United States stand out in the overall ranking in research innovation and maintain a considerable edge in knowledge creation. The rapid rise of Chinese cities/metropolitan areas is also notable, with top cities ranking highly and a number of other emerging cities are on the rise.

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3.1

A comprehensive analysis of research innovation

The GIHI2024 ranking in research innovation is shown in Table 5.

TABLE 5

Ranking and scores of the top 100 GIHs in research innovation

Rank	City/metropolitan area	Research Innovation	Science and Technology Human Resources	Research Institutions	Scientific Infrastructure	Knowledge Creation
1	New York MA	100.00	88.35	87.81	79.37	100.00
2	Beijing	99.75	82.65	97.94	96.91	88.72
3	Boston MA	97.02	100.00	76.17	64.79	97.32
4	San Francisco - San Jose	95.55	92.55	75.48	100.00	90.06
5	Guangdong - Hong Kong - Macao Greater Bay Area	88.27	66.92	100.00	77.09	79.30
6	Baltimore - Washington	86.84	85.08	69.04	63.76	93.79
7	London MA	86.16	75.16	78.77	69.21	90.20
8	Paris MA	80.76	73.92	76.17	79.82	76.50
9	Shanghai	78.81	68.63	83.15	73.26	71.70
10	Los Angeles - Long Beach - Anaheim	76.41	70.42	76.17	60.00	75.34
11	Chapel Hill - Durham - Raleigh	75.91	78.45	70.96	60.00	71.23
12	Tokyo MA	75.62	67.71	69.04	95.80	71.53
13	Chicago - Naperville - Elgin	74.59	70.55	70.96	67.51	73.39
14	Zurich	73.16	76.55	69.04	61.69	67.43
15	Nanjing	72.48	73.18	70.96	60.00	67.68
16	Melbourne	72.04	68.43	69.04	64.42	71.91
17	Seoul MA	71.87	64.71	70.96	68.25	72.01
18	Wuhan	71.60	67.10	72.88	66.78	67.32
19	Munich	71.55	72.07	69.04	64.79	66.79
20	Copenhagen	70.63	70.59	69.04	60.00	67.50
21	Singapore	70.34	66.66	69.04	64.79	69.17
22	Atlanta MA	70.28	64.98	69.04	63.39	71.21
23	Kyoto - Osaka - Kobe	70.24	68.78	69.04	70.90	64.69
24	Sydney	70.24	66.88	67.12	64.42	70.81
25	Philadelphia MA	70.06	68.61	64.52	60.00	72.78
26	Stockholm	69.76	68.30	67.12	67.14	67.19
27	Houston MA	69.37	65.24	69.73	63.09	67.95
28	Seattle - Tacoma - Bellevue	69.30	67.61	64.52	61.03	71.47
29	Pittsburgh	69.29	70.12	67.12	60.00	66.49
30	San Diego MA	69.20	69.61	64.52	62.73	68.59
31	Toronto MA	69.09	67.22	64.52	62.06	70.97
32	Xi'an	68.77	66.60	70.96	60.00	64.71

3.Research innovation

Rank	City/metropolitan area	Research Innovation	Science and Technology Human Resources	Research Institutions	Scientific Infrastructure	Knowledge Creation
33	Rome	68.61	68.57	64.52	66.78	66.74
34	Amsterdam MA	68.25	66.38	65.21	65.16	67.88
35	Montreal MA	68.21	66.67	67.12	62.06	66.49
36	Daejeon	68.15	74.46	61.92	65.45	62.67
37	Hangzhou	67.84	66.27	68.36	60.00	65.34
38	Moscow	67.48	68.38	62.60	75.69	63.01
39	Barcelona MA	67.34	66.44	61.92	66.48	68.43
40	Berlin MA	67.31	66.10	61.92	67.14	68.48
41	Vancouver MA	67.30	67.18	64.52	63.76	65.76
42	Brisbane	67.14	67.49	64.52	61.69	65.71
43	Milan	67.10	66.96	62.60	61.69	68.16
44	Changsha	67.09	65.29	69.04	61.03	63.33
45	Chengdu	66.97	63.19	69.04	63.39	64.37
46	Tianjin	66.96	64.80	69.04	62.06	63.14
47	Taipei	66.72	73.50	60.00	62.06	63.06
48	Hefei	66.54	64.57	66.44	68.47	62.86
49	Lyon - Grenoble	66.31	66.26	62.60	70.53	63.84
50	Manchester	66.30	66.55	64.52	61.69	64.46
51	Nagoya MA	66.07	66.02	64.52	69.87	61.68
52	Madrid	65.96	67.40	60.00	61.69	67.45
53	Vienna	65.94	66.75	62.60	62.06	65.20
54	St. Louis	65.82	65.99	64.52	60.00	64.36
55	Helsinki	65.68	67.12	62.60	61.03	64.50
56	Minneapolis - Saint Paul	65.61	64.66	64.52	60.00	65.17
57	Dallas - Fort Worth	65.35	64.34	64.52	60.00	64.82
58	Austin	65.30	64.43	64.52	64.13	63.23
59	Harbin	65.07	64.45	64.52	65.08	62.27
60	Sao Paulo	64.91	65.10	62.60	63.76	63.64
61	Changchun	64.78	63.54	66.44	61.69	61.56
62	Perth	64.57	65.82	62.60	60.00	63.26
63	Hamburg	64.52	63.91	60.00	74.95	62.82
64	Phoenix MA	64.47	62.71	64.52	63.09	63.18
65	Jinan	64.35	64.36	64.52	61.03	61.86
66	Dublin	64.29	67.44	60.00	60.00	63.59

Rank	City/metropolitan area	Research Innovation	Science and Technology Human Resources	Research Institutions	Scientific Infrastructure	Knowledge Creation
67	Denver MA	63.93	65.13	60.00	62.06	64.35
68	Rotterdam	63.83	63.90	62.60	60.00	63.30
69	Göteborg	63.81	64.50	62.60	60.00	62.65
70	Lanzhou	63.67	66.19	61.92	61.69	60.70
71	Lisbon	63.66	66.18	60.00	61.69	62.68
72	Dalian	63.65	63.34	63.83	61.69	61.57
73	Brussels	63.63	63.21	62.60	60.00	63.50
74	Cologne	63.57	64.70	62.60	60.00	61.80
75	Xiamen	63.45	63.17	64.52	60.00	61.06
76	Prague	63.37	65.37	60.00	63.39	62.19
77	Frankfurt	63.34	62.95	62.60	63.09	61.96
78	Zhengzhou	63.32	62.37	64.52	60.00	61.53
79	Tel Aviv	63.29	63.23	61.92	61.69	62.72
80	Fuzhou	63.02	62.78	63.83	60.00	61.03
81	Warsaw	62.93	65.48	60.00	60.00	62.05
82	Chongqing	62.90	60.89	63.83	61.69	62.10
83	Qingdao	62.81	63.48	61.92	60.00	61.78
84	Suzhou	62.67	60.98	64.52	60.00	61.25
85	Buenos Aires	62.47	65.07	60.00	61.03	60.92
86	Kuala Lumpur	62.44	63.93	60.00	60.00	62.36
87	Doha	62.34	65.12	60.00	60.00	60.87
88	Cincinnati	62.30	63.91	60.00	60.00	62.03
89	Miami MA	62.28	63.03	60.00	60.00	62.86
90	Portland	62.14	63.13	60.00	60.00	62.41
91	Budapest	62.07	63.36	60.00	61.69	61.41
92	Bangkok	61.91	63.36	60.00	60.00	61.56
93	Central National Capital Region (Delhi)	61.90	61.03	60.00	61.03	63.58
94	Chennai MA	61.79	63.48	60.00	60.00	61.13
95	Stuttgart	61.76	62.88	60.00	61.03	61.32
96	Mexico City	61.75	62.96	60.00	60.00	61.56
97	Detroit MA	61.56	62.22	60.00	60.00	61.81
98	Bengaluru	61.55	61.07	61.92	60.00	60.97
99	Ankara	61.50	62.61	60.00	60.00	61.25
100	Dusseldorf	61.32	62.57	60.00	60.00	60.82

3.Research innovation

FIGURE 5

Quartile graph of ranking in research innovation for cities/ metropolitan areas in Asia, Europe, and North America

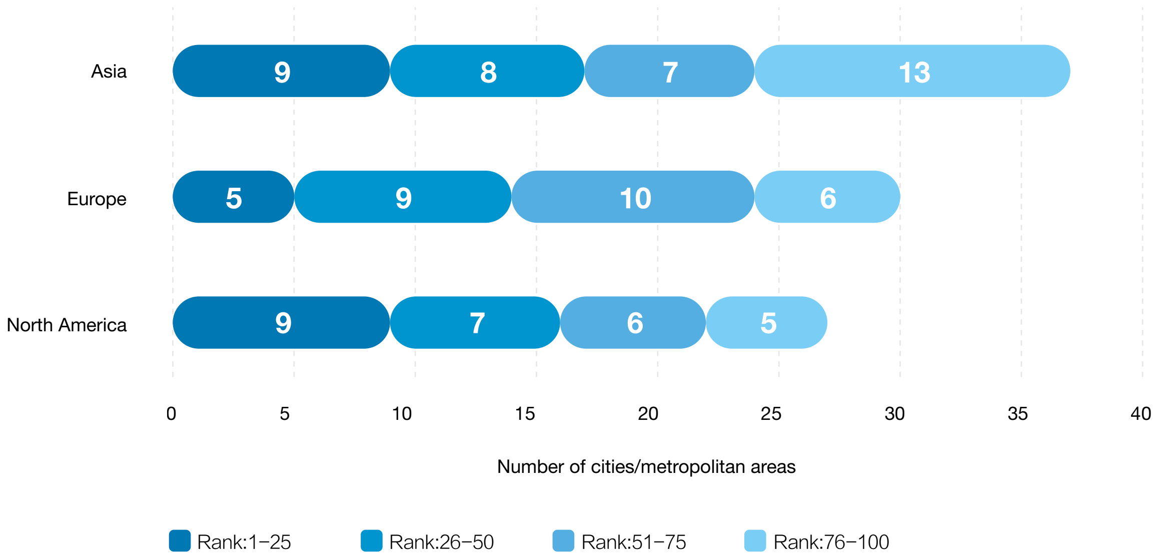


TABLE 6

A comparison of the top 20 GIHs in research innovation between 2022-2024

City/metropolitan area	Rank 2024	Rank 2023	Rank 2022
New York MA	1	1	1
Beijing	2	2	4
Boston MA	3	3	3
San Francisco - San Jose	4	4	2
Guangdong - Hong Kong - Macao Greater Bay Area	5	7	5
Baltimore - Washington	6	5	10
London MA	7	6	8
Paris MA	8	8	16
Shanghai	9	9	25
Los Angeles - Long Beach - Anaheim	10	10	11
Chapel Hill - Durham - Raleigh	11	11	14
Tokyo MA	12	12	39
Chicago - Naperville - Elgin	13	13	17
Zurich	14	14	13
Nanjing	15	15	59
Melbourne	16	16	28
Seoul MA	17	17	55
Wuhan	18	25	47
Munich	19	18	31
Copenhagen	20	22	26

The United States continues to lead in research innovation. New York MA, Boston MA and San Francisco-San Jose have been in the top five for four consecutive years and in 2024 they rank first, third, and fourth, respectively. Beijing has ranked second for two consecutive years. Guangdong-Hong Kong-Macao Greater Bay Area ranks fifth, while Wuhan and Copenhagen enter the top 20 for the first time.

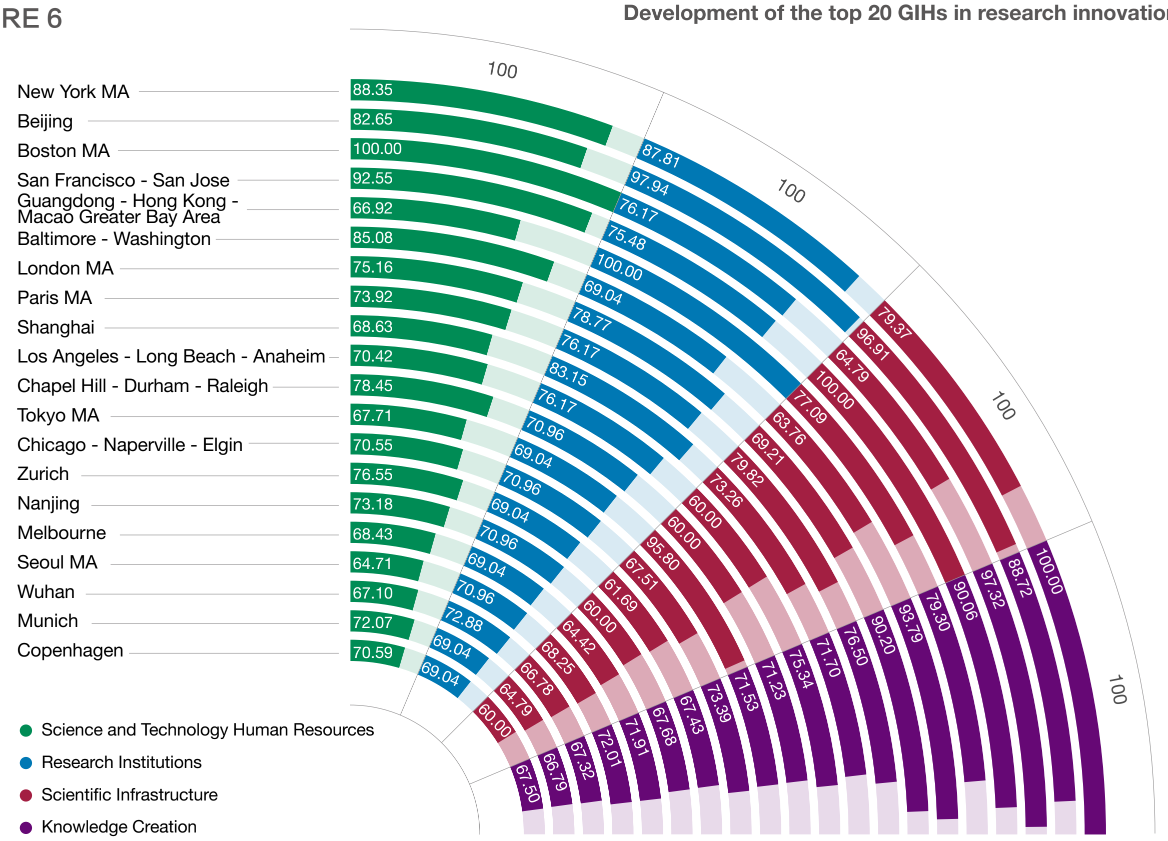
Geographically cities/metropolitan areas in North America rank relatively higher while most European cities rank in the middle range (25th–75th) (Figure 5). Asian cities are relatively dispersed and tend to cluster at the top or at the bottom.

As the trends indicate, the ranking of the top 20 cities/metropolitan areas in research innovation has remained largely unchanged and the rapid rise of Chinese cities is prominent (Table 6). Since 2020, New York MA has been leading in research innovation and Boston MA has stayed at number three. Beijing ranks second, which was also its ranking last year. New York MA has maintained its lead thanks to its strength in knowledge creation. It comes in first in the number of highly cited papers and the total citations from patents, policy reports and clinical trials. Beijing ranks first in the number of top 200 world-class research institutions but comes in second in the number of active researchers (per million people), the number of large scientific facilities and the number of top 500 supercomputers. Boston MA ranks first and second in science and technology human resources, and knowledge creation, respectively. Wuhan's overall ranking has increased significantly in the past three years, going up 22 places in 2023 and up seven places this year. Wuhan not only maintains its edge in research institutions, it is also up by eight and four places in science and technology human resources, and knowledge creation, respectively. It is noteworthy that China is making progress in research innovation and cities such as Wuhan, Hangzhou, Changsha and Tianjin have significantly improved their rankings in this indicator.

The GIHI top 20 cities/metropolitan areas in research innovation have varied performance across each sub-indicator (Figure 6). New York MA and London MA, which lead the list, outperform in knowledge creation and Beijing excels in research institutions and scientific infrastructure. Boston MA and Baltimore-Washington focus on the synergistic development of science and technology human resources and knowledge creation. Guangdong-Hong Kong-Macao Greater Bay Area and Shanghai stand out in research institutions. San Francisco-San Jose and Tokyo MA use their solid scientific infrastructure to ensure a well-rounded performance in innovation.

FIGURE 6

Development of the top 20 GIHs in research innovation



3.Research innovation

3.2 Science and technology human resources

Scientific and technological talent is key to driving innovation. Considering key factors such as the distribution and agglomeration of scientific talent, the GIHI2024 uses two indicators — the number of active researchers (per million people) and the number of top scientific award winners — to measure a GIH's talent pool. These indicators assess the quantity and quality of the talent and indicate how attractive and strong the innovation environment is. Figures 7 and 8 show the number of active researchers (per million people) and the number of winners of top scientific awards for the top 20 cities/metropolitan areas in science and technology human resources, respectively.

The top five cities/metropolitan areas in science and technology human resources are Boston MA, San Francisco-San Jose,

FIGURE 7 Number of active researchers (per million people) for the top 20 GIHs in science and technology human resources

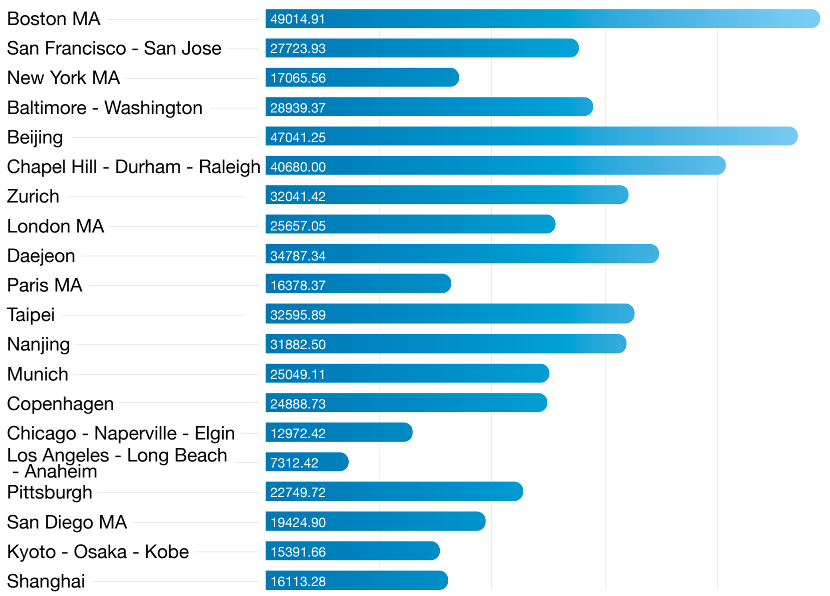
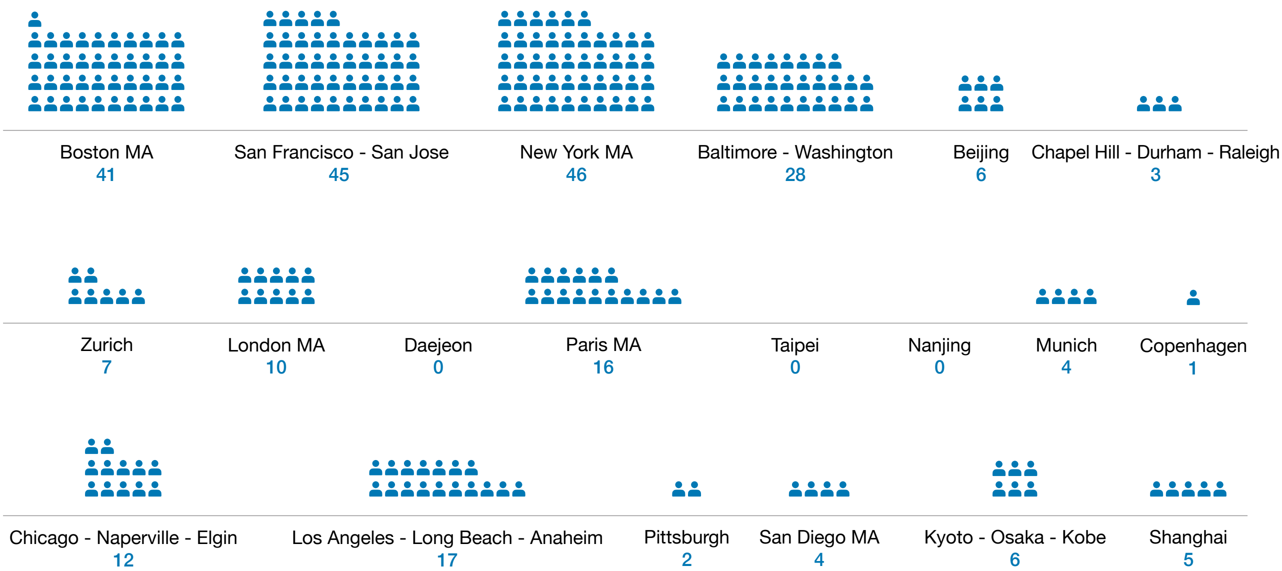


FIGURE 8 Number of winners of top scientific awards for the top 20 GIHs in science and technology human resources



New York MA, Baltimore-Washington and Beijing. Among the top 20, there are nine cities in North America, six in Asia and five in Europe. Since last year, Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area and Tianjin have moved up by 15, 29 and 12 places, respectively.

Boston MA is home to Harvard University, the Massachusetts Institute of Technology and many other top universities that have excellent science and technology human resources. It ranks first in the list with 49,014 active researchers per million people. Based on the number of winners of top scientific awards, Boston MA ranks third with 41, slightly behind New York MA with 46 and San Francisco-San Jose with 45. The United States has many more winners of top scientific awards owing to its outstanding research strength and innovation capability.

Beijing ranks second in the number of active researchers per million people, with an increase of 13% compared to 2023. It highlights Beijing's success in attracting and cultivating high-level scientific talent and its enhanced influence in the global innovation network.

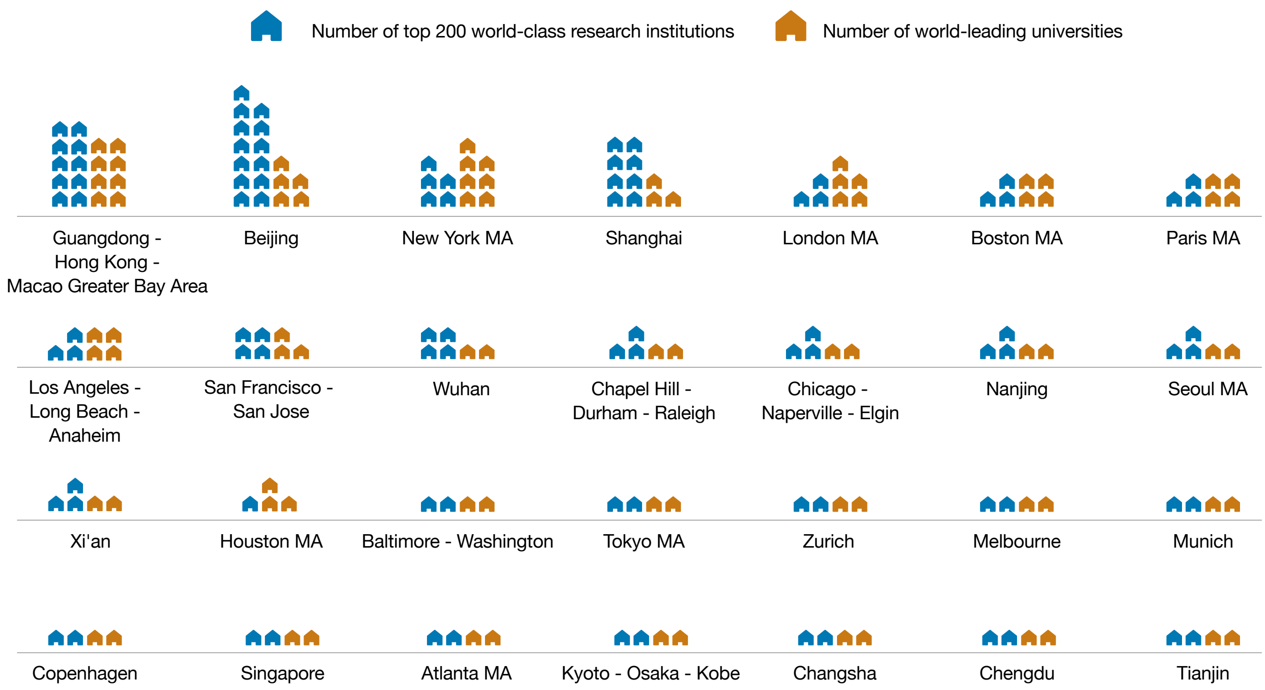
3.3 Research institutions

Research institutions are the key entities of innovation. As the sources of original innovation and disruptive technology, research institutions adjust strategies and resources to adapt to changing policies, playing a key role in basic research, the application of technology and cutting-edge innovation. This report measures the performance of universities and research institutions in a city by the number of world-leading universities and the number of top 200 world-class research institutions it has.

As shown in Figure 9, the top five cities/metropolitan areas for research institutions and top universities are Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, New York MA, Shanghai and London MA. Among the top 20, North America occupies nine spots, Asia has 13 and Europe takes up five spots. Guangdong-Hong Kong-Macao Greater Bay Area comes out on top with ten top 200 research institutions and eight world-leading universities. Beijing has jumped to second place with 13 top 200 research institutions and five world-leading universities. New York MA comes third with five top 200 research institutions and seven world-leading universities. Shanghai ranks fourth again with eight top 200 research institutions and three world-leading universities. Overall, Chinese cities/metropolitan areas outperform others taking three spots in the top five. In addition, Wuhan, Nanjing, Xi'an, Changsha, Chengdu and Tianjin are all in the top 20 due to their strong growth and excellent performance.

FIGURE 9

Number of world-leading universities and top 200 world-class research institutions for the top 20 GIHs in research institutions



3.Research innovation

3.4
Scientific infrastructure

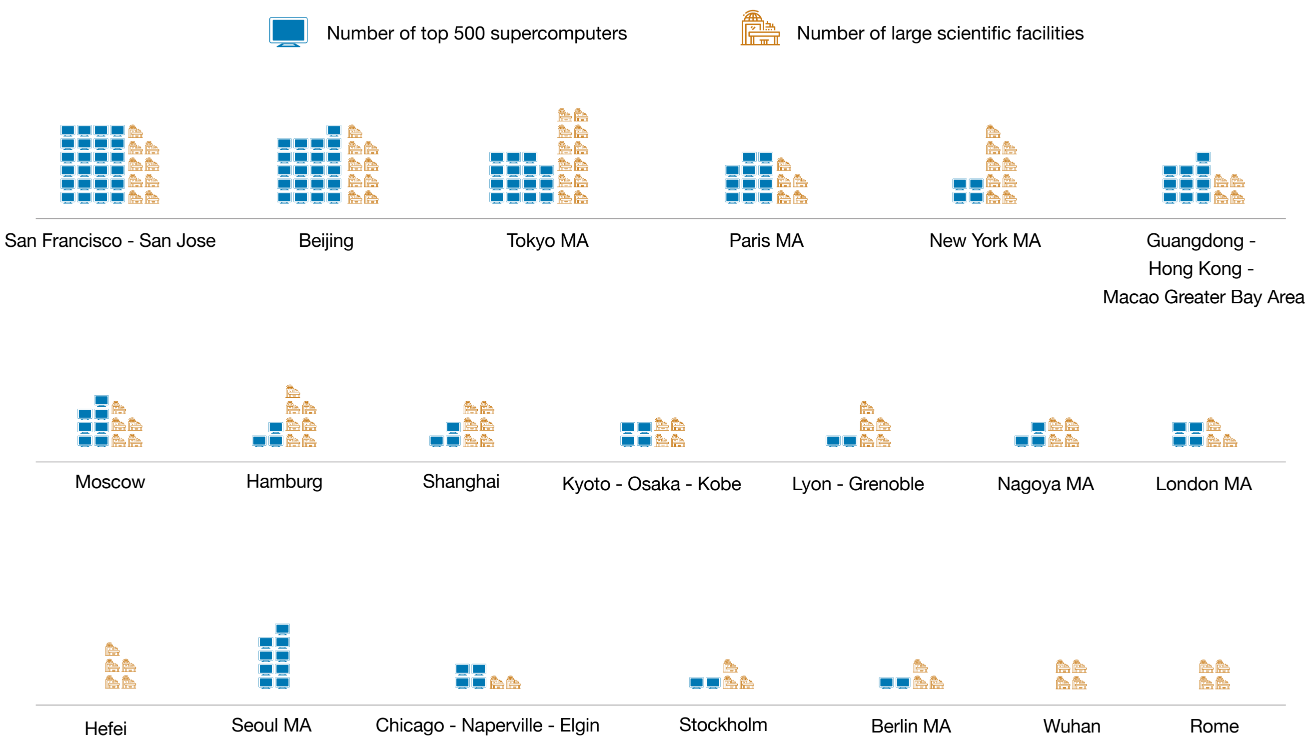
Scientific infrastructure is the core platform for innovation, providing key technical support for researchers to carry out cutting-edge research. It is not only an important tool to make major breakthroughs, but also a strategic asset to attract top research teams and projects around the world. The GIHI2024 measures the development of scientific infrastructure by the numbers of large scientific facilities and top 500 supercomputers in a city/ metropolitan area.

As shown in Figure 10, the top five cities/metropolitan areas in scientific infrastructure are San Francisco-San Jose, Beijing, Tokyo MA, Paris MA and New York MA. Among the top 20, Asia occupies nine spots, Europe has eight and North America only three. In particular, San Francisco-San Jose, Beijing and Tokyo MA remain the leaders in scientific infrastructure, far ahead of other cities/ metropolitan areas.

The large scientific facilities are relatively concentrated and the top five cities measured by this indicator are Tokyo MA, Beijing, San Francisco-San Jose, New York MA and Hamburg. These cities account for one-third of the total large scientific facilities in all the cities assessed. China has several large scientific facilities under construction, which will be put into operation in the near future. The top five cities with the most top 500 supercomputers are San Francisco-San Jose, Beijing, Tokyo MA, Paris MA and Guangdong-Hong Kong-Macao Greater Bay Area. According to the list of top 500 supercomputers published in November 2023, the United States remains the leader with 161 supercomputers, six of which are in the top ten. Frontier, the only exascale supercomputer on the list is owned by the United States. Its computing power is far ahead of other supercomputers and it tops the list once again.

FIGURE 10

Number of top 500 supercomputers and large scientific facilities for the top 20 GIHs in scientific infrastructure



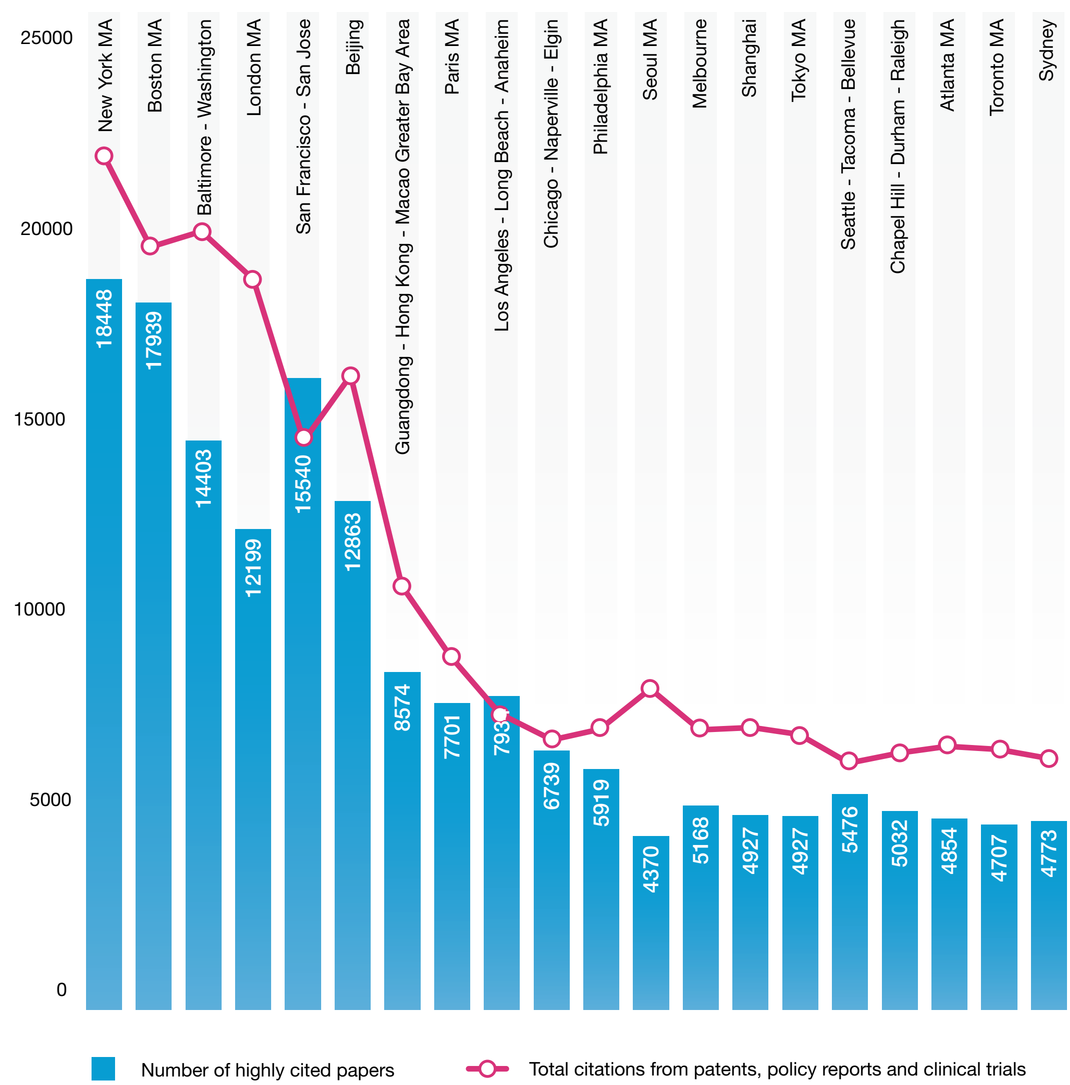
3.5
Knowledge creation

Knowledge is the source and driving force of innovation. This report uses the number of highly cited papers published by a city/metropolitan area to measure its original innovation capability and influence. It uses the total citations from patents, policy reports and clinical trials to measure the impact of research papers on technological innovation, policymaking and medical practice.

As shown in Figure 11, the top five cities/metropolitan areas in knowledge creation are New York MA, Boston MA, Baltimore-Washington, London MA and San Francisco-San Jose. The United States takes up ten spots in the top 20 as well as the top three. By individual indicators, New York MA, Boston MA, San Francisco-San Jose, Baltimore-Washington, Beijing and London MA boast over 10,000 highly cited papers and are better at original innovation and knowledge transformation than other cities. Their total citations from patents, policy reports and clinical trials also stand out.

FIGURE 11

Number of highly cited papers and total citations from patents, policy reports and clinical trials for the top 20 GIHs in knowledge creation



3.Research innovation

FOCUS
Global Co-authorship

Papers that are co-authored and published by scholars from two or more countries/regions reflect cross-border academic exchanges and cooperation, helping to promote the global spread of knowledge. Previous research has shown that internationally co-authored papers gain better citations and are more influential among global peers. International collaboration enables researchers to access rare resources, complement each other's expertise, expand their horizons and enhance their research capabilities, thereby solidifying a city's foundation as a science hub.

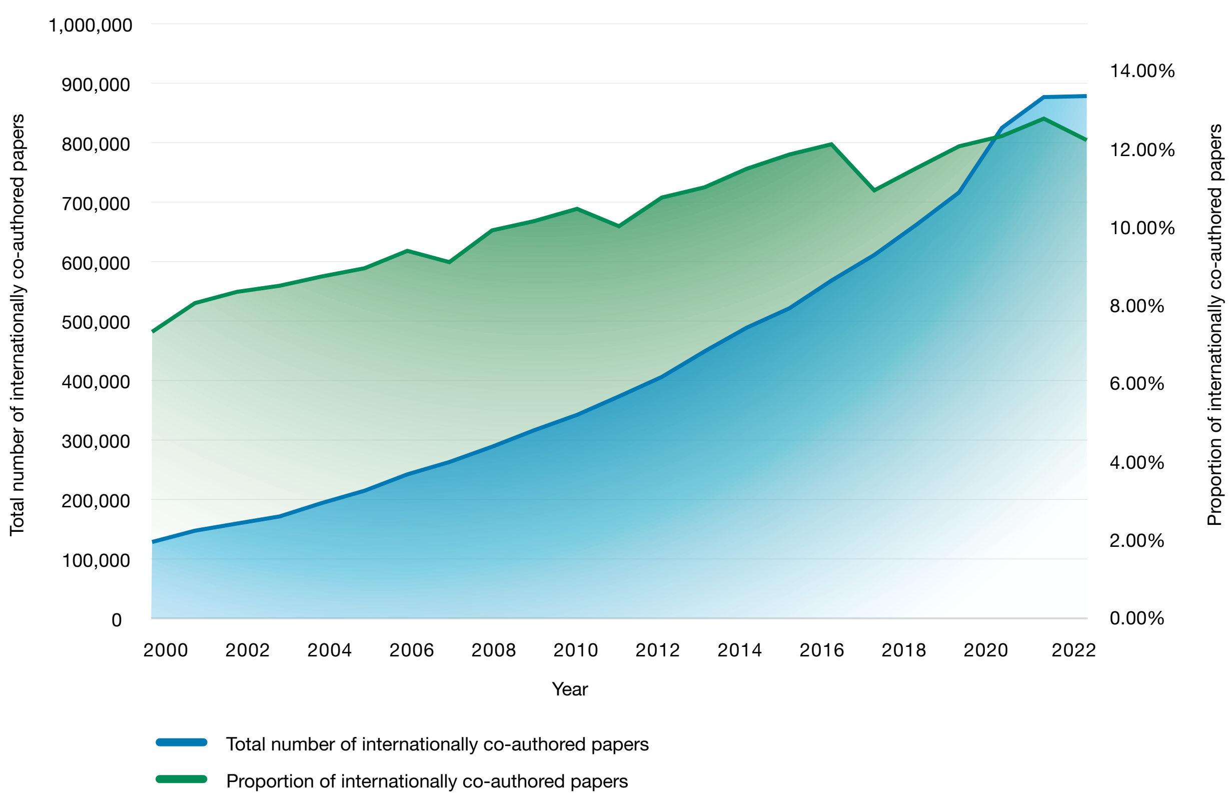
For many countries, international cooperation in science and technology is critical to innovation and competitiveness. To expand the knowledge boundaries, international cooperation could reduce or share the high cost of basic research, avoid wasting research and development resources and improve research efficiency. International cooperation could also leverage global academic resources, such as research funds, human resources and scientific infrastructure, and make public funding investment more cost-effective.

Global overview

As 'big science' gains momentum, the growing trend of international cooperation has become a crucial driver to innovation. Based on the statistics of the Dimensions database (Figure 12), the number of published internationally co-authored papers worldwide has increased significantly, from 129,900 in 2000 to 879,800 in 2022, with an average annual compound growth rate (CAGR) of 8.67%. The growth rate of internationally co-authored papers is higher than that of the total papers, resulting in their proportion of the total papers — which will be referred to as the proportion of internationally co-authored papers in this report — up from 7.24% in 2000 to 12.09% in 2022. However, since 2020, the growth rates of the number and the proportion of internationally co-authored papers in the world have slowed down, which is partly due to COVID-19 pandemic.

FIGURE 12

The annual trend of internationally co-authored papers



Performance by city

The number of internationally co-authored papers published by a city reflects how active it is in academic collaboration. The proportion of internationally co-authored papers indicates how internationalized a city's academic activity is. According to the Dimensions database, between 2000 and 2022 the top ten cities/metropolitan areas by the number of internationally co-authored papers — which we refer to as elite cities — are London MA, New York MA, Paris MA, Beijing, Baltimore-Washington, Boston MA, San Francisco-San Jose, Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area and Melbourne.

These elite cities are located in North America (four in the United States), East Asia (two in China and one in Japan), Europe (one each in the United Kingdom and France) and Oceania (one in Australia). The US cities dominate international academic cooperation. Moreover, these cities not only lead international cooperation in academic research, but also boast the greatest academic influence in the world, ranking high in the annual assessment based on 'the number of highly cited papers'.

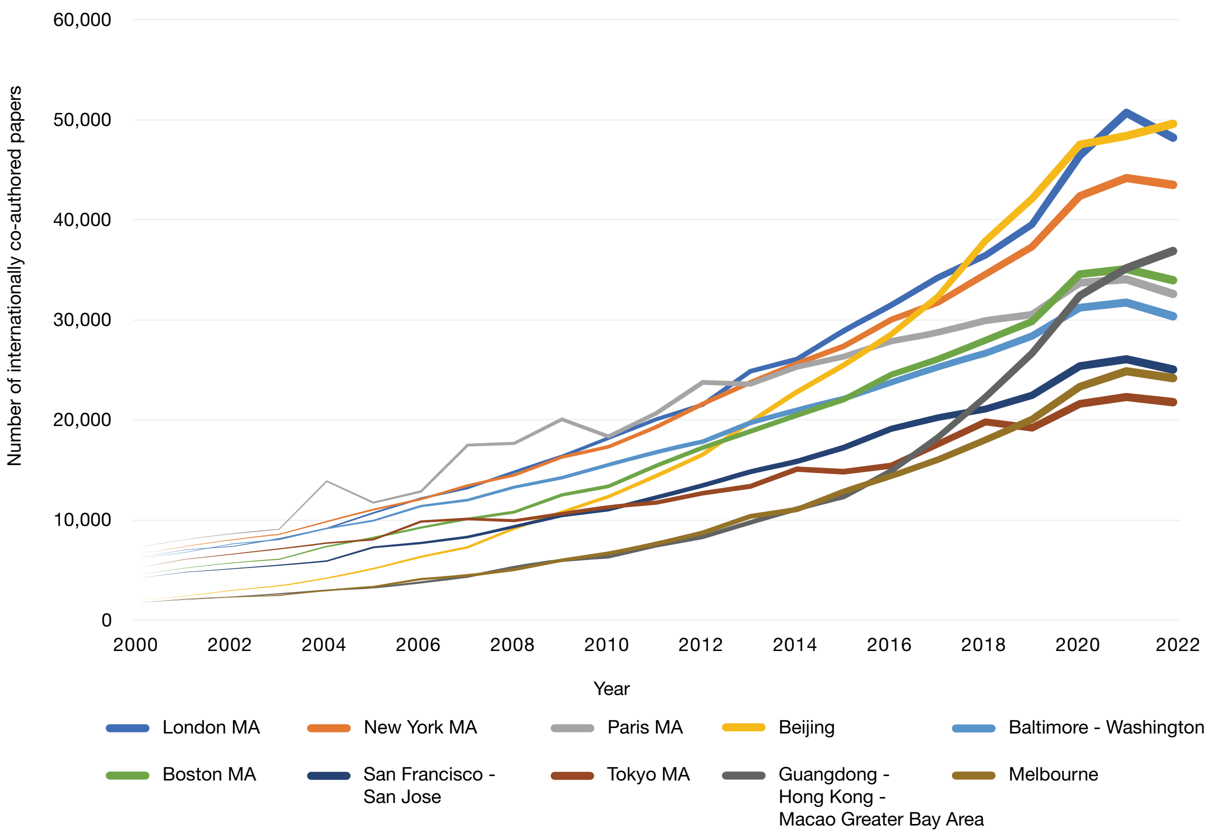
The world's most influential scientific cities/metropolitan areas also lead in international cooperation in research. The COVID-19 pandemic has reduced global academic output and affected international cooperation. However, Beijing and Guangdong-Hong Kong-Macao Greater Bay Area have bucked the trend and increased the number of internationally co-authored papers.

Trends

In line with the global trend, the number of internationally co-authored papers by the ten elite cities has been trending upwards (Figure 13). In particular, Beijing and Guangdong-Hong Kong-Macao Greater Bay Area have an average annual compound growth rate of 15.12% and 14.18% and have joined the first and second echelons over the past five years.

FIGURE 13

The annual trends of the top 10 cities/ metropolitan areas in the number of internationally co-authored papers



3.Research innovation

The COVID-19 pandemic hindered international academic exchanges and has had a prolonged impact on research output. Since 2020, the growth rate of annual publications and internationally co-authored papers by elite cities have slowed down notably (Figure 14) and posted negative growth in 2022, with only Beijing and Guangdong-Hong Kong-Macao Greater Bay Area exhibiting growth.

By the proportion of internationally co-authored papers, the elite cities demonstrate a considerable edge in the level of internationalization. As shown in Figure 15, the proportion of internationally co-authored papers in these cities has been higher than the global average for a long time, indicating that they play a key role in academic cooperation across countries. It is worth noting that despite the COVID-19 pandemic, the proportion of internationally co-authored papers in most elite cities continues to grow. This shows that even with limited academic exchanges, these cities still take an active part in international cooperation. The proportions of internationally co-authored papers by Beijing and Guangdong-Hong Kong-Macao Greater Bay Area have decreased slightly. This is mainly because the growth rates of total publications from these cities/metropolitan areas are higher than that of internationally co-authored papers, which leads to the relative decline in the proportion of internationally co-authored papers.

FIGURE 14 The annual growth rate of internationally co-authored papers and the anuual growth rate of total publications for the top 10 cities/metropolitan areas in the number of internationally co-authored papers (2020-2022)

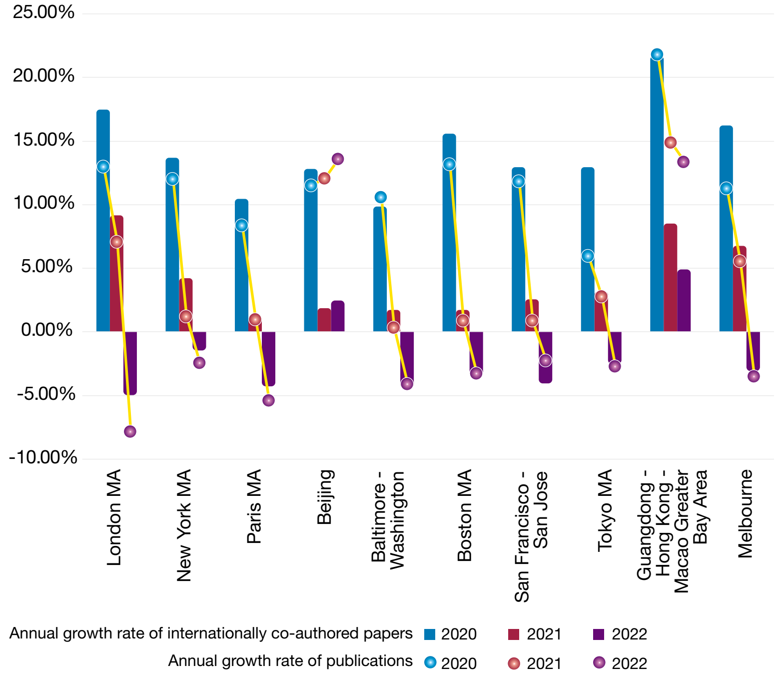
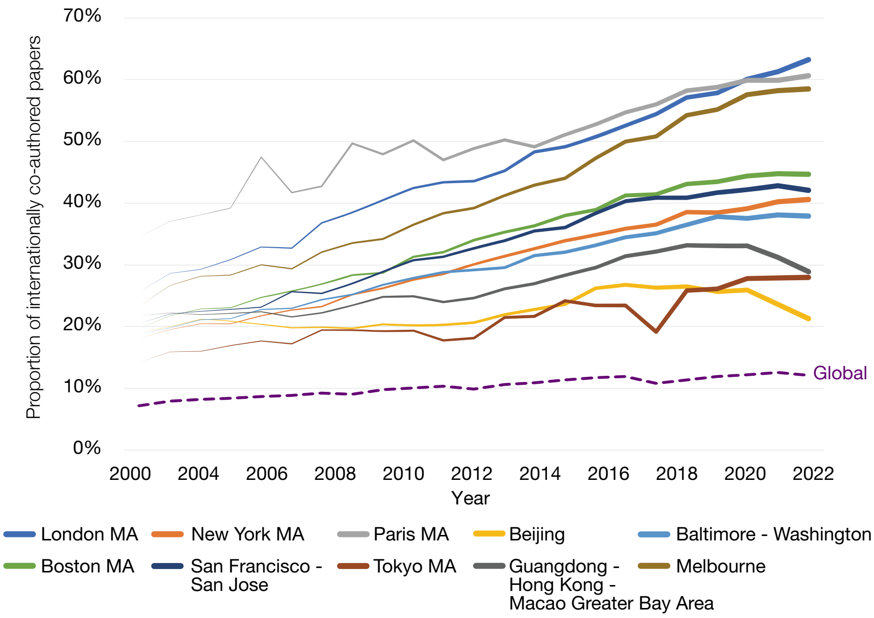


FIGURE 15 The annual trend of the proportion of internationally co-authored papers for the top 10 cities/metropolitan areas in the number of internationally co-authored papers



Current picture

Figure 16 presents an overview of the internationally co-authored papers published by elite cities in 2022, where the horizontal axis indicates the number of internationally co-authored papers published by each city and the vertical axis indicates the proportion of global collaborative papers. Each bubble represents an elite city and the size of the bubble indicates the total number of publications by each city.

By the number of internationally co-authored papers (horizontal axis), Beijing, London MA and New York MA are the top three by a significant margin, far above the average of 34,592 papers for the ten elite cities. Guangdong-Hong Kong-Macao Greater Bay Area, Boston MA, Paris MA and Baltimore-Washington form the second echelon.

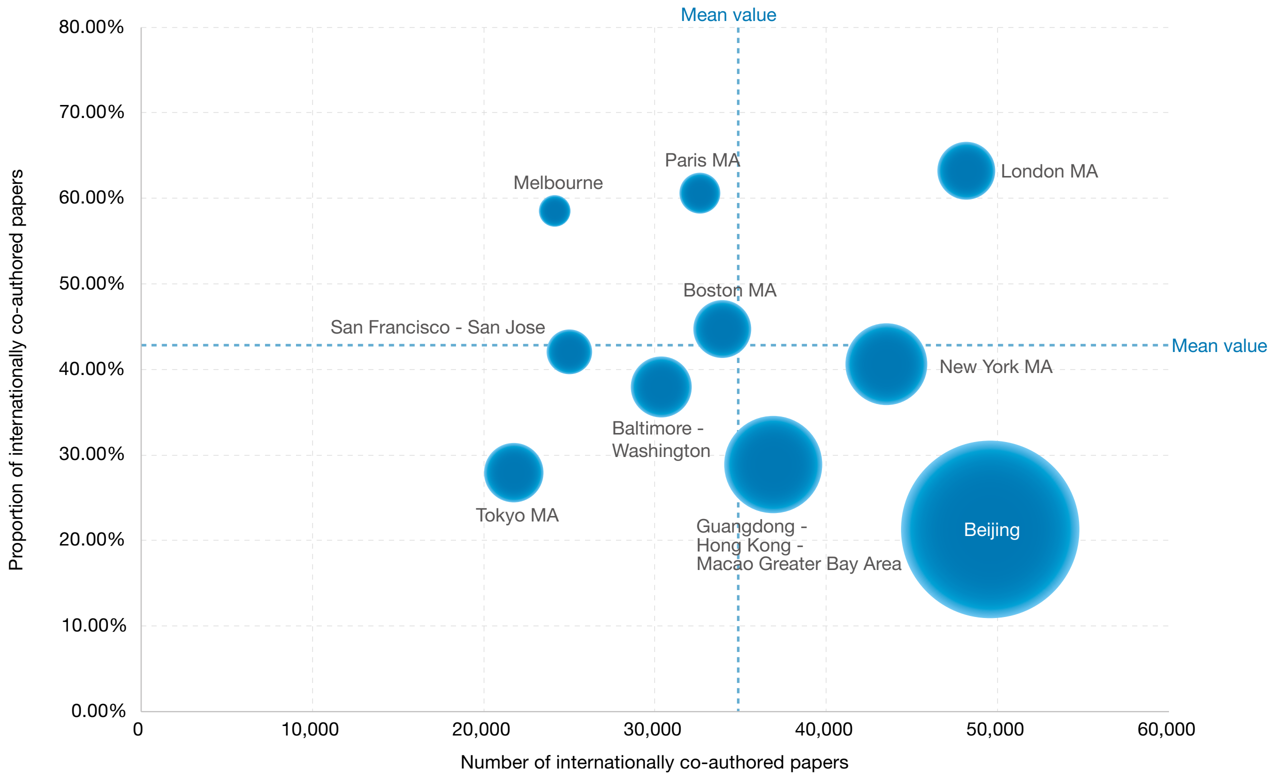
The performance of the elite cities varies a lot by the proportion of internationally co-authored papers (vertical axis).

- Global cooperation-oriented: London MA, Paris MA and Melbourne are the top three, with the proportions of internationally co-authored papers exceeding 50%, much higher than the average of for the elite cities (42.58%). These European and Oceanian cities/metropolitan areas have gained distinct competitiveness by actively carrying out international cooperation and effectively leveraging rare external resources.
- Balanced type: the proportions of internationally co-authored papers of the four US cities/metropolitan areas are close to or slightly above the average. This shows that US cities/metropolitan areas attach importance to domestic cooperation as well as international cooperation. This is mainly because the United States has extensive research resources.
- Domestic cooperation-oriented: three cities/metropolitan areas in East Asia have lower proportions of internationally co-authored papers, which is related to their relatively low level of internationalization and the rapid growth of their total publications.

> **In 2022, Beijing ranked first in the number of internationally co-authored papers and in the total number of publications. Among the elite cities, the proportion of internationally co-authored papers varies by region, with that for European and Oceanian cities exceeding 50%. The US cities are more balanced in national and international co-authorship, while the Asian cities have a relatively lower proportion of internationally co-authored papers.**

FIGURE 16

An overview of the top 10 cities/ metropolitan areas in the number of internationally co-authored papers (2022)



3.Research innovation

Discipline characteristics

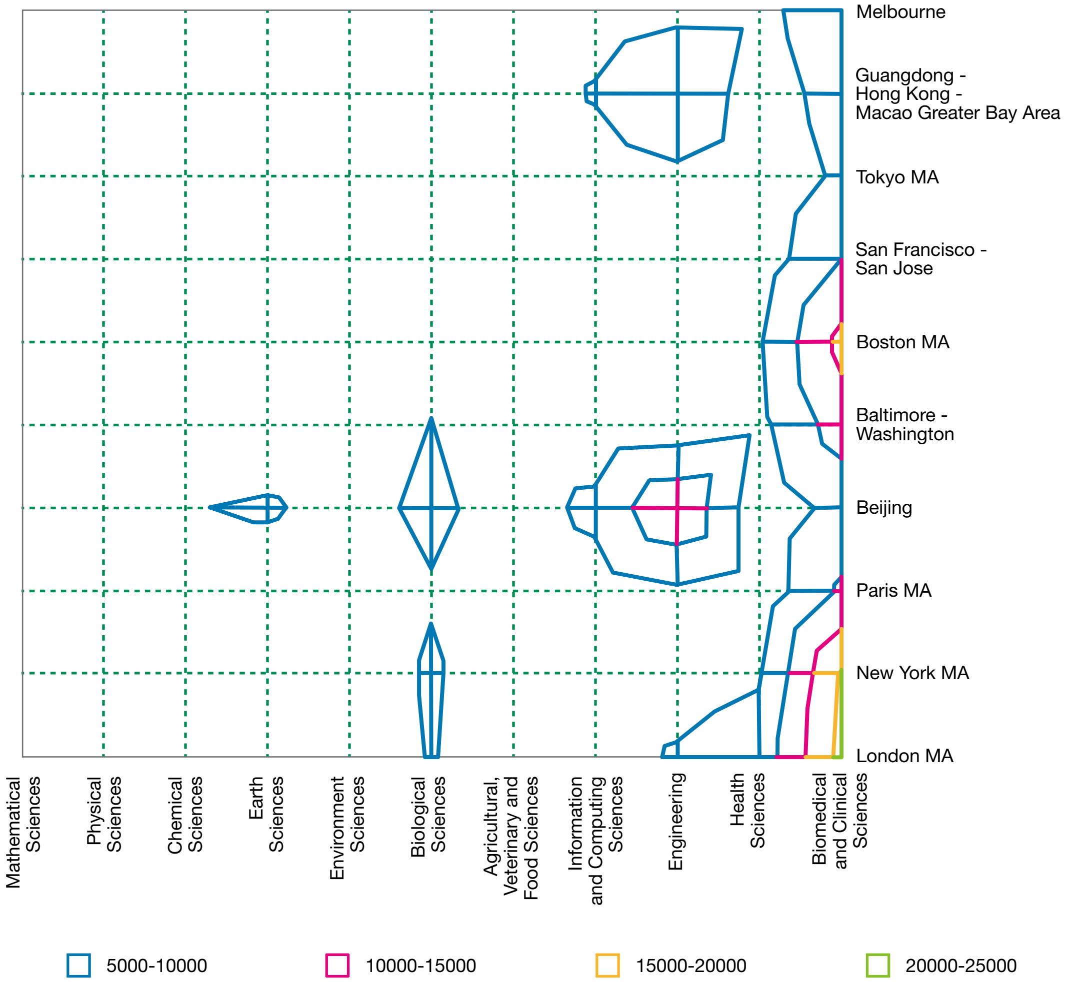
This report reviews the internationally co-authored papers in the fields of science, technology, engineering and medicine (11 disciplines in total) by the elite cities in 2022.

As shown in Figure 17, disciplines such as biomedical and clinical sciences, health sciences, biological sciences, engineering, information and computing sciences, and earth sciences are hot fields for international cooperation for the elite cities. Biomedical and clinical research is the most active field, with each elite city publishing more than 5,000 internationally co-authored papers in this area. London MA and the US cities such as New York MA and Boston MA, dominate international cooperation in this field. Beijing and Guangdong-Hong Kong-Macao Greater Bay Area stand out for international cooperation in engineering, information and computing sciences, ranking first and second, respectively. In addition, Beijing also publishes the largest number of internationally co-authored papers in biological sciences, earth sciences, physical sciences, chemical sciences, environmental sciences, agriculture, veterinary and food sciences.

Biomedical and clinical sciences is one of the hot fields for international cooperation. Cities in the United States and in China have different strengths in different subject areas. Beijing ranks first in the number of internationally co-authored papers across eight disciplines in the fields of science, technology, engineering, and medicine.

FIGURE 17

The contour map by discipline for the top 10 cities/ metropolitan areas in the number of internationally co-authored papers (2022)



Note: The color of the intersection of the vertical axis (city/metropolitan area) and the horizontal axis (discipline) indicates the number range of internationally co-authored papers in the corresponding discipline of a city/metropolitan area (see the legend).

Physical sciences, earth sciences and environmental sciences are the three disciplines with the highest level of internationalization for the elite cities. Expanding the boundaries of human knowledge, jointly addressing global challenges and achieving sustainable development are important cornerstones of global academic cooperation.

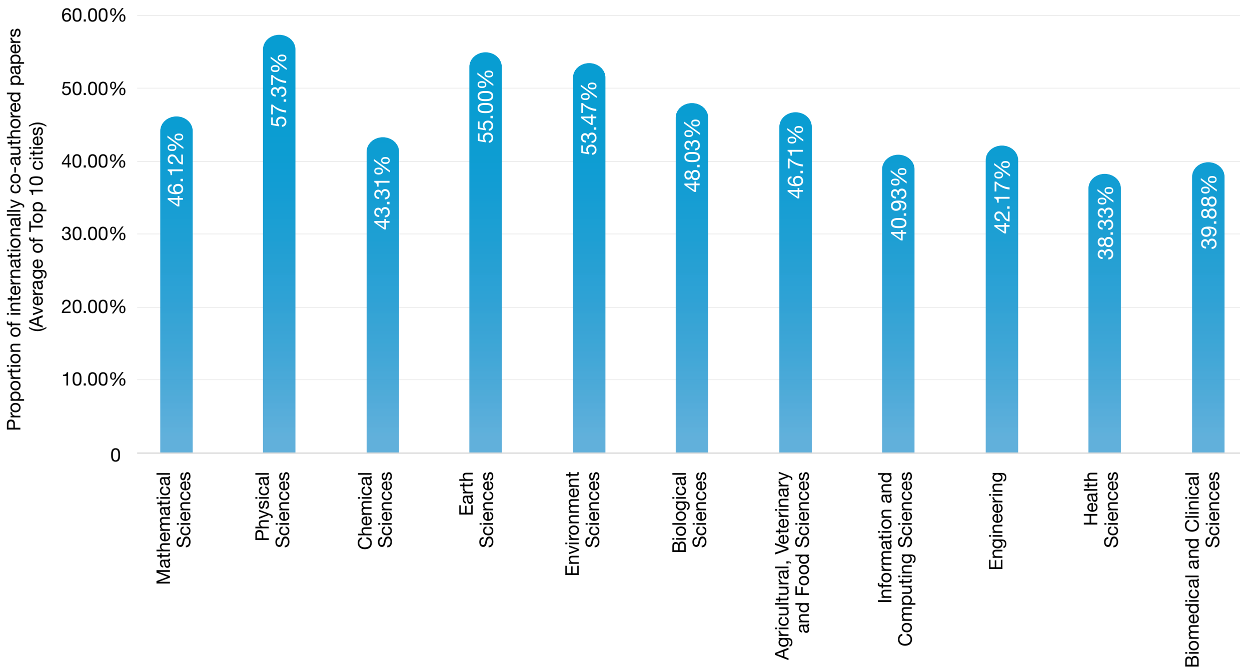
For these elite cities, a horizontal comparison of the proportion of internationally co-authored papers by discipline reflects the varied level of internationalization. As shown in Figure 18, the elite cities have a higher level of internationalization in physical sciences, earth sciences and environmental sciences, with more than half of the papers in those disciplines being co-authored internationally.

As basic research moves towards both micro and macro dimensions, especially for advanced modern physics, such as high-energy particle physics, astrophysics, nuclear physics, plasma physics, condensed matter physics and quantum physics, the exploration of the basic physical laws of the Universe under extreme conditions has become all the more urgent. This kind of research often relies on large scientific facilities, which usually require support from many countries because of their high cost and complexity. The International Thermonuclear Experimental Reactor (ITER), for example, facilitates global cooperation in the field of controlled nuclear fusion by bringing together funds, talent and technologies from multiple countries. This kind of international collaboration not only plays an important role in physics and provides new solutions for future energy resources, it also facilitates global academic exchanges.

Earth sciences and environmental sciences are highly interdisciplinary and explore all aspects of the planet. Interdisciplinary cooperation on a global scale is urgently needed to address severe challenges such as climate change, environmental pollution and the loss of biodiversity. The International Ocean Discovery Programme (IODP), for example, brings together scientists from different countries to explore the history of the planet, climate change, deep biosphere and geological hazards, by drilling the seafloor and collecting sediments and rock samples. IODP allows scientists around the world to jointly formulate scientific projects and share their findings, which has driven scientific cooperation and provided a crucial foundation for solving global challenges, such as climate change and the development of marine resources. International cooperation is necessary to address environmental challenges and realize sustainable development.

FIGURE 18

The average proportion of internationally co-authored papers by discipline for the top 10 cities/ metropolitan areas in the number of internationally co-authored papers(2022)



4. Innovation economy

As the global economy continues to recover, GIHs are strongly supported by enabling technologies and the leading cities have demonstrated great potential in scientific and technological innovation. The market value of high-tech manufacturing enterprises has generally experienced positive growth. The United States remains the main leader of innovation and has the largest number of leading innovative companies. Asian cities excel in the revenue of listed companies in the new economy sector.

4.1

A comprehensive analysis of innovation economy

The GIHI2024 innovation economy ranking is shown in Table 7.

TABLE 7

Ranking and scores of the top 100 GIHs in innovation economy

Rank	City/metropolitan area	Innovation Economy	Technological Innovation Capacity	Innovative Enterprises	Emerging Industries	Economic Growth
1	San Francisco - San Jose	100.00	78.63	100.00	100.00	83.73
2	Beijing	84.07	100.00	78.14	70.51	70.97
3	New York MA	79.48	76.84	77.39	70.86	80.77
4	Tokyo MA	75.63	80.29	71.88	64.91	78.26
5	Guangdong - Hong Kong - Macao Greater Bay Area	74.95	70.23	75.31	71.45	71.43
6	Seoul MA	74.85	78.81	64.62	71.18	77.65
7	Dublin	73.65	62.32	62.14	69.65	100.00
8	Boston MA	72.38	71.47	71.49	61.82	80.98
9	Seattle - Tacoma - Bellevue	70.15	68.35	62.74	66.04	81.88
10	Shanghai	70.00	68.67	71.87	62.45	72.27
11	Paris MA	69.99	65.05	65.14	64.09	84.88
12	Daejeon	69.19	79.61	60.07	60.06	77.70
13	London MA	68.75	62.14	67.19	61.91	83.52
14	San Diego MA	68.46	68.75	63.63	62.23	78.93
15	Singapore	68.44	61.55	62.22	60.38	93.47
16	Kyoto - Osaka - Kobe	68.39	71.13	63.67	60.79	77.97
17	Dallas - Fort Worth	68.37	61.70	61.84	66.42	83.31
18	Taipei	68.25	68.04	61.57	65.36	76.87
19	Munich	68.16	68.89	61.61	60.18	84.17
20	Abu Dhabi	67.99	60.13	60.15	61.01	95.56
21	Austin	67.26	63.69	62.53	60.89	84.12
22	Nagoya MA	67.23	71.33	61.20	60.12	77.66
23	Milan	66.91	61.40	60.66	60.68	88.88
24	Hangzhou	66.48	67.53	65.34	60.28	72.27
25	Chicago - Naperville - Elgin	66.35	61.50	63.28	62.58	78.78
26	Stockholm	66.34	61.80	61.84	61.17	83.07
27	Los Angeles - Long Beach - Anaheim	66.26	61.72	65.33	60.82	77.83
28	Houston MA	66.13	62.26	60.74	60.68	84.16
29	Baltimore - Washington	66.08	61.84	62.80	62.07	78.80
30	Amsterdam MA	66.01	61.23	61.67	60.79	83.26
31	Copenhagen	65.91	61.11	60.90	60.23	85.19
32	Denver MA	65.67	60.80	61.00	61.59	82.04

4.Innovation economy

Rank	City/metropolitan area	Innovation Economy	Technological Innovation Capacity	Innovative Enterprises	Emerging Industries	Economic Growth
33	Phoenix MA	65.66	62.14	60.96	62.08	79.47
34	Nanjing	65.47	68.88	61.23	60.01	73.10
35	Tel Aviv	65.29	60.55	62.74	60.07	80.44
36	Bengaluru	65.14	60.45	62.89	60.23	79.40
37	Madrid	65.12	60.71	60.74	61.73	79.86
38	Xiamen	65.07	62.23	60.74	60.06	80.56
39	Miami MA	65.06	60.67	61.30	60.19	81.37
40	Suzhou	64.95	65.36	62.44	60.05	73.32
41	Hamburg	64.94	60.84	60.67	60.01	81.97
42	Rotterdam	64.94	60.68	60.07	60.19	82.80
43	Atlanta MA	64.92	61.61	61.17	60.64	78.99
44	Lyon - Grenoble	64.89	61.22	60.07	60.00	82.19
45	Wuhan	64.88	64.62	61.18	60.24	75.61
46	Brussels	64.86	60.95	60.52	60.47	80.92
47	Chapel Hill - Durham - Raleigh	64.86	62.73	60.81	60.18	78.64
48	Philadelphia MA	64.85	61.59	62.15	60.31	77.69
49	Warsaw	64.82	60.56	60.15	60.37	82.00
50	Stuttgart	64.81	62.82	60.37	60.03	79.29
51	Lisbon	64.75	60.09	60.07	60.00	83.03
52	Dusseldorf	64.75	60.92	60.30	60.05	81.51
53	Zurich	64.73	62.30	60.51	60.03	79.37
54	Minneapolis - Saint Paul	64.71	61.59	61.20	60.23	78.75
55	Central National Capital Region (Delhi)	64.70	60.33	61.28	60.35	79.97
56	Helsinki	64.68	61.36	61.04	61.06	77.73
57	Mumbai MA	64.65	60.52	62.02	60.64	77.84
58	Berlin MA	64.60	62.50	61.70	60.07	76.56
59	Las Vegas	64.59	60.38	60.30	60.03	81.55
60	Frankfurt	64.59	61.20	60.60	60.01	80.04
61	Budapest	64.54	60.40	60.07	60.21	81.36
62	Vienna	64.50	61.00	60.29	60.01	80.40
63	Göteborg	64.49	60.59	60.30	60.02	80.86
64	Istanbul	64.34	60.40	60.36	60.21	79.99
65	Barcelona MA	64.29	61.02	60.29	60.27	78.99
66	Hefei	64.29	64.40	61.24	60.06	73.50

Rank	City/metropolitan area	Innovation Economy	Technological Innovation Capacity	Innovative Enterprises	Emerging Industries	Economic Growth
67	Buenos Aires	64.24	60.11	60.22	60.07	80.40
68	Prague	64.24	60.39	60.07	60.00	80.36
69	Cincinnati	64.22	61.58	60.22	60.11	78.34
70	Fuzhou	64.21	61.36	60.45	60.07	78.27
71	Rome	64.14	60.34	60.30	60.04	79.58
72	St. Louis	64.06	61.36	60.15	60.20	77.88
73	Cologne	64.05	60.00	60.30	60.02	79.67
74	Qingdao	64.01	63.10	60.80	60.02	74.70
75	Perth	63.91	60.05	60.00	60.00	79.46
76	Manchester	63.91	60.43	60.21	60.01	78.59
77	Pittsburgh	63.89	61.39	60.30	60.19	76.87
78	Xi'an	63.84	63.04	60.30	60.10	74.67
79	Jinan	63.78	63.37	60.52	60.03	73.75
80	Busan	63.77	61.66	60.00	60.01	76.77
81	Changsha	63.76	62.43	61.10	60.04	73.90
82	Dalian	63.73	61.73	60.29	60.00	76.03
83	Portland	63.66	60.61	60.44	60.02	76.91
84	Chengdu	63.61	63.44	61.31	60.03	71.66
85	Chennai MA	63.49	60.12	60.22	60.00	77.64
86	Detroit MA	63.45	60.84	60.37	60.00	76.01
87	Moscow	63.27	61.04	60.22	60.56	74.86
88	Toronto MA	63.15	61.10	61.51	62.22	69.08
89	Mexico City	63.04	60.09	60.35	60.21	75.08
90	Vancouver MA	63.02	61.47	60.94	60.78	70.93
91	Kuala Lumpur	62.97	60.14	60.15	60.22	74.80
92	Doha	62.83	60.04	60.00	60.23	74.90
93	Jakarta	62.60	60.00	60.50	60.81	73.13
94	Tianjin	62.47	62.40	60.66	60.08	70.46
95	Melbourne	62.20	60.35	60.74	60.48	71.26
96	Ankara	62.15	60.08	60.15	60.00	73.27
97	Dubai	61.87	60.03	60.49	60.10	72.14
98	Montreal MA	61.79	60.70	60.88	61.04	67.85
99	Brisbane	61.78	60.10	60.22	60.04	71.18
100	Lanzhou	61.63	61.50	60.00	60.00	69.62

4.Innovation economy

According to the assessment of the innovation economy, San Francisco-San Jose tops the list, followed by Beijing, New York MA, Tokyo MA and Guangdong-Hong Kong-Macao Greater Bay Area (Table 7). The ranking indicates that San Francisco-San Jose has extended its lead in innovative companies and emerging industries.

Geographically, the innovation economy is more developed in North America, Asia and Europe, and the distribution of Asian

FIGURE 19

Quartile graph of ranking in innovation economy for cities/ metropolitan areas in Asia, Europe, and North America

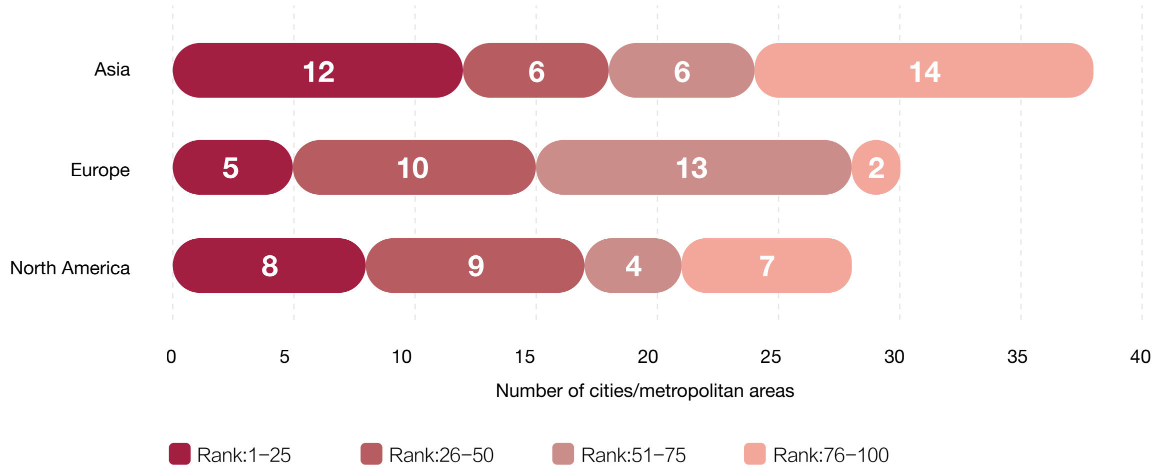


TABLE 8

A comparison of the top 20 GIHs in innovation economy between 2022-2024

City/metropolitan area	Rank 2024	Rank 2023	Rank 2022
San Francisco - San Jose	1	1	1
Beijing	2	4	3
New York MA	3	3	4
Tokyo MA	4	2	2
Guangdong - Hong Kong - Macao Greater Bay Area	5	5	7
Seoul MA	6	6	6
Dublin	7	10	8
Boston MA	8	7	11
Seattle - Tacoma - Bellevue	9	11	12
Shanghai	10	15	13
Paris MA	11	14	18
Daejeon	12	35	22
London MA	13	17	20
San Diego MA	14	16	14
Singapore	15	12	17
Kyoto - Osaka - Kobe	16	13	5
Dallas - Fort Worth	17	8	15
Taipei	18	9	9
Munich	19	21	10
Abu Dhabi	20	24	95

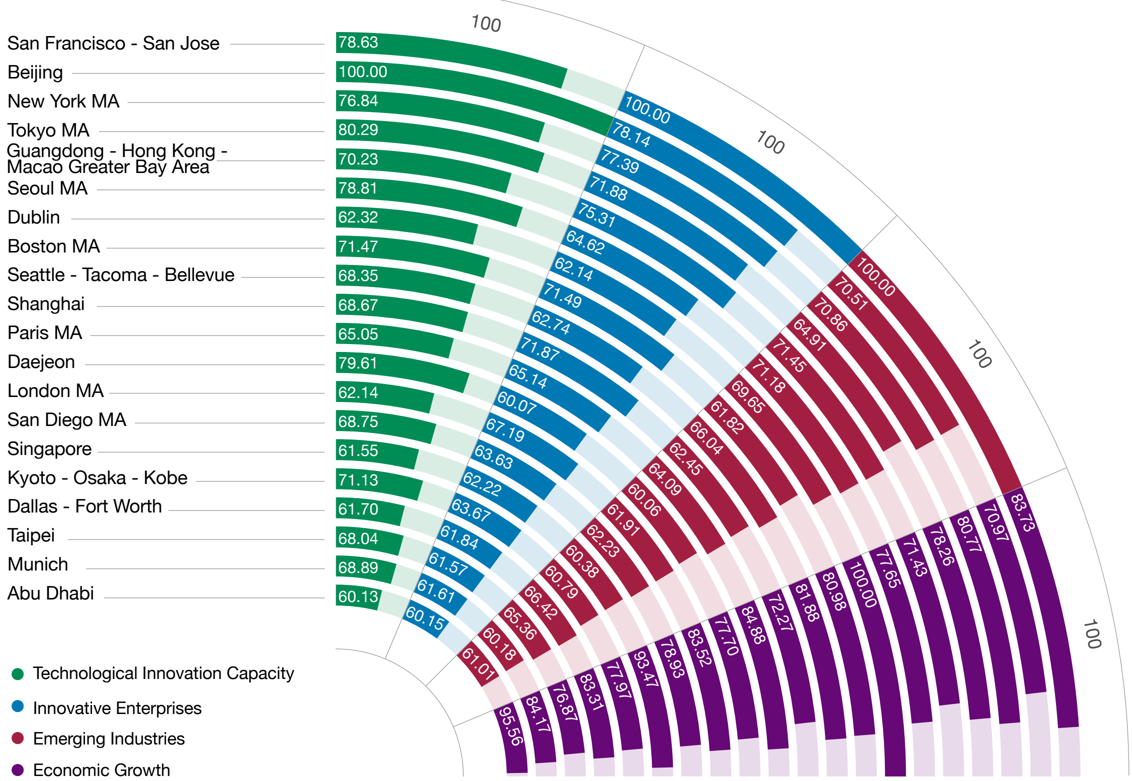
cities on the list is relatively scattered (Figure 19). Among the top 20, there are ten cities in Asia, six in North America and four in Europe. Asian cities are more scattered in the list of top 100 cities/metropolitan areas and are mainly clustered at the top or the bottom and have high economic disparity. The distribution of cities in Europe and North America is highly concentrated at the top of the list.

As shown by the trends seen in Table 8, the innovation economy is particularly competitive among top cities that compete with their distinct advantages. San Francisco-San Jose has ranked first for four consecutive years and its solid technology innovation and finance system has attracted a variety of high-tech companies and start-ups, top technology talent and high-tech industry clusters. Beijing has achieved significant growth in the number of unicorn companies and labour productivity, beating New York MA and Tokyo MA to the second place in innovation economy. New York MA and Tokyo MA rank third and fourth, respectively. New York MA stands out in innovative enterprises and emerging industries and Tokyo MA relies on its technological innovation to drive economic growth. In the past three years, the overall ranking of Seoul MA and Guangdong-Hong Kong-Macao Greater Bay Area has been stable at the top, and Seattle-Tacoma-Bellevue, Paris MA, London MA and Abu Dhabi have moved up year by year within the top 20, with Seattle-Tacoma-Bellevue making it to the top ten for the first time. Compared to last year, Daejeon, Shanghai, London MA and Abu Dhabi have seen a surge in innovation economy. Daejeon has excelled in technological innovation capabilities, Seattle-Tacoma-Bellevue and London MA have made breakthroughs enabled by technological innovation in high-tech manufacturing industries, Paris and Abu Dhabi have added value in the new economy sector and Abu Dhabi has experienced strong economic growth. Dublin and Munich have also had significant growth in innovation economy in the past year.

As the global leader in innovation economy, San Francisco-San Jose is at the top in the innovative enterprises and emerging industries sub-indicators (Figure 20). It also scores well in technological innovation capacity and economic growth. Beijing is top for technological innovation capacity and Daejeon records strong performance in technological innovation capacity and economic growth. Dublin, Singapore, Abu Dhabi, Paris MA, Munich, London MA, Dallas-Fort Worth and other cities/metropolitan areas have achieved high economic growth, with Dublin scoring the highest in this sub-indicator.

FIGURE 20

Development of the top 20 GIHs in innovation economy



4.Innovation economy

4.2 Technological innovation capacity

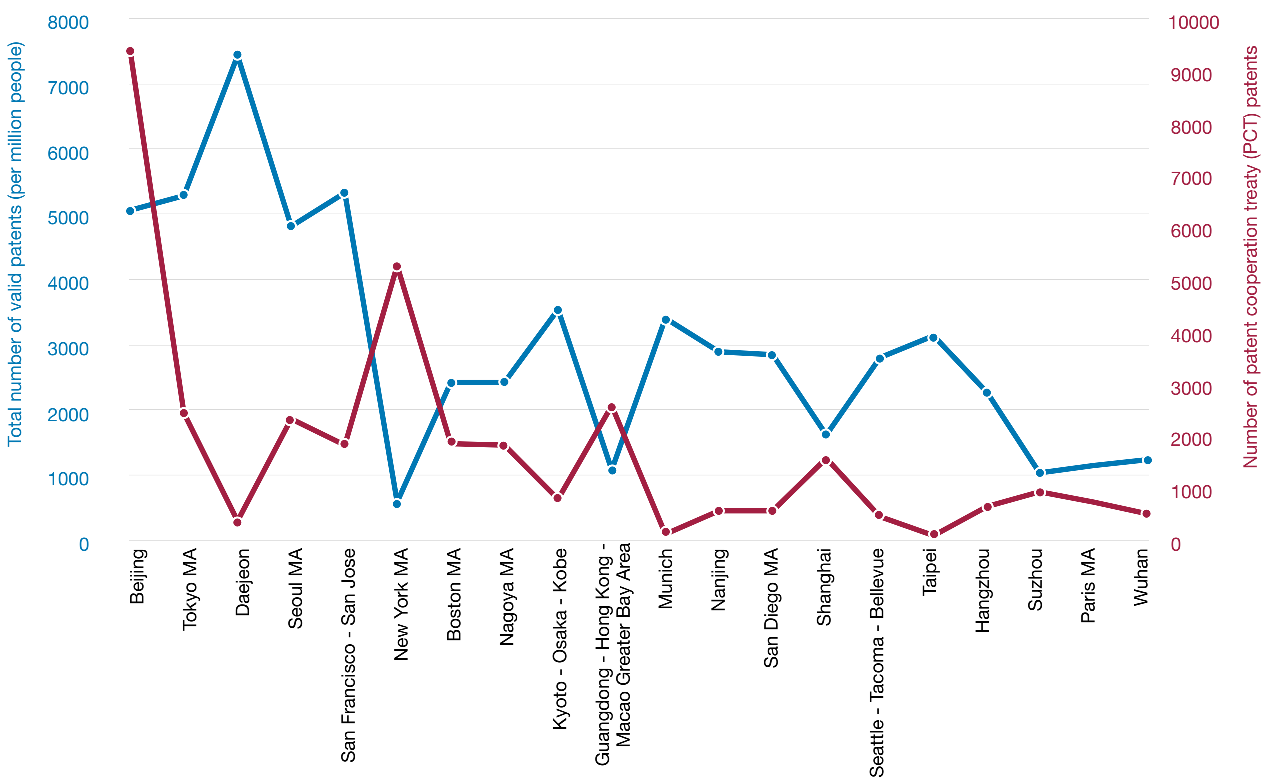
Patents are an important indicator of technological innovation capacity. The quantity and quality of patents reflect the level of technological innovation in a city/metropolitan area. This report evaluates technological innovation capacity using the number of valid patents (per million people) and PCT patents for 2023 in AI, smart chips, renewable energy and biomedicine. The top five cities/metropolitan areas in technological innovation capacity are Beijing, Tokyo MA, Daejeon, Seoul MA and San Francisco-San Jose (Figure 21).

North America and Asia are key hubs for global technological innovation. Asia has further improved its innovation capacity and made its mark in the global innovation landscape. Among the top 20, 13 cities are in Asia, five in North America and two in Europe. For the number of valid patents (per million people), five cities/metropolitan areas — Daejeon, San Francisco-San Jose, Tokyo MA, Beijing and Seoul MA — have more than 4,000 patents per million people. Daejeon ranks first with 7,430. It has increased investment and policy support for the biotechnology sector in recent years, which has facilitated development and innovation in biomedicine. San Francisco-San Jose comes in second with 5,336 valid patents per million people. As home to many world-renowned high-tech companies, San Francisco-San Jose is well-known for its AI and smart chips and is also a leader in the high-tech market. Tokyo MA ranks third with 5,289 valid patents per million people and comes first by the total number of valid patents in fields such as smart chips, renewable energy and biomedicine.

For the number of PCT patents in 2023, Beijing is far ahead with 9,372, followed by New York MA (5,273) and Guangdong-Hong Kong-Macao Greater Bay Area (2,574). Tokyo MA and Seoul MA rank fourth and fifth, respectively. There are 13 cities in Asia among the top 20 list for this indicator. In recent years, Asian cities/metropolitan areas, represented by Beijing, Guangdong-Hong Kong-Macao Greater Bay Area and Tokyo MA have been very active in innovation in AI, smart chips, renewable energy and biomedicine.

FIGURE 21

Total number of valid patents (per million people) and number of PCT patents for the top 20 cities/metropolitan areas in technological innovation capacity



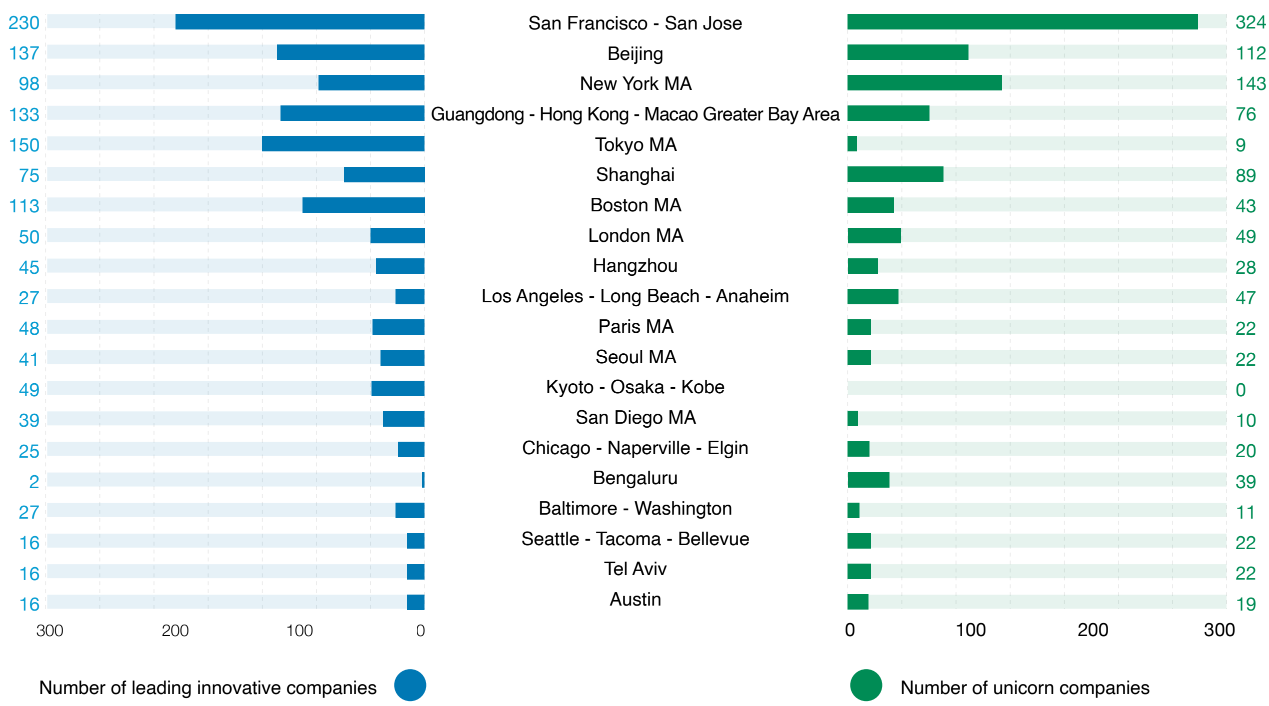
4.3
Innovative enterprises

Enterprises are the major players in technological innovation. This report uses the number of leading innovative companies and the number of unicorn companies to measure the scale and vitality of innovative companies. The top five cities/metropolitan areas by number of innovative enterprises are San Francisco-San Jose, Beijing, New York MA, Guangdong-Hong Kong-Macao Greater Bay Area and Tokyo MA (Figure 22). In the top 20 list, North America and Asia take nine spots each and Europe has the other two.

For the number of innovative enterprises, top cities including San Francisco-San Jose and New York MA as they have attracted more leading innovative companies driven by the wave of exploration into AI. More than any other city/metropolitan area, San Francisco-San Jose has an increase of 13 leading innovative companies in the past year making a total of 230. San Francisco Bay Area has a solid economic and industrial foundation, an open venture capital environment, and abundant policy and financial support, which could provide a good growing environment for science and technology enterprises. Asian cities also perform well, with Tokyo MA, Beijing and Guangdong-Hong Kong-Macao Greater Bay Area ranking second to fourth with 150, 137 and 133 leading innovative companies, respectively. The growth trend shows that most of these new enterprises are in the field of information technology, and the progress of AI has given rise to many new innovative companies. The United States remains at the forefront of scientific and technological innovation, taking up eight spots in the top 20 cities/metropolitan areas for leading innovative companies.

The number of unicorn enterprises indicates that competition in this indicator is less volatile. Overall, the top cities/ metropolitan areas are trending upwards. San Francisco-San Jose has the most with 324 unicorns, followed by New York MA with 143 and Beijing with 112. The unicorns in the United States are mainly in software services, financial technology, AI and health-care technology. The unicorn companies in China focus on AI, semiconductors and new energy. San Francisco-San Jose is the city where unicorns are growing at the fastest pace, with 14 new unicorn companies being recorded in the past year, followed by Guangdong-Hong Kong-Macao Greater Bay Area with an increase of nine new unicorns. Cities/metropolitan areas including Bengaluru, Berlin and Sao Paulo are having a 'growth spurt' of innovation and have more unicorns than leading innovative companies. For instance, Bengaluru has 39 unicorns but only two leading innovative companies, Berlin has 20 unicorns but only four leading innovative companies and Sao Paulo has 16 unicorns but only three leading innovative companies.

FIGURE 22 **Number of leading innovative companies and unicorn companies for the top 20 cities/ metropolitan areas of innovative enterprises**



4.Innovation economy

4.4 Emerging industries

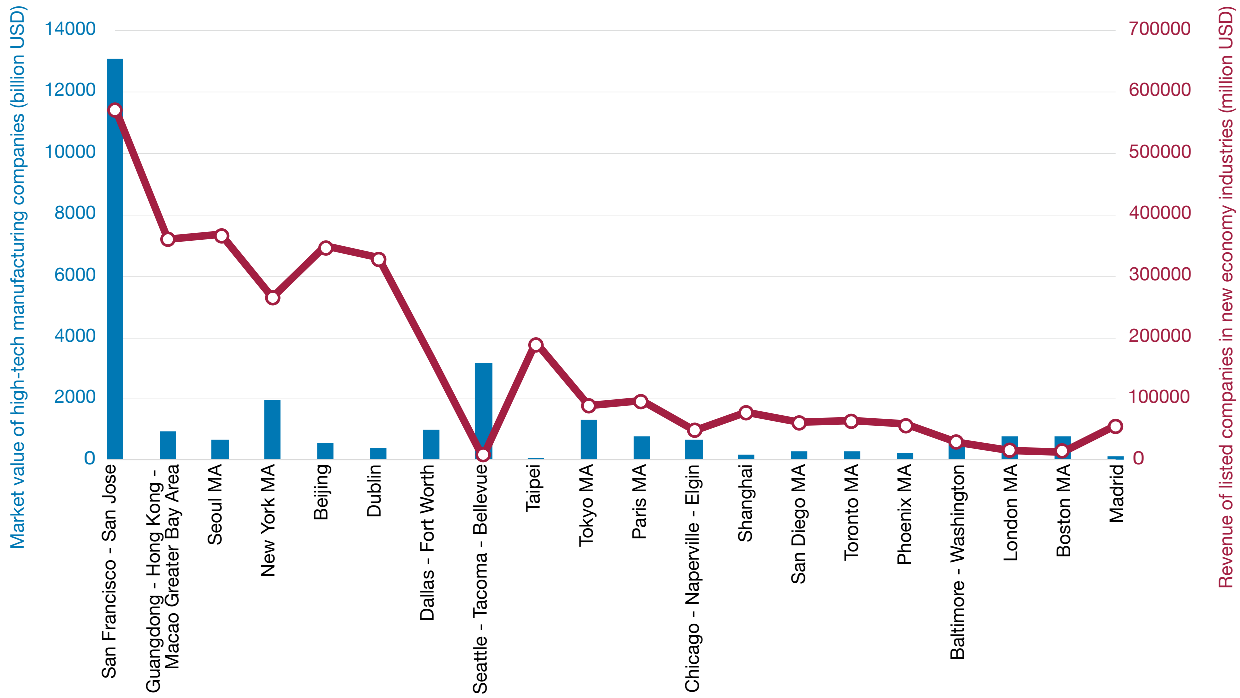
Emerging industries in this report refer to high-tech manufacturing and new economy industries that help sustain the competitive edge of the economy, such as biomedicine, high-end equipment manufacturing and next-generation information technology. This report uses the market value of high-tech manufacturing companies and the revenue of listed companies in new economy industries to measure the activity of emerging industries. The top five cities/metropolitan areas in emerging industries are San Francisco-San Jose, Guangdong-Hong Kong-Macao Greater Bay Area, Seoul MA, New York MA and Beijing (Figure 23). In the top 20 list, North America takes up ten spots, Asia has six and Europe has four.

The rise of AI has driven the robust development of the high-tech manufacturing industry. The market value of enterprises in the information technology sector has increased rapidly, but that of the biomedical sector has trended down significantly. San Francisco-San Jose, Seattle-Tacoma-Bellevue and New York MA are the top three cities/metropolitan areas by market value of high-tech manufacturing companies. They are home to high-tech companies, such as Nvidia, Apple, Microsoft and Google, that drive the development of the manufacturing sector and help them stay ahead. Geographically, cities/metropolitan areas in the United States stand out. The market value of high-tech manufacturing enterprises in the assessed North American cities/metropolitan areas accounts for 71.7% of all the evaluated cities. Compared with 2023, the market value of high-tech manufacturing enterprises in the top cities/metropolitan areas has grown, with San Francisco-San Jose registering the highest growth of US$ 5,071.91 billion, followed by Seattle-Tacoma-Bellevue with US$ 778.76 billion and Baltimore-Washington with US$ 346.07 billion.

When looking at the revenue of listed companies in new economy industries, Asian cities/metropolitan areas stand out, although San Francisco-San Jose has extended its lead. The top five cities/metropolitans are San Francisco-San Jose, Seoul MA, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing and Dublin. Asia takes up three of the top five spots for this indicator and has seen breakthroughs in scientific and technological innovation enabled by the digital economy. The vitality of innovation in Asia not only drives the region's economic growth but also makes it a key driver for the global economy. By the amount of increase, San Francisco-San Jose still ranks first with more than US$ 36.5 billion, which is closely related to the recovery of the financial sector and the growth of the technology sector. By contrast, most of the top cities experience negative growth, lagging further behind San Francisco-San Jose.

FIGURE 23

The market value of high-tech manufacturing companies and the revenue of listed companies in the new-economy sector for the top 20 cities/metropolitan areas in emerging industries



4.5 Economic growth

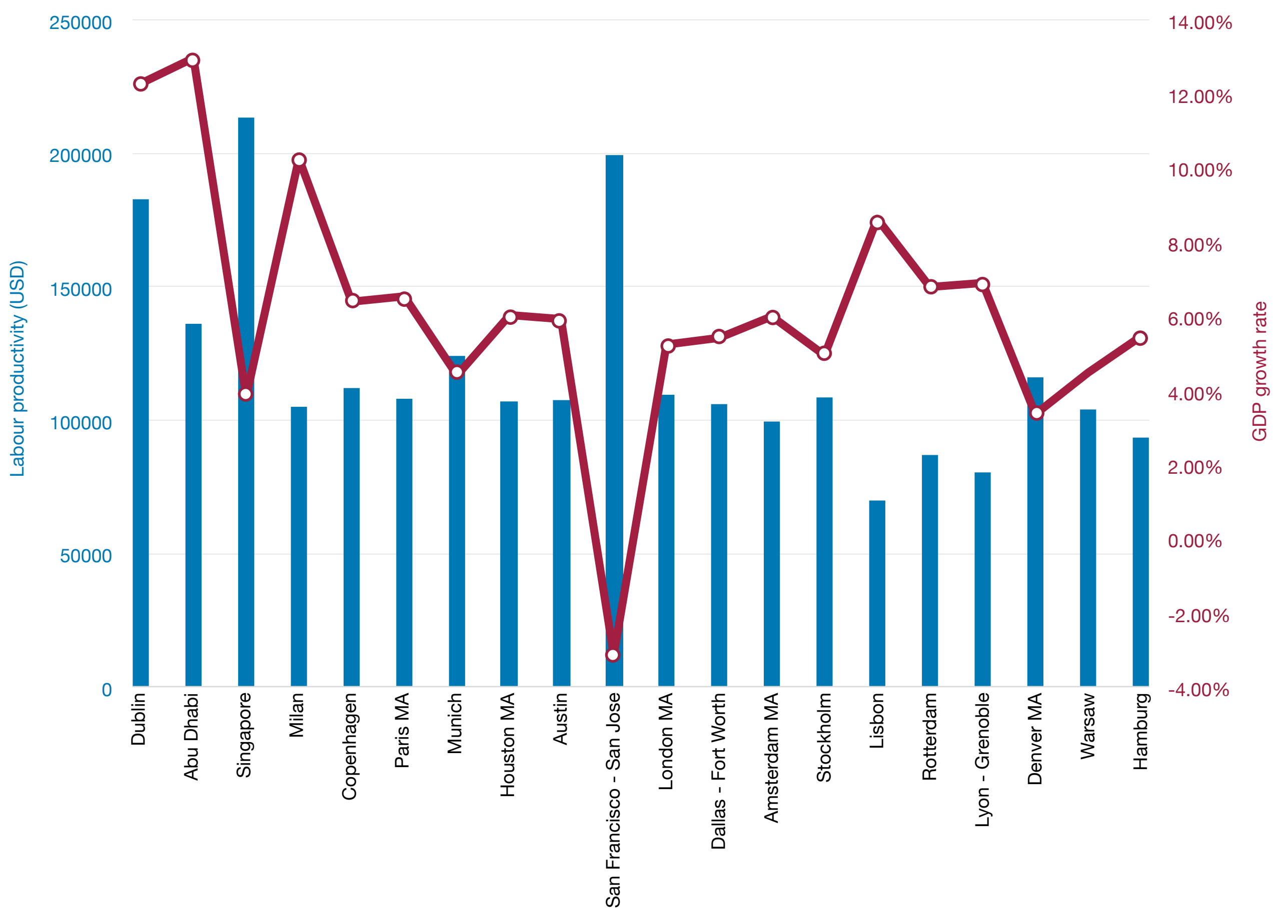
This report uses the GDP growth rate in 2022, adjusted by purchasing power parity (PPP) to measure a city's overall economic growth and living standards. Labour productivity in 2022 is used to measure social productivity. The top five cities/metropolitan areas in economic growth are Dublin, Abu Dhabi, Singapore, Milan and Copenhagen (Figure 24). Among the top 20 cities/metropolitan areas, Europe occupies 13 spots, the United States occupies five spots and Asia occupies two spots.

The impact of the COVID-19 pandemic is easing and the global economy is on track to recovery according to GDP growth. The GDP growth rates for Abu Dhabi, Dublin, Bengaluru, Milan and Central National Capital Region, which make up the top five, are all over 10%. In 2022, 86% of the assessed cities/metropolitan areas achieved positive GDP growth and 17.5% of the cities/metropolitan areas posted higher GDP growth rates than the previous year.

Global labour productivity has trended up steadily, with Europe and the United States taking the lead. The top five cities/metropolitan areas are Singapore, San Francisco-San Jose, Dublin, Seattle-Tacoma-Bellevue and Boston MA. Singapore, as the financial centre of southeast Asia and a global trade hub, has an economic structure dominated by high value-added industries as well as government-led investment in education, which have improved the country's overall labour productivity. San Francisco-San Jose is home to tech giants, such as Apple, Google and Facebook, and it provides high value-added products and services to boost labour productivity of the region. The top 20 cities/metropolitan areas are mainly located in North America and Europe, which account for ten and eight spots, respectively.

FIGURE 24

The GDP growth rate and labour productivity for the top 20 cities/metropolitan areas in economic growth



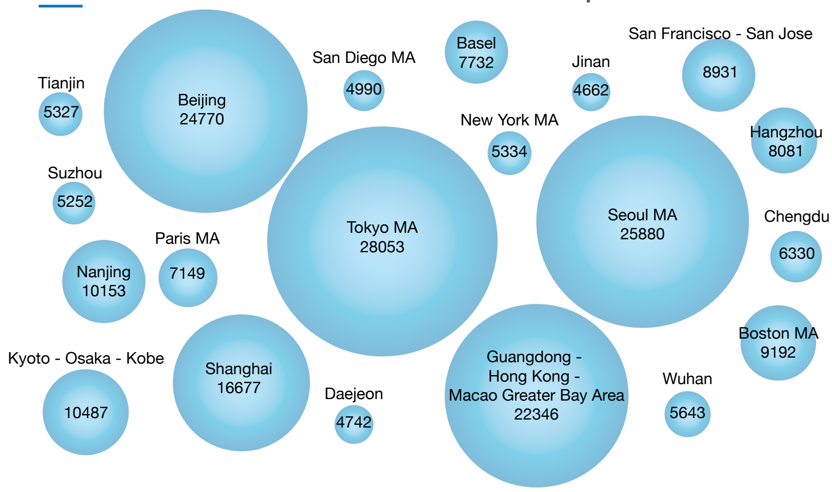
4.Innovation economy

FOCUS

Patents for biomedicine

In recent years, science and technology is characterized by cross-sector development. AI, materials sciences and high-energy physics have provided vital support for cross-sector innovation in biomedicine. Gene therapy, AI-based pharmaceuticals, synthetic biology, brain-computer interfaces and other fields have experienced growth spurts. A revolution in life sciences and technology is on the horizon, pushing humans to transform themselves. Globally, GIHs continue to accelerate the use of biomedical innovation resources and large scientific facilities to drive innovation in biomedicine and to grasp the opportunities brought by new rounds of technological revolution. To further explore the innovation capacity of GIHs in biomedicine, this report uses the public patent data in biomedicine and data on investment and large scientific facilities to present the latest developments of GIHs in biomedicine from three perspectives: overall trends, innovation entities and future prospects.

FIGURE 25 Top 20 cities/metropolitan areas in the number of valid patents in biomedicine



Overall trends of global biomedical innovation and development

Data regarding patents published since 1963 have been used to determine the number of valid patents in the cities/metropolitan areas (Figure 25). Tokyo MA tops the list with 28,053 valid patents, followed by Seoul MA, Beijing, Guangdong-Hong Kong-Macao Greater Bay Area and Shanghai, all of which are in East Asia. For the top 20 cities/metropolitan areas by country, China and the United States take up ten and four spots, respectively, while Europe, Japan and South Korea each occupy two spots, indicating that the health-care sector is prominent around the world. China stands out in the international competition in many sub-sectors of biomedicine, supported by its large market demand, substantial research and development investment and top scientific and technological innovation talent. China is also working to expand its global presence in this area.

Europe, the United States, and Japan still dominate in the number of PCT patents in biomedicine (Figure 26). Tokyo MA, Boston MA and San Francisco-San Jose are the top three cities with 32,354, 21,875, and 17,796 PCT patents each. For the top 20 cities/metropolitan areas by country/region, the United States takes up ten spots, Europe takes up four, China takes up three and Japan takes up two spots, both in the top five. The United States, Europe and Japan still lead in the number of PCT patents and are the main players in the global market of biomedical innovation.

FIGURE 26 Top 20 cities/metropolitan areas in the number of PCT patents in biomedicine

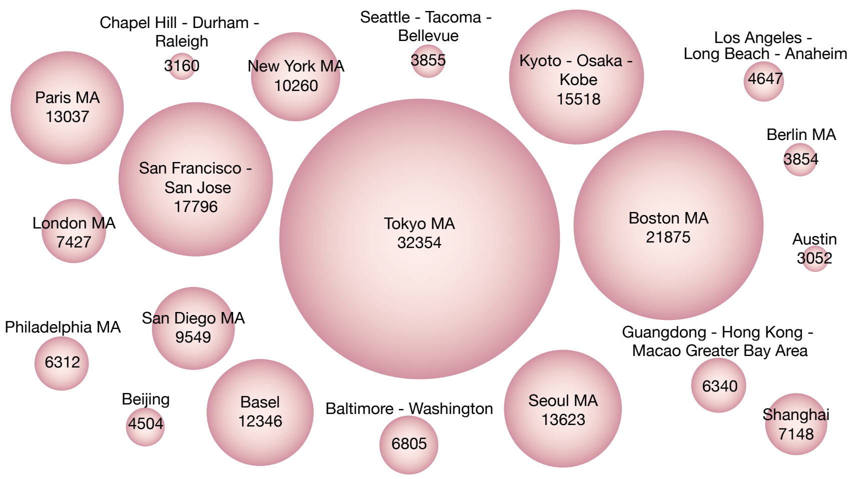
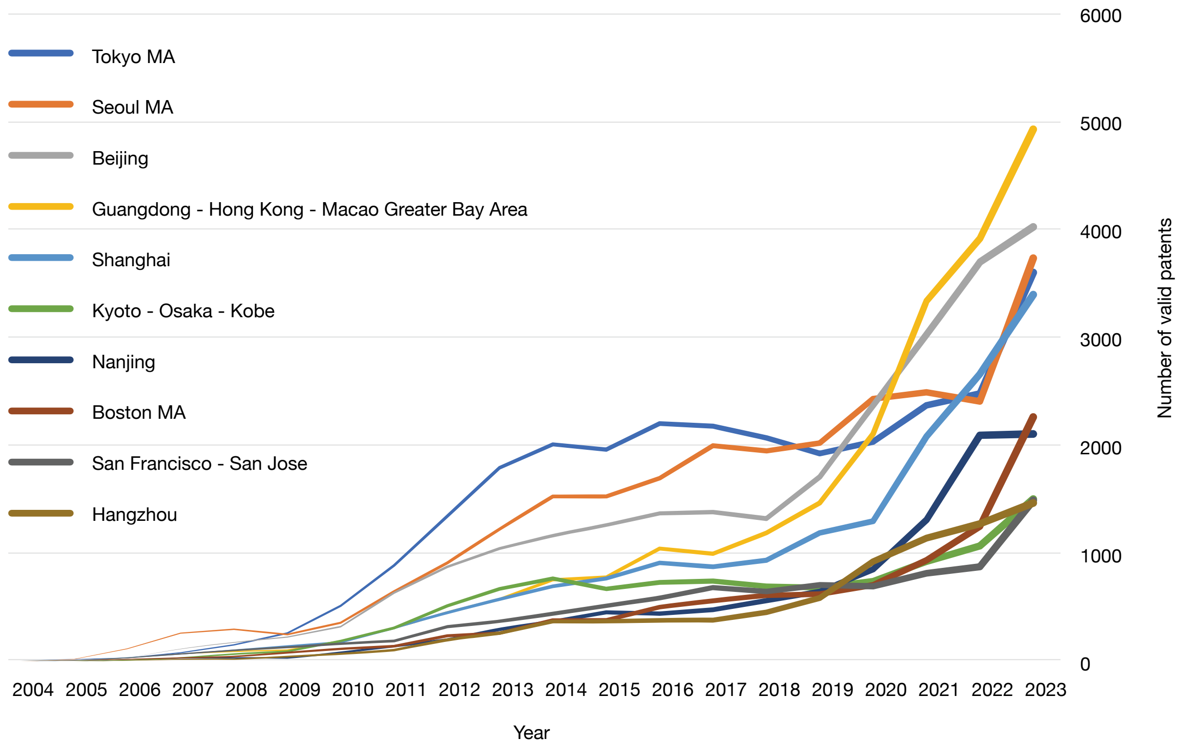


FIGURE 27

The annual trend of the top 10 cities/ metropolitan areas in the number of valid patents in biomedicine



The COVID-19 pandemic led to an explosion in technological innovation in biomedicine since 2020 and Chinese cities have entered a stage of accelerated development.

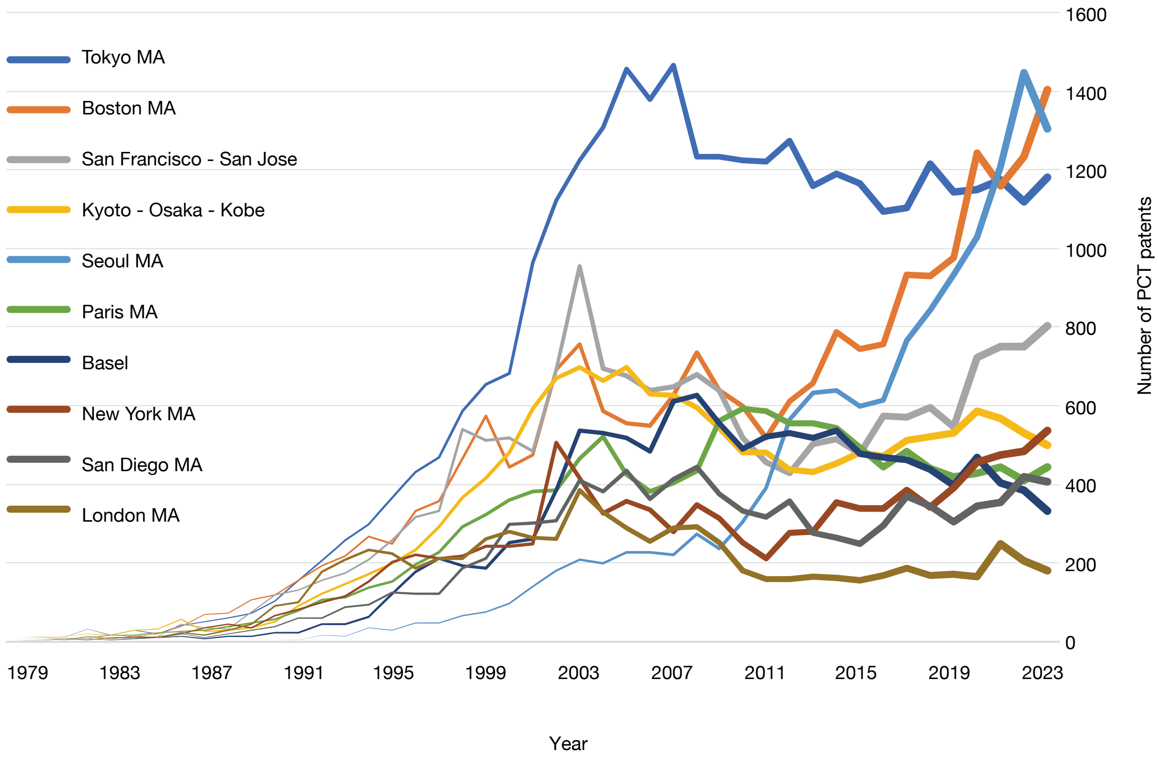
The history of global biomedical patents can be divided into three distinct stages:

The first stage is up to the beginning of the 21st century and exhibited slow growth. Innovation in biomedicine mostly followed the basic research paradigm of molecular biology and various research methods were used to understand the physiological or pathological activities of organisms by revealing the structure and function of individual genes or proteins at the molecular level. The study of complex interactions and regulatory mechanisms between biomolecules was hindered by the high-resolution imaging technology, which slowed down innovation in biomedical science and technology. Until 2004, the number of valid patents in GIHs only had single-digit growth annually.

The second stage is from 2000 to 2020 where there was a phase of rapid growth in valid patents in biomedicine. During this time, science and technology advanced at a faster pace. In particular, the rise of computational biology driven by developments in information technology brought about change. At the beginning of the 21st century, the Human Genome Project changed the paradigm of the development in systems biomedicine. Gene editing and cell therapy have transformed

FIGURE 28

The annual trend of the top 10 cities/ metropolitan areas in PCT patents in biomedicine



from theory to clinical practice. As shown in Figure 27, the number of valid patents in biomedicine increased rapidly from 2005 to 2019. The total valid patents of Tokyo MA in 2012 topped 1,000 for the first time, while Seoul MA and Beijing topped 1,000 in 2013. Guangdong-Hong Kong-Macao Greater Bay Area and Shanghai achieved this milestone in 2016 and 2019, respectively.

At the third stage, after COVID-19 became a pandemic in 2020, the number of valid patents in biomedicine has grown exponentially. When looking at the average annual growth of valid patents in the past three years, Boston MA (48.80%), Shanghai (38.70%) and Guangdong-Hong Kong-Macao Greater Bay Area (34.02%) grew most rapidly. PCT patents increased rapidly between 1990 and 2003, followed by a stage of high volatility, during which the growth rate of PCT patents in Tokyo MA remained the highest in the world (Figure 28). Boston MA and Seoul MA have caught up quickly since 2012 and surpassed Tokyo MA around 2020 to become new centres of growth for global PCT patents. In comparison, due to the increase of domestic demand, Chinese cities underperform in PCT patent applications and only a few leading technology companies are willing to seek overseas expansion.

Analysis of the innovation entities of the world's biomedical innovation hubs

The GIHI focuses on the top 20 cities/metropolitan areas by the number of biomedical PCT patents. It identifies the top 20 institutions in each city/metropolitan area by the number of PCT patents and examines the patent concentration and the types of institution in the cities to get a better picture of biomedical innovation of the 20 cities (Figure 29).

Paris MA, New York MA, Baltimore-Washington, Beijing, Austin and Chapel Hill-Durham-Raleigh are the leading biomedical innovation hubs that rely on universities and research institutions. Factoring in major universities and research institutions, Paris MA is home to many national research institutions such as the French National Institute for Health and Medical Research, the French National Centre for Scientific Research and the Institut Pasteur. The top ten universities and research institutions account for 64.75% of the total biomedical PCT patents in Paris MA. New York MA also has many prestigious universities and research institutions such as Columbia University, Yale University, The Rockefeller University, New York University, the Sloan Kettering Institute and the Ludwig Cancer Research. The top ten universities and research institutions contribute 50.96% of the total PCT patents for the city. However, the top ten universities and research institutions in Beijing only contribute 23.82% of its total PCT patents. In China, high-level universities and research institutions are

FIGURE 29 The distribution by the type of representative biomedical innovation hubs in the world

most concentrated in Beijing, including Tsinghua University, Peking University, China Agricultural University, the Chinese Academy of Medical Sciences, the Chinese Academy of Sciences, the Academy of Military Medical Sciences, the National Institute of Biological Sciences and other high-level research institutions. Therefore, the performance of Beijing's top ten institutions is less impressive. Duke University and the University of North Carolina account for more than half of the total PCT patents of Chapel Hill-Durham-Raleigh at 59.34%. The University of Texas alone accounts for 76.87% of the total PCT patents of Austin. The biomedical hubs led by universities and research institutions benefit from the concentration of research and development resources, facilities and talent which facilitate original breakthroughs and transformations in biomedicine.

Boston MA, San Francisco-San Jose, Shanghai, Guangdong-Hong Kong-Macao Greater Bay Area and Seattle are biomedical innovation hubs that rely on the world-leading innovation ecosystem. These cities/metropolitan areas have relatively diversified centres of innovation, which provide the region with a resilient environment for biomedical innovation. This is most evident for Boston MA and Shanghai, which have a similar number of PCT patents from universities, research institutions and enterprises. The top 20 enterprises, research institutions and universities in Boston MA contribute 5,346, 4,556 and 3,897 PCT patents, respectively, accounting for 24.44%, 20.83% and 17.81% of the total PCT patents of the city. Shanghai has diversified centres of innovation, such as Biowindow Gene Development, BioMarin, the Institute of Materia Medica, the Chinese Academy of Sciences, the Shanghai Institute of Medical Engineering and Fudan University, which have collectively formed a collaborative ecosystem. Meanwhile, ATLATL, an open laboratory and centre for innovation and research, has footprints in both Kendall Square in Boston and Zhangjiang Hi-Tech Park in Shanghai, suggesting that the value of the biomedical innovation ecosystems in both cities are recognized by world-leading generators of innovation.

Tokyo MA, Kyoto, Seoul MA, Basel, Philadelphia, San Diego, London MA, Los Angeles and Berlin are biomedical innovation hubs that rely on leading technology companies. The leading technology companies not only facilitate the translation from ideas to results, but also act as the key carriers for the development of biomedicine in GIHs. Tokyo MA and Seoul MA stand out in this respect. Among the top 20 institutions by the number of PCT patents in Tokyo MA, 16 are enterprises, which account for one-third of the total patents with over 11,000. If Tokyo MA represents a city that has a high concentration of leading technology companies, then Basel represents a city of 'polarized innovation', with Novartis, Roche and Syngenta owning as many as 9,661 biomedical PCT patents, accounting for 78.25% of Basel's total. Research shows that leading technology companies' cross-sector development plays a key role in a city's interdisciplinary integration and innovation in biomedicine. For example, by driving interactions between chemistry and biomedicine, Seoul MA has become the world's main source of innovation in the cosmetics sector. By integrating technologies in smart chips and biomedicine, San Diego now leads the world in nucleic acid drugs, gene sequencing and biochips.

How innovations will explode in the future

The findings in this report have been used to investigate biomedical innovation hubs and their paths towards innovation and explore what might affect the development of biomedicine in the future.

1. Large scientific facilities are a key driver for future innovation and the development of biomedicine

Cities with a larger number of PCT patents partly overlap with those with more large scientific facilities. In the cities where large scientific facilities are more concentrated, the output of PCT patents is also higher. For these cities, large scientific facilities provide professional equipment and services that enable innovation and the development of key industries.

It is found that among the top biomedical clusters in the United States, such as Boston MA, San Francisco-San Jose and New York MA, the vast majority of invention patents rely heavily on the support of large scientific facilities in national laboratories.

Biomedical innovation in Boston MA is reliant on the National Emerging Infectious Disease Laboratories (NEIDL) at Boston University, which focuses on infectious diseases that could turn into major public health concerns. Located within BioSquare, a biomedical research and business park adjacent to the Boston University campus, NEIDL has made remarkable contributions to life sciences and industrial development in Boston MA, Massachusetts and the US as a whole.

The biomedical innovation in San Francisco-San Jose benefits from the United States Department of Energy Joint Genome Institute (JGI), especially the large scientific facilities designed for biomedicine at the Lawrence Berkeley National Laboratory, which focus on genomic innovation and creating a sustainable bioeconomy. The state-of-the-art cryo-electron microscopy facilities Cryo-EM/ET Stanford-SLAC, jointly operated by Stanford University and the National Accelerator Laboratory, provides high-resolution cryo-electron microscopy detection and scanning for atomic-resolution structure determination and frozen electron tomography specimens. It also provides high-level bioassay technology and a public platform for innovation in the San Francisco Bay Area.

In New York MA, the Laboratory for BioMolecular Structure (LBMS) at the Brookhaven National Laboratory boasts the most advanced large facility in life sciences and uses cryo-electron microscopy to study tissue structures of organisms and accelerates the development of biotechnology and medicine.

Large scientific facilities are vital carriers for building comprehensive national science centres in Beijing, Shanghai and Guangdong-Hong Kong-

Macao Greater Bay Area and they provide key support for interdisciplinary sub-fields, such as medical imaging, synthetic biology and brain science. For example, the synchrotron radiation light source allows researchers to conduct non-destructive detection and real-time analysis of the structure and function of cells and tissues. The technology has been applied to the structural analysis of biological macromolecules, such as proteins, glycogen and nucleic acids, and has also been used to study more complex systems, such as cells and tissues. It is obvious that the progress of cutting-edge science and technology in biomedicine are deeply tied to large scientific facilities and the use of such facilities has become a crucial shortcut for major discoveries in biomedicine.

Beijing launched the multi-mode, multi-scale biomedical imaging facility at the end of 2023 to create an integrated biomedical imaging technology cluster. The National Facility for Protein Science is a large scientific facility designed for biomedical study built by China, which has branches in Beijing and Shanghai. The National Facility for Protein Science (Beijing), led by the Academy of Military Medical Sciences, focuses on the cryo-electron microscopy system, providing technical support for protein structure analysis at near-atomic resolution.

The National Facility for Protein Science (Shanghai) (NFPSS), led by the Shanghai Advanced Research Institute, Chinese Academy of Sciences, is the world's first comprehensive large scientific facility for life sciences. It consists of nine technical systems that form a complete and advanced equipment system designed for protein research. Specifically, the Shanghai-XFEL Beamline Project, which is based on the Shanghai Soft X-ray Free Electron Laser could provide visualization and real-time imaging services at nanoscale and ultra-high resolution and support research in life sciences and drug development. The NFPSS offers a high-level platform, which allows universities and institutes, the innovation centres at large enterprises and small and medium-sized enterprises to pursue innovation and development. It helps build Shanghai into a biomedical research hub and helps development in China more widely.

In November 2023, Guangdong-Hong Kong-Macao Greater Bay Area officially put into operation two large scientific facilities in Guangming Science City, Shenzhen. The construction was led by the Shenzhen Institute of Advanced Technology, which is part of the Chinese Academy of Sciences. The first is a platform for synthetic biology research for the intelligent design and automatic casting of artificial organisms. It is the first large infrastructure for synthetic biology research in China that integrates software control, hardware and synthetic biology applications. The second is the infrastructure for brain analysis and simulation, which is the world's first cross-species, full-scale brain science platform that focuses on brain analysis, brain editing and brain simulation. It aims to drive an increase in basic and applied research in brain science. In addition, the China National GeneBank (CNGB), operated and maintained by BGI Research (Shenzhen), is the first national gene bank in China and one of the largest gene banks in the world. It focuses on the storage, reading and open sharing of biological genetic resources and is a world-leading biological genetic resource.

2. Venture capital helps attract tech giants

Venture capital, one of the most important resources for innovative enterprises, also plays a key role in building biomedical innovation hubs. Understanding investment and financing in biomedicine in regions that have a high number of PCT patents could provide better insights into the development of global biomedical innovation hubs.

Global biomedical investment and financing are concentrated in China and the United States and in specific cutting-edge areas. From January 2020 to July 2024, 7,875 investment events were recorded (including mergers and acquisitions) in MedAlpha, with a total amount of US$ 862.180 billion. Historically, innovation investment in biomedicine has had fluctuations. A large amount of venture capital flows to the United States and China, accounting for about 80% of the total cross-border investment and financing in biomedicine globally. By investment round, the investment events from seed to series A account for about 30% of the total. The projects that receive investment involve clinical research, small molecules, large molecules, drug discovery and cell therapy, and are mainly in the fields of rare diseases, tumours, blood, cardiovascular diseases and neurology.

Technology giants focus on early-stage venture capital. Companies in the United States have diverse access to venture capital and access to venture capital for Chinese companies varies from region to region. Data on investment and financing for companies with more than 700 PCT patents identify a total of 574 investment events from 13 biomedical technology giants. The outbound investment of these 13 enterprises is mostly in the United States, accounting for 52.61% of the total, followed by China at 17.60%. China receives most funding from organizations such as Lilly Asia Ventures and AstraZeneca's China International Capital Corporation Fund. By investment round, the investment events from seed to series A account for 40.94% of the total, higher than the global average (30%). The portfolio companies focus on small molecules, gene therapy, mRNA and AI-driven research, which implies that large pharmaceutical companies are committed to investing early, investing small, investing hard technology and investing for the longer term.

In conclusion, future biomedical innovation, especially the creation of new intellectual property rights, depends not only on market resources and venture capital, but also on the innovation ecosystem and large scientific facilities for biomedicine. A combination of all these elements could further accelerate biomedical innovation. At present, the global biomedical innovation hubs with cutting-edge PCT patents, large facilities and venture capital are better equipped and present huge challenges to latecomers.

5. Innovation ecosystem

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In innovation ecosystem, overseas investment and financing have driven the rapid rise of Asian cities in the ranking. Global demand for air travel continues to pick up and the flow of professional talent has increased significantly for GIHs. As global capital flows and venture capital investment activity keeps slowing down, the reshuffle in global supply chains has injected capital liquidity and resilience to emerging markets.

5.1

A comprehensive analysis of innovation ecosystem

The GIHI2024 ranking for innovation ecosystem is shown in Table 9.

TABLE 9

Ranking and scores of the top 100 GIHs in innovation ecosystem

Rank	City/metropolitan area	Innovation Ecosystem	Openness and Collaboration	Support for Start-ups	Public Services	Innovation Culture
1	London MA	100.00	94.99	82.86	100.00	100.00
2	San Francisco - San Jose	97.13	81.72	100.00	89.21	89.80
3	New York MA	95.88	86.00	95.59	93.88	83.45
4	Shanghai	87.93	87.91	91.93	86.52	65.56
5	Singapore	84.75	86.37	71.88	95.22	79.25
6	Guangdong - Hong Kong - Macao Greater Bay Area	84.63	100.00	71.55	88.61	67.79
7	Boston MA	82.91	80.13	78.52	78.51	83.32
8	Paris MA	82.81	82.21	72.46	91.91	79.43
9	Beijing	80.71	90.74	71.75	83.10	69.69
10	Amsterdam MA	79.65	69.32	64.95	99.74	89.52
11	Baltimore - Washington	79.28	76.52	70.61	86.80	80.97
12	Toronto MA	78.92	72.97	66.57	84.20	91.68
13	Dubai	78.65	71.02	61.26	97.53	91.06
14	Tokyo MA	78.51	84.74	65.37	83.51	78.45
15	Munich	78.11	70.81	72.97	77.14	87.60
16	Dallas - Fort Worth	77.91	73.38	64.76	91.20	85.39
17	Seoul MA	77.79	79.63	68.28	85.91	76.32
18	Los Angeles - Long Beach - Anaheim	77.22	72.80	67.62	90.61	80.15
19	Abu Dhabi	77.07	75.57	60.17	87.02	89.58
20	Madrid	76.89	69.76	70.85	82.56	83.94
21	Seattle - Tacoma - Bellevue	76.84	71.85	66.76	82.38	87.24
22	San Diego MA	75.66	70.15	67.82	77.78	87.20
23	Chicago - Naperville - Elgin	75.65	69.44	68.18	88.33	79.88
24	Austin	75.51	66.72	67.94	79.41	89.49
25	Copenhagen	74.91	65.65	63.28	97.10	82.60
26	Zurich	74.82	64.27	64.62	87.25	89.20
27	Stockholm	74.78	66.38	65.93	88.12	84.03
28	Chapel Hill - Durham - Raleigh	74.33	69.07	64.32	79.15	88.13
29	Frankfurt	74.26	62.25	69.88	89.91	80.33
30	Hamburg	74.23	65.59	65.42	69.28	97.57
31	Miami MA	74.11	64.65	67.98	85.32	83.00
32	Helsinki	74.08	62.52	62.11	86.88	92.72

5.Innovation ecosystem

Rank	City/metropolitan area	Innovation Ecosystem	Openness and Collaboration	Support for Start-ups	Public Services	Innovation Culture
33	Denver MA	73.44	63.38	67.33	80.66	86.63
34	Sydney	73.31	70.52	68.01	80.83	76.55
35	Berlin MA	72.77	69.22	67.37	68.23	86.37
36	Vancouver MA	72.77	66.73	63.25	78.22	87.99
37	Sao Paulo	72.59	65.29	74.27	79.94	72.16
38	Dublin	72.52	68.95	65.65	78.52	80.88
39	Barcelona MA	72.34	69.58	65.09	79.81	79.40
40	Phoenix MA	72.30	64.08	64.15	84.68	83.67
41	Rome	72.09	65.72	68.75	73.26	82.72
42	Dusseldorf	72.06	60.37	71.47	77.24	82.26
43	Atlanta MA	71.75	67.88	65.59	82.52	76.80
44	Montreal MA	71.68	66.77	66.42	75.79	81.59
45	Manchester	71.57	62.50	65.40	78.29	85.99
46	Houston MA	71.32	69.74	64.44	80.54	76.21
47	Tel Aviv	70.86	62.50	75.02	72.68	73.99
48	Milan	70.85	66.37	66.98	79.61	75.77
49	Pittsburgh	70.82	64.95	65.97	78.76	79.43
50	Minneapolis - Saint Paul	70.72	64.16	64.58	80.52	80.77
51	Philadelphia MA	70.61	69.45	64.77	77.99	75.61
52	Melbourne	70.29	68.94	64.77	75.75	76.80
53	Lyon - Grenoble	70.01	62.85	64.17	80.26	80.79
54	Taipei	69.86	67.20	64.53	78.30	75.96
55	Hangzhou	68.90	72.46	65.26	75.63	67.38
56	Bengaluru	68.41	69.31	68.35	65.55	72.44
57	Portland	68.30	61.81	63.01	78.52	79.31
58	Kyoto - Osaka - Kobe	68.29	70.53	60.77	75.70	74.05
59	Lisbon	68.20	62.27	65.77	77.17	75.45
60	Brisbane	68.18	62.76	63.58	74.25	80.07
61	Rotterdam	67.99	63.80	61.61	75.83	79.85
62	St. Louis	67.94	63.64	63.22	77.57	76.32
63	Vienna	67.54	62.77	61.89	80.62	75.74
64	Las Vegas	67.54	60.51	63.13	79.94	77.15
65	Doha	67.48	61.47	60.00	83.65	77.57
66	Moscow	67.44	65.32	61.03	67.69	82.93

Rank	City/metropolitan area	Innovation Ecosystem	Openness and Collaboration	Support for Start-ups	Public Services	Innovation Culture
67	Perth	67.41	61.29	65.71	74.60	75.95
68	Cologne	67.35	60.00	69.13	67.99	77.24
69	Cincinnati	67.32	61.18	62.20	75.25	80.35
70	Nanjing	67.29	72.58	62.99	75.96	64.95
71	Warsaw	67.07	64.06	62.84	72.97	76.82
72	Mumbai MA	67.06	71.47	69.00	65.12	64.80
73	Nagoya MA	66.86	63.10	60.25	73.62	80.50
74	Göteborg	66.50	62.78	60.28	76.94	77.26
75	Central National Capital Region (Delhi)	66.48	68.44	67.91	66.20	67.29
76	Brussels	66.12	62.40	62.16	66.89	81.05
77	Detroit MA	65.96	62.04	63.00	76.85	72.54
78	Hefei	65.93	68.54	66.44	73.73	61.99
79	Mexico City	65.85	61.60	71.51	65.95	68.45
80	Kuala Lumpur	65.61	66.83	61.57	69.18	73.23
81	Buenos Aires	65.52	60.83	64.76	65.80	78.04
82	Wuhan	65.47	70.18	62.01	75.40	63.62
83	Suzhou	65.20	67.56	62.69	75.27	64.99
84	Stuttgart	64.86	61.62	63.80	66.73	75.62
85	Bangkok	64.76	62.93	61.48	75.22	70.86
86	Daejeon	64.68	62.02	60.94	75.00	72.64
87	Tianjin	64.44	65.89	61.08	77.68	65.05
88	Chengdu	64.21	68.98	63.34	72.00	61.49
89	Xi'an	64.17	69.14	61.00	72.00	64.50
90	Busan	64.10	62.50	60.45	71.71	73.24
91	Prague	63.53	62.15	64.48	60.00	74.51
92	Istanbul	63.34	63.86	66.67	68.47	62.57
93	Qingdao	63.08	65.50	61.02	74.26	63.62
94	Zhengzhou	62.84	63.90	61.45	76.04	62.84
95	Jinan	62.81	64.89	61.52	75.65	61.73
96	Budapest	62.43	61.73	61.63	64.91	71.90
97	Chongqing	62.39	66.36	61.74	71.65	61.16
98	Dalian	62.14	63.37	61.32	75.13	61.99
99	Changsha	61.81	65.04	61.33	69.90	62.71
100	Johannesburg	61.69	61.07	60.37	62.63	73.72

5.Innovation ecosystem

Globally, London MA leads in innovation ecosystem, followed by San Francisco-San Jose and New York MA. Among the top 20 cities/metropolitan areas, Asia occupies eight spots, North America occupies seven and Europe has five.

Geographically, cities/metropolitan areas in Europe and the United States rank relatively high, while Asian cities/metropolitan areas diverge greatly (Figure 30). Among the top 50 cities in innovation ecosystem, 78% are in Europe or North

FIGURE 30

Quartile graph of ranking in innovation ecosystem for cities/metropolitan areas in Asia, Europe and North America

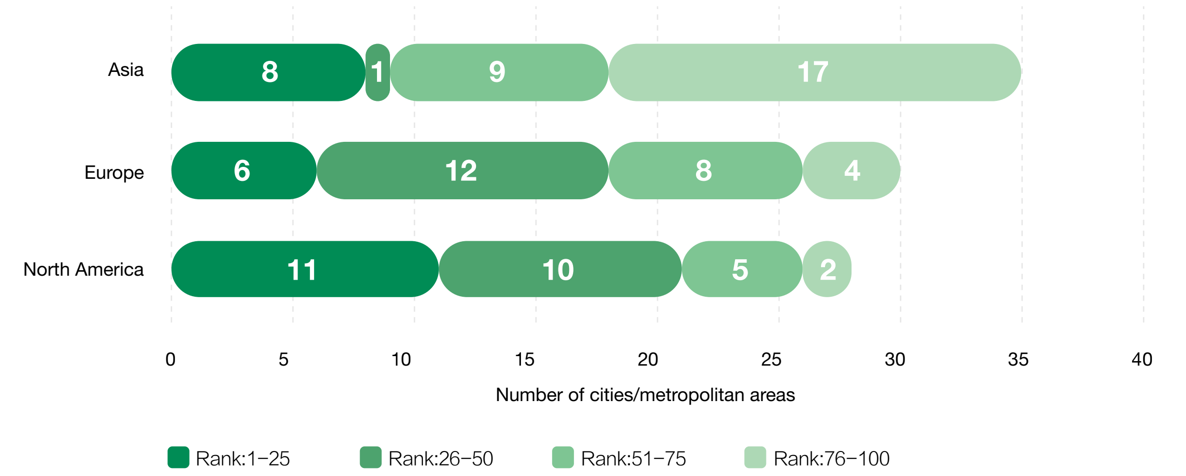


TABLE 10

A comparison of the top 20 GIHs in innovation ecosystem between 2022-2024

City/metropolitan area	Rank 2024	Rank 2023	Rank 2022
London MA	1	2	2
San Francisco - San Jose	2	1	1
New York MA	3	3	3
Shanghai	4	13	12
Singapore	5	7	10
Guangdong - Hong Kong - Macao Greater Bay Area	6	6	4
Boston MA	7	8	8
Paris MA	8	4	9
Beijing	9	11	5
Amsterdam MA	10	14	11
Baltimore - Washington	11	15	18
Toronto MA	12	12	6
Dubai	13	9	33
Tokyo MA	14	24	20
Munich	15	17	13
Dallas - Fort Worth	16	16	22
Seoul MA	17	5	14
Los Angeles - Long Beach - Anaheim	18	20	16
Abu Dhabi	19	43	41
Madrid	20	21	15

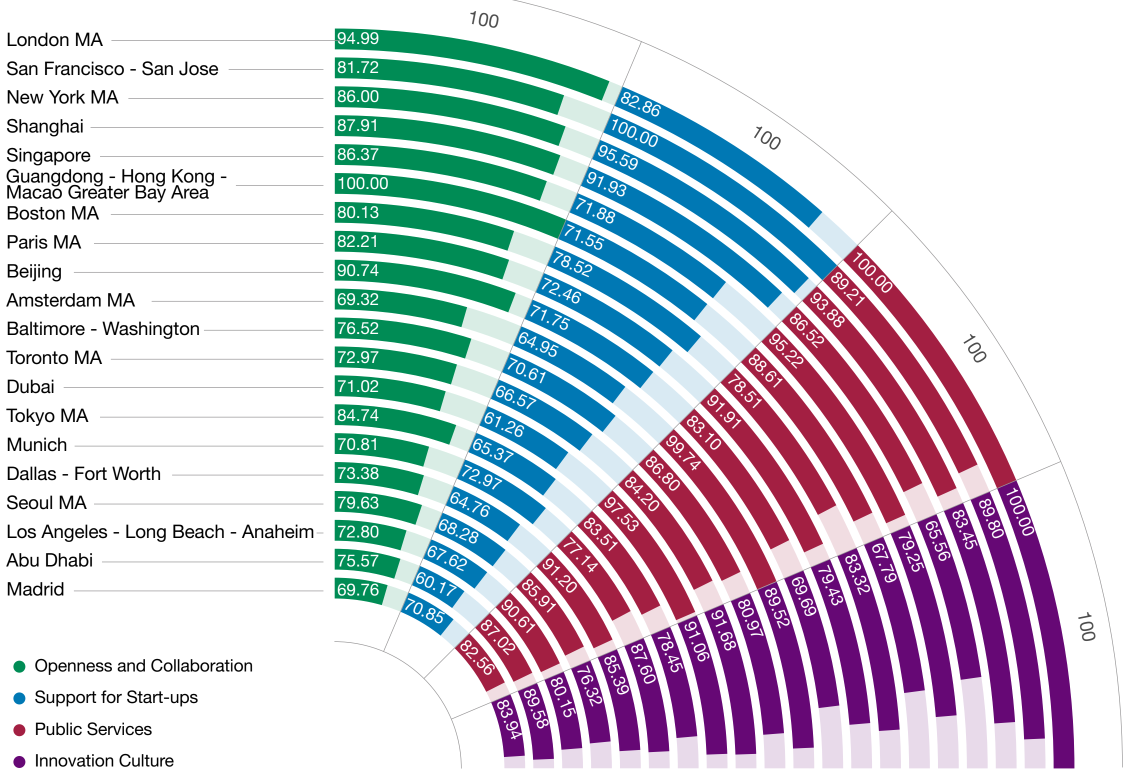
America. Representing Asia, Shanghai and Singapore make it into the top five and Guangdong-Hong Kong-Macao Greater Bay Area and Beijing are among the top ten, but nearly half of Asian cities rank lower than 75th.

As the trends indicate, the rankings of the top 20 cities/metropolitan areas in innovation ecosystem remained unchanged and some Asian cities/metropolitan areas have made remarkable gains (Table 10). Since 2020, London MA, San Francisco-San Jose and New York MA have remained in the top three of the innovative ecosystem ranking, with London MA and San Francisco-San Jose alternately leading the list and New York MA maintaining its third place. Shanghai, Tokyo MA and Abu Dhabi have had impressive growth, moving up nine places, ten places and 24 places, respectively, compared to last year. Shanghai is up by six places in openness and cooperation and up by 19 places in public services. Its foreign direct investment (FDI) has increased by 80%, moving it to fourth place and its outward foreign direct investment (OFDI) has doubled. Active foreign capital flows and international flights have injected vitality into the city. Tokyo MA moved up four places in openness and cooperation and seven places in support for start-ups, and its FDI has increased by 1.3 times. Abu Dhabi moved up 18 places in openness and cooperation, up 37 places in public services and up 10 places in innovation culture. It ranked third with US$ 52.36 billion in OFDI and first in broadband connection speed. Singapore's ability to attract capital and its support for innovation have increased its ranking in the past three years, entering the top ten list in FDI, OFDI, venture capital (VC) and private equity (PE) investment.

Figure 31 shows the performance of the top 20 cities/metropolitan areas in innovation ecosystem across each sub-indicator. London MA ranks first in the world in public services and innovation culture and fourth in support for start-ups. With a development pattern similar to London MA, Amsterdam, Dubai, Dallas-Fort Worth and Abu Dhabi all rank among the top 20 in public services and innovation culture. A well-developed infrastructure and inclusive culture make these cities/metropolitan areas attractive as they have great innovation potential. San Francisco-San Jose, New York MA and Shanghai perform particularly well in support for start-ups, ranking in the top three for VC and PE investment, each exceeding US$ 15 billion for the total amount of VC and PE. Guangdong-Hong Kong-Macao Greater Bay Area, Beijing and Tokyo MA stand out in openness and cooperation. Singapore and Paris MA drive innovation by having high-quality public services, ranking among the top 20 in the number of data centres and broadband connection speed. This solid infrastructure provides robust support for digital transformation and innovation. Each of these cities has its own development pattern and strength, jointly creating a diversified innovation ecosystem.

FIGURE 31

Development of the top 20 GIHs in innovation ecosystem



5.Innovation ecosystem

5.2 Openness and collaboration

Openness and cooperation are key driving forces in an innovation ecosystem. GIHI2024 evaluates a city's level of openness and collaboration using such indicators as paper co-authorship network centrality, patent collaboration network centrality, FDI and OFDI.

Guangdong-Hong Kong-Macao Greater Bay Area, London MA, Beijing, Shanghai and Singapore are the top five cities/metropolitan areas in openness and collaboration. Among the top 20 cities/metropolitan areas, ten of them are in Asia, seven in the United States and only two in Europe. Cities including Shanghai, Abu Dhabi and Mumbai have greatly improved their rankings.

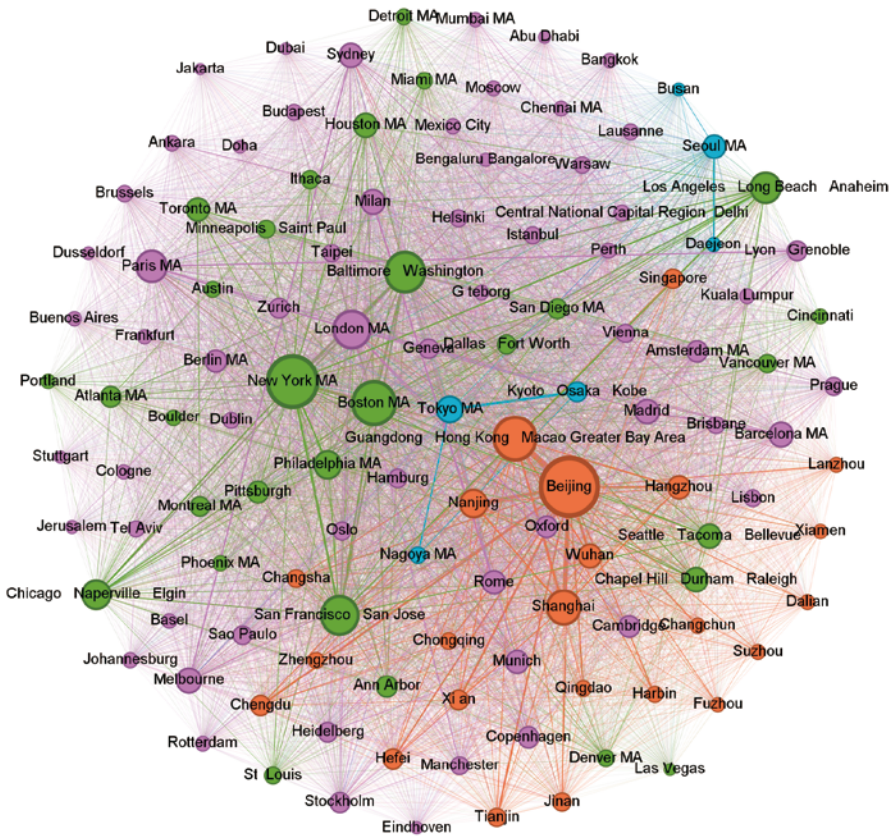
Based on data from 2023, this report analyses the paper co-authorship among cities across disciplines and the patent cooperation in AI, smart chips, biomedicine and renewable energy technology, to reveal the structure of the knowledge and technology cooperation network for GIHs. The node size indicates the importance and impact of a city/metropolitan area in the network, reflecting how active and important it is in research cooperation and innovation. The thickness of the connecting lines measures the closeness of cooperation among the cities/metropolitan areas, revealing which cities are more closely and frequently engaged in cooperation.

Figure 32 visualizes the GIHI paper co-authorship network. This high-density cooperation network consists of two core sub-networks: one centred on Chinese cities such as Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, Shanghai and Nanjing, the other centred on US cities such as New York MA, Boston MA, Baltimore-Washington and San Francisco-San Jose.

Cities in the United States and China prefer local-oriented cooperation, while European cities mostly cooperate with cities in Europe and the United States. The top ten cities that Beijing, Guangdong-Hong Kong-Macao Greater Bay Area and Shanghai co-authored papers with are all in China, suggesting a strong tendency towards domestic collaboration. Although New York MA plays an important role in global cooperation, London MA is the only overseas city in the top ten that it partners with. London MA features a more

FIGURE 32

The GIHs paper co-authorship network (2023)



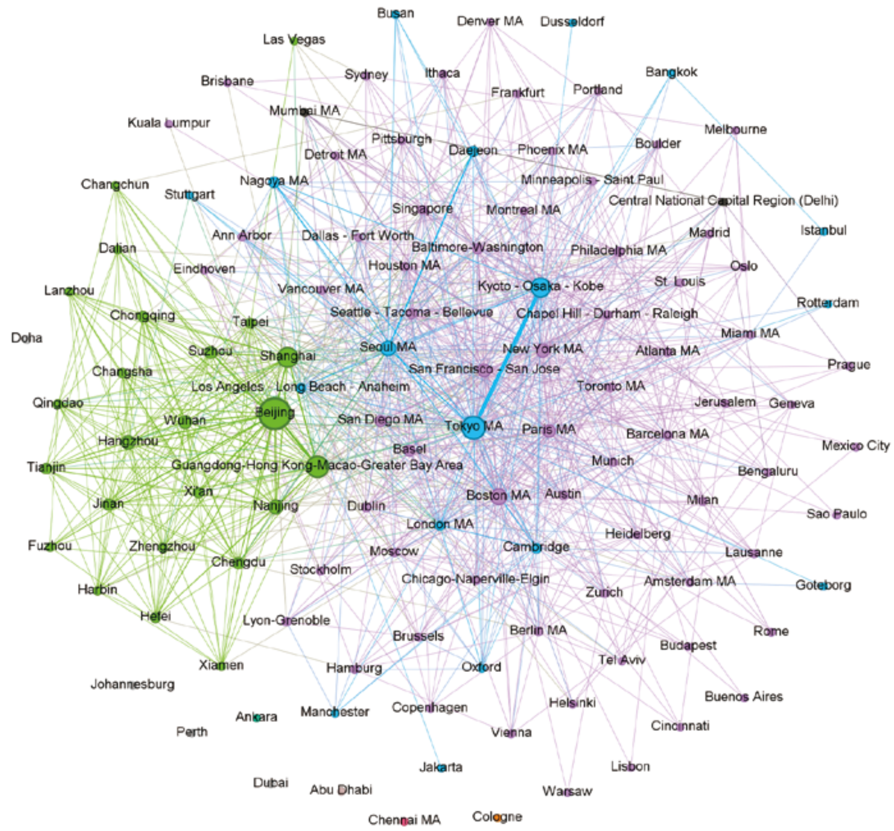
international pattern of cooperation with top ten collaborators including New York MA, Boston MA, Paris MA and Barcelona. Asian cities such as Tokyo MA and Seoul MA actively collaborate with cities in China, the United States and Europe, while maintaining a close partnership with cities from the same country. In particular, Singapore has a close tie with Chinese cities on co-authored papers, with four of its top five partners being Chinese cities. Together, these partnerships contribute to a diversified global innovation network.

Figure 33 shows the patent collaboration network of GIHs and reveals the global trend of patent technology flow and knowledge sharing. San Francisco-San Jose, New York MA, Boston MA, Tokyo MA and Paris MA, as the top five cities/metropolitan areas in network centrality, form the heartland of international technological innovation and cooperation. San Francisco-San Jose plays a pivotal role in AI, smart chips and biomedicine. It has close partnerships with Boston MA, New York MA, Tokyo MA, Seoul MA, Paris MA and Guangdong-Hong Kong-Macao Greater Bay Area. Tokyo MA acts as a core node in the cooperation network for both AI and smart chips and collaborates with cities such as Kyoto-Osaka-Kobe, Seoul MA, Nagoya, London MA, Los Angeles-Long Beach-Anaheim. In China, 15 cities, including Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, Shanghai, Hangzhou and Nanjing, work together closely, especially in renewable energy. Their strong ability in innovation has driven technical transformation and knowledge dissemination both within the region and beyond.

Although the overall density of the technical cooperation network is not high, its degree of internationalization is impressive. Network hubs such as San Francisco-San Jose, Tokyo MA and Paris MA have partnerships all over the world, forming an extensive network. Although more than 90% of cooperation for Chinese cities take place within the country, these cities also have stable 'twin city' cooperation with their global counterparts, especially in AI and smart chips. These twin cities include Beijing and San Francisco-San Jose, Guangdong-Hong Kong-Macao Greater Bay Area and Dallas-Fort Worth, Shanghai and Tokyo MA, and Nanjing and Seoul MA.

FIGURE 33

The GIHs patent collaboration network (2023)



5.Innovation ecosystem

Due to geopolitical tensions and trade protectionism, the total amount of foreign investment in the cities declined by about 4% in 2023 and there were regional differences. Although FDI in Europe and North America fell by about 38%, Asia bucked the trend with an increase of 46%. Cities such as Kuala Lumpur, Shanghai, Tokyo MA, Dubai and Mumbai in particular have experienced significant increases. Figure 34 shows a comparison of the top 20 cities/metropolitan areas in FDI for 2022 and 2023. Singapore, London MA, Dubai, Shanghai and Mumbai are the top five destinations for FDI investment. Many multinational companies are turning to southeast Asia and south Asia, especially Singapore, Malaysia and India, to boost the resilience of supply chains and reduce labour costs. This shows that global enterprises are seeking more diversified and stable supply chains and the vitality and potential of Asia has helped it become a popular destination for global investment.

Figure 35 shows the top 20 cities/metropolitan areas for OFDI in 2022 and 2023. In 2023, Guangdong-Hong Kong-Macao Greater Bay Area, London MA, Abu Dhabi, Beijing and Paris MA made up the top five. Chinese cities, such as Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, Hangzhou and Shanghai, have shown strong growth momentum, suggesting that China is transforming into a capital exporter. Chinese companies, such as Zhejiang Geely Holding Group and Xinyi Glass Holdings Limited are making strategic cross-border investments to secure the resources needed in key industries, including electric vehicles and renewable energy. Mubadala Investment Company in Abu Dhabi, which was the world's largest foreign investor in 2023, with a capital investment of US$ 41.8 billion, focuses on accelerating the economic transformation in the United Arab Emirates through AI innovation in areas such as health care and space technology. These investment patterns reflect the shared focus and strategies that global investors have for future industries.

FIGURE 34 A comparison of the foreign direct investment (FDI) in the top 20 cities/metropolitan areas between 2022-2023

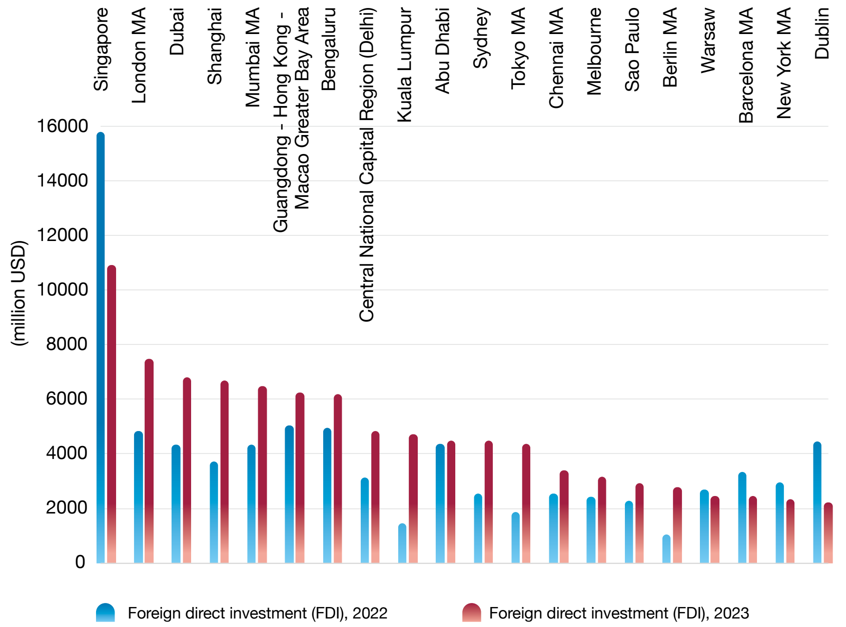
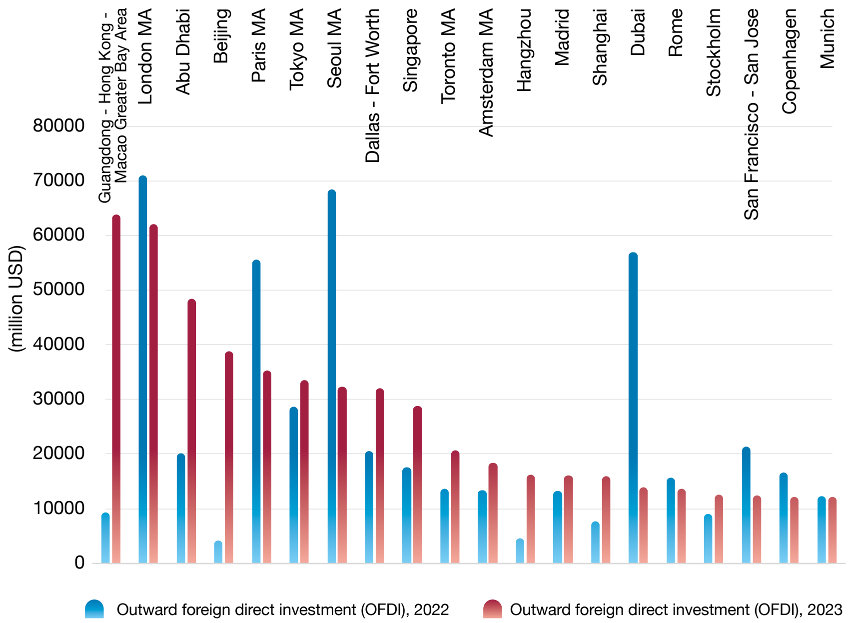


FIGURE 35 A comparison of the outward foreign direct investment (OFDI) in the top 20 cities/ metropolitan areas between 2022-2023



5.3
Support for start-ups

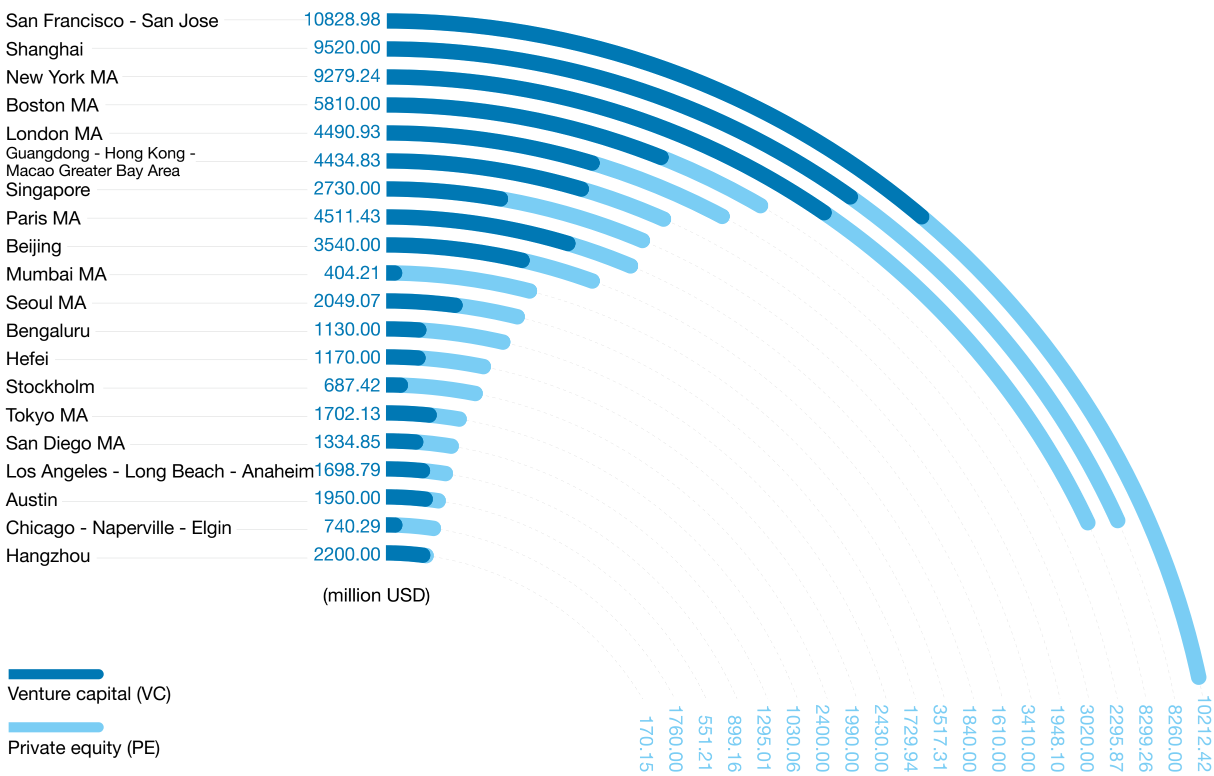
Support for start-ups provides the resources and environment needed to incubate start-ups and is a cornerstone for promoting innovation and entrepreneurship. This report evaluates the capital and business environment that drives local innovation and entrepreneurship by measuring the amount of VC and PE investment and the number of registered lawyers (per million people).

The top five cities/metropolitan areas in support for start-ups are San Francisco-San Jose, New York MA, Shanghai, London MA and Boston MA. Among the top 20 cities/metropolitan areas, Europe dominates the list taking eight spots. German cities/metropolitan areas such as Munich, Düsseldorf and Cologne rank high in the number of registered lawyers per capita, indicating a high level of legal services and rule of law in these regions, which help create the best business environment. VC activity in Asian cities such as Shanghai, Singapore, Beijing and Guangdong-Hong Kong-Macao Greater Bay Area are robust overall.

Figure 36 shows the total amount of VC and PE in the top 20 cities/metropolitan areas in support for start-ups. The core cities can be divided into three echelons based on the amount of total investment: San Francisco-San Jose, Shanghai and New York MA lead the way with more than US$15 billion in venture capital, forming the first echelon; Boston MA, London MA, Guangdong-Hong Kong-Macao Greater Bay Area, Singapore, Paris MA and Beijing are in the second echelon with US$ 5–10 billion in VC. Other cities/metropolitan areas belong to the third echelon. As the trends indicated, the global VC market declined significantly in 2023. The total amount of VC and PE investment in the assessed cities shrank by nearly 40% and only 22 of them had an increase in the total amount of financing. Some cities such as Hefei, Pittsburgh, Perth, Lyon-Grenoble and Mumbai saw significant growth, with Hefei and Pittsburgh growing by 1.5 times and 3.5 times in total financing, respectively. Hefei's growth was driven by its strong development in some key sectors, including semiconductors, biomedicine and new energy. For example, technological breakthroughs in dynamic random-access memory helped ChangXin Memory Technologies secure US$ 1.993 billion of financing in 2023. Pittsburgh, with its strengths in autonomous systems and advanced manufacturing technologies, has attracted a large amount of technology talent from Silicon Valley and is emerging as a global robotics hub. In particular, the city gains plenty of VC in hardware and robotics, represented by autonomous driving companies such as Stack AV and Aurora.

FIGURE 36

The top 20 cities/metropolitan areas in total venture capital (VC) and private equity (PE) investment



5.Innovation ecosystem

5.4 Public services

Urban public services provide infrastructure support for technology companies and innovators, which help stabilize the innovation environment. The GIHI2024 uses the number of data centres (public clouds), broadband connection speed, the number of international flights (per million people) and the level of e-governance to measure the maturity of infrastructure and the convenience of daily life.

The top five cities/metropolitan areas in public services are London MA, Amsterdam MA, Dubai, Copenhagen and Singapore. Among the top 20 cities/metropolitan areas, eight are in Europe, six are in the United States and six are in Asia.

Figure 37 shows that London MA is first on the list with 218 data centres, thanks to market demand and its sophisticated cooling technology and energy management systems. Paris had 17 new data centres in the past year, which was attributed to the French government's focus on future industries and especially the construction of digital

FIGURE 37 **Numbers of international flights (per million people) and that of data centres (public clouds) for the top 20 GIHs in public services**

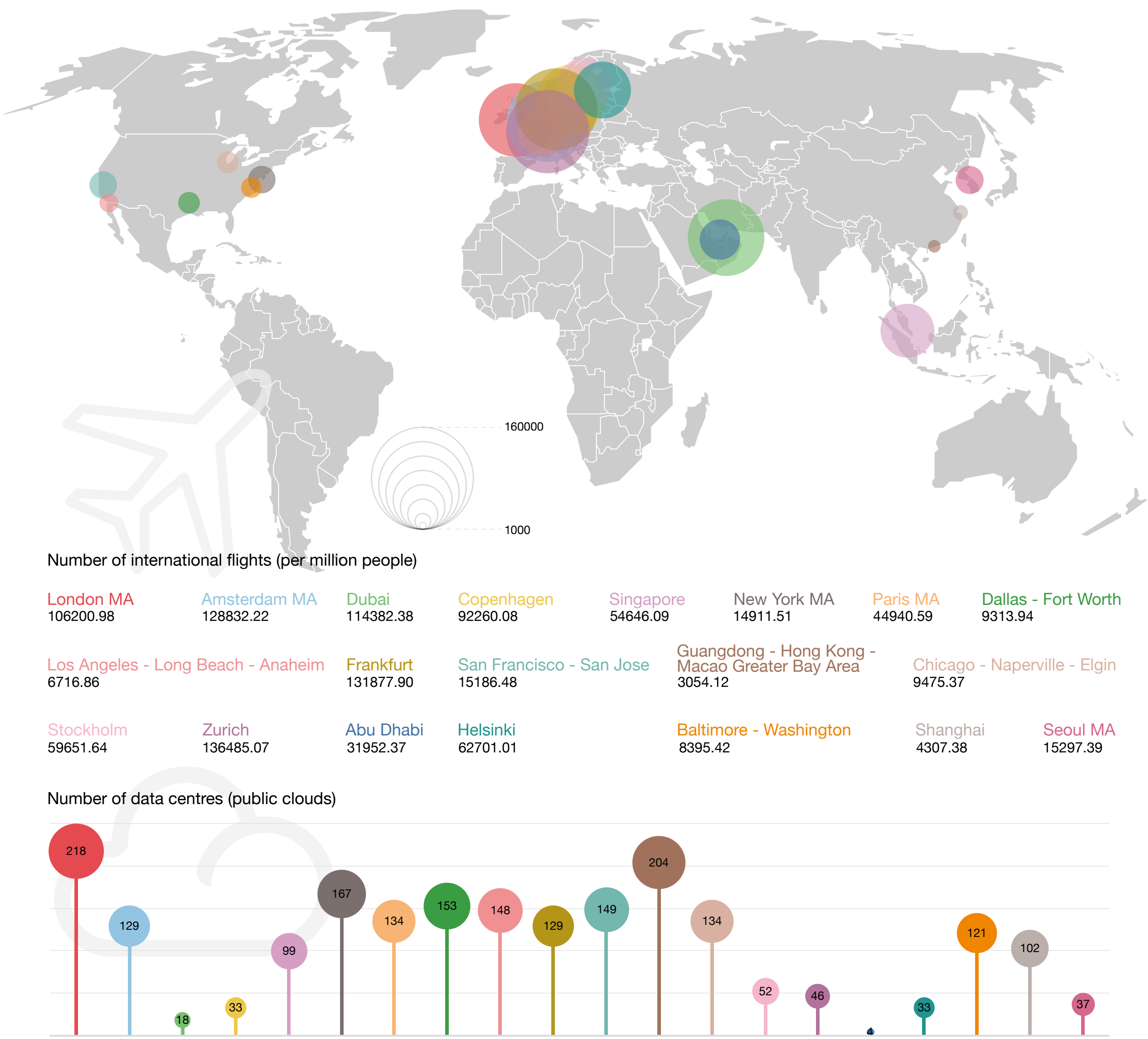
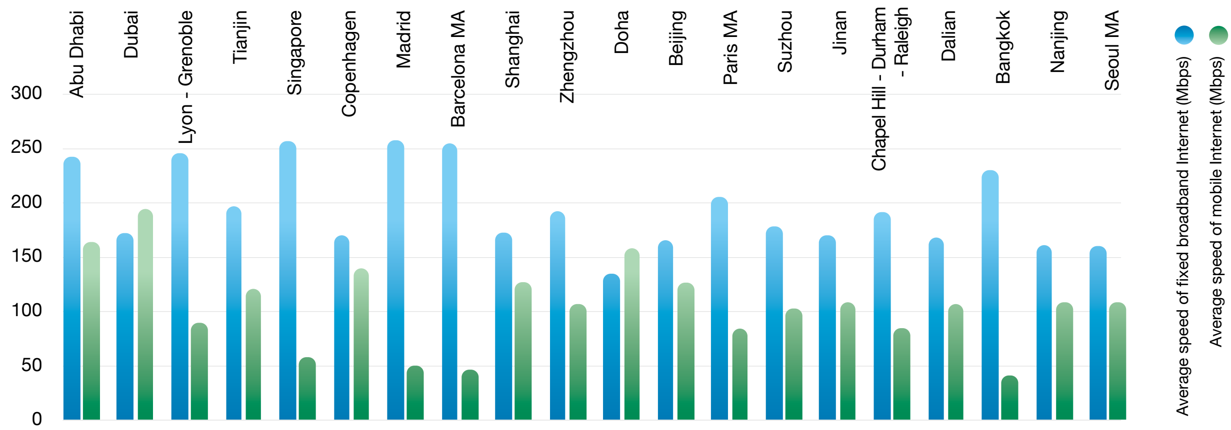


FIGURE 38

Average speed of fixed broadband Internet and of mobile Internet for the top 20 GIHs in public services



infrastructure driven by its Choose France initiative. Meanwhile, the investment and expansion of global data centre operators in Paris MA, such as NTT and Equinix, have also played a key role in meeting the growing demand for data processing in France and the rest of Europe. The United States is the world's largest market for Internet and technology and the demand for data traffic and storage has led to a large number of data centres. The operational needs of Internet giants and the needs of enterprises have further promoted the quantity and expansion of data centres.

The demand for air travel has picked up worldwide since the COVID-19 pandemic and the number of international flights from the assessed cities increased by 25.2% in 2023 compared to 2022. The Asian market was particularly robust and the number of flights increased by 69.6% in 2023, and although international flights have recovered significantly for Chinese cities, they have not reached pre-pandemic levels. London MA, Paris MA, Istanbul, Amsterdam MA and Dubai are the top five cities/metropolitan areas for number of international flights. They act as aviation hubs in the global airline network and support international exchanges.

In terms of the fixed broadband speed and mobile network speed, the performance of European and Asian cities has been balanced. As shown in Figure 38, cities such as Madrid, Singapore, Barcelona, Lyon-Grenoble and Abu Dhabi excel in fixed broadband speed. Cities including Dubai, Abu Dhabi, Doha, Copenhagen and Stockholm rank high in mobile network speed. Several cities in China have generally performed well in mobile network speed, with Shanghai, Beijing and Tianjin offering speeds of over 120 Mbps. In addition, Tianjin, Zhengzhou and Suzhou also outperform in fixed broadband speed.

5.5 Innovation culture

Innovation culture is a catalyst for urban development. It not only stimulates the vitality of a city, but also provides a platform and resources for innovators and can empower a city with sustainable competitiveness. The GIHI2024 measures a city's innovation culture by examining the professional talent inflow (per million people), residents' average years of schooling and the number of public museums and libraries (per million people).

The top five cities/metropolitan areas in innovation culture are London MA, Hamburg, Helsinki, Toronto MA and Dubai. Among the top 20 cities, only Dubai and Abu Dhabi in the United Arab Emirates are Asian cities, the rest are from Europe or the United States. European cities/metropolitan areas generally perform well. Six European cities rank in the top ten in residents' average years of schooling, seven European cities rank in the top ten in the number of public museums and libraries (per million people). Hamburg and London MA are in the top five for both indicators. These European cities have long been centres of culture, education and arts, with residents having a high level of literacy and education and a high demand for public cultural facilities. In recent years, the European Union has focused on cultural and creative sectors, which boosts a city's culture of innovation and provides the foundation for sustainable development.

Dubai, Abu Dhabi, Toronto MA, Austin and London MA are the top five cities in professional talent inflow (per million people). The immigration policies in these cities generally determine how attractive they are to international talent. The United Arab Emirates has introduced open immigration policies and tax incentives, making it one of the largest recipients of foreign labour in the world, with 96% of employees in the tech industry being immigrants. Bengaluru, as the digital hub of India, gathers nearly half of India's research and development workforce, ranking tenth in this indicator. Compared to 2022, 70% of the assessed cities have had significant increases in professional talent inflow, which indicates the recovery of global economy and an increased demand for high-level talent.

6. Summary

GIHI2024 is based on three dimensions: research innovation, innovation economy and innovation ecosystem. The selection of measurements includes a variety of factors, such as tradition and future prospects, science and technology, economy and social progress, performance and environment. The goal is to identify important factors that affect the performance of GIHs and explore the elements that contribute to successful innovation.

GIHs have been key drivers for the recovery of the global economy since the COVID-19 pandemic. In the global innovation landscape, cities in Europe and the United States still lead the world, while Asian cities are experiencing robust growth in research innovation and innovation ecosystem. Competition among leading cities has intensified, especially in the innovation economy and innovation ecosystem rankings. Bay areas have shown they have a clear advantage, with San Francisco Bay Area, New York Bay Area, Guangdong-Hong Kong-Macao Greater Bay Area and Tokyo Bay Area all ranking among the top ten and each demonstrating a distinct development pattern. For example, the boom in AI has allowed San Francisco Bay Area to stay well ahead in the rankings. Four development patterns have been identified in the top 20 cities and the overview of their performance show that the capability to innovate in science is the main force behind leading GIHs. There are also a number of mini-hubs that have become 'outperformers', driving innovation by leveraging their advantages in specific fields.

Asia is catching up quickly in the sub-indicators of research innovation through significant investment in scientific infrastructure. In innovation economy, the market value of high-tech manufacturing enterprises keeps growing as the global economy continues to recover. The United States still dominates in innovation economy, although Asian cities have accelerated the growth of their digital economy. In innovation ecosystem, the strong growth in foreign investment and financing has allowed leading Asian cities to overtake their counterparts. Global demand for air travel continues to revive and the inflow of professional talent into GIHs has seen a notable increase. Although global capital flows have slowed, the flow of capital and resources resulting from the restructuring of the global supply chain has provided emerging markets with high levels of capital mobility and resilience.

Research is increasingly taking the form of 'big science' with enhanced cooperation worldwide. The three disciplines that have the highest degree of international collaboration are physical sciences, earth sciences and environmental sciences. Biomedical and clinical research is one of the hot fields for international cooperation. The most influential cities/metropolitan areas play a leading role in academic cooperation and it is on the rise. It is notable that growth in international cooperation in Beijing and the Guangdong-Hong Kong-Macao Greater Bay Area has been on the increase even during the COVID-19 pandemic.

Global innovation in biomedicine has seen renewed growth since 2020. The United States, Europe, Japan and China are leading in this area. Advancements in AI and materials sciences have facilitated cross-sector innovation in biomedicine. Based on national research institutions, leading innovation ecosystems, and the global collaboration network led by multinational companies, GIHs have developed diverse innovation patterns. In the future, breakthroughs in biomedicine will rely on large scientific facilities, the integration of cross-disciplinary technology and venture capital.

As the global economy faces a mix of challenges and opportunities, GIHs are set to play a more important role in supporting economic recovery, promoting human well-being and addressing global challenges. Uncertainties are driving an adjustment to globalization and bringing challenges such as geopolitical tensions, supply chain restructuring, climate crisis and energy transition. The rise of emerging technologies is providing strong support for economic recovery and transformation, especially advancement in AI, quantum computing and green technology. Global economic growth will depend on technological innovation, digital transformation and international cooperation. GIHs will play a vital role in ensuring the vitality of the global economy by spearheading technological breakthroughs, strengthening supply chains and participating in global governance and cooperation.

The global innovation network is dynamic and evolving and the index system needs to be further improved. We invite evaluators, practitioners and policymakers across the world who have read this report to make comments and suggestions so that this can be achieved.

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Appendix

Appendix I: Adjustments to the GIHI Indicators

GIHI2024	Adjustments	Details
06.Number of top 500 supercomputers	Data source	As China no longer reports its supercomputer list to the Global Top 500 Supercomputers, GIHI 2024 used data from the 2023 China High-Performance Computer Performance TOP100 list, in addition to the list of top 500 supercomputers.
09.Total number of valid patents (per million people)	Statistical connotation	Adjustment of patent search strategy: patent data was collected from the four fields of artificial intelligence, smart chips, biomedicine and renewable energy technology, with reference to the classification systems defined in the Key Digital Technology Patent Classification System (2023) and the Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021).
10.Number of Patent Cooperation Treaty (PCT) patents	Statistical connotation	Adjustment of patent search strategy: patent data was collected from the four fields of artificial intelligence, smart chips, biomedicine, and renewable energy technology, with reference to the classification systems defined in the Key Digital Technology Patent Classification System (2023) and the Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021). The statistical period has been changed to a single year.
18.Patent collaboration network centrality	Statistical connotation	Adjustment of patent search strategy: After the adjustment, patent data was collected from the four fields of artificial intelligence, smart chips, biomedicine, and renewable energy technology, with reference to the classification systems defined in the Key Digital Technology Patent Classification System (2023) and the Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021).
25.Broadband connection speed	Data source	The source of fixed broadband speed has been changed from Testmy.net to Speedtest to be consistent with the source of mobile network speed data.

Appendix II: GIHI indicator definitions and data sources

A.Research Innovation

01. Number of active researchers (per million people)

Definition: The number of researchers who had publications between 2019 and 2023 per million people in the assessed city. If a researcher had more than one publication during this period, he/she will be counted only once.
Data sources: Digital Science – Dimensions

02. Number of winners of top scientific awards

Definition: The top scientific awards refer to Nobel prizes (excluding the prizes for literature and peace), the Fields Medal and the Turing Award. The winners are calculated according to the city where they currently work or live. About statistics: (1) the winners are identified on the official websites; (2) the city is determined by their current workplace or institution by using "biography" and "institution" in Wikipedia, and then summed up. Cities in which the winner works part time are all included.
Data sources: Turing Award website (https://amturing.acm.org/byyear.cfm); Nobel Prize website (https://www.nobelprize.org/); Fields Prize website (https://www.mathunion.org/imu-awards/fields-medal). Data as of 24 June 2024.

03. Number of world-leading universities

Definition: This study uses the number of top 200 universities in the Shanghai Ranking's Academic Ranking of World Universities (ARWU) 2023 to characterize a city's leading universities.
Data sources: Shanghai Ranking's Academic Ranking of World Universities (ARWU) 2023 (https://www.shanghairanking.cn/rankings/arwu/2023)

04. Number of top 200 world-class research institutions

Definition: The number of top 200 scientific institutions in scientific publications according to the Nature Index 2023. For affiliated institutions located in different cities, we use Nature Index's signature metric, Share, to measure if the affiliated institution has met the criteria of being the top 200 scientific institutions. With a Share higher than the 200th institution, the affiliated institution is counted, otherwise not. A description of how the Share is calculated is available here: https://www.nature.com/articles/d41586-020-02580-2.
Data sources: Nature Index

05. Number of large scientific facilities

Definition: The number of large scientific facilities in the assessed city. The large scientific facilities counted in this report include two major categories: dedicated research installations, including research installations built for major science and technology goals in specific disciplinary fields; and public experimental platforms, including large public experimental installations with strong support capabilities for basic, applied basic research and applied research in multidisciplinary fields. Those fields include energy, materials, geography, astronomy, biology, environment, nuclear physics and high-energy physics. To ensure the independence of indicators, the large scientific facilities do not include supercomputers or scientific installations with supercomputer characteristics.
Data sources: Data are collected from various plans of large scientific facilities in different countries, the official websites of the main management agencies of the facilities and relevant literature, which are then confirmed and supplemented by experts from various departments organized by Tsinghua University.

06. Number of top 500 supercomputers

Definition: A supercomputer is a computer consisting of hundreds or more processors that can process large and complex tasks that cannot be performed using ordinary PCs and servers. This study assesses the level of development of IT science facilities in each city by measuring the number of the world's top 500 supercomputers. As China no longer reports its supercomputer list to the Global Top 500 Supercomputers, the GIHI 2024 also includes the data from the 2023 China High-Performance Computer Performance TOP100 list.
Data sources: Global Top 500 Supercomputers, data as of November 2023 (https://www.top500.org/statistics/sublist/) and the 2023 China High-Performance Computer Performance TOP100 list (http://www.hpc100.cn/top100/22/).

07. Number of highly cited papers

Definition: The number of the top 1% of highly cited papers of each discipline between 2000 and 2022. If a paper is in the top 1% of highly cited papers in several disciplines, it is counted only once.
Data sources: Digital Science – Dimensions

08. Total citations from patents, policy reports and clinical trials

Definition: Total citations of scientific papers published in the city between 2019 and 2023 from patents, policy reports and clinical trials, an indicator that looks at the impact of scientific papers outside the academic community and the level of knowledge transfer.
Data sources: Digital Science – Dimensions

B.Innovation Economy

09. Total number of valid patents (per million people)

Definition: This indicator focuses on the stock of valid patents, which are patents that are still in force after the patent application has been granted (the patent is still within the legal

term of protection and the patentee is required to have paid the required annual fee). This year's research is based on the Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021) and the Key Digital Technology Patent Classification System (2023), which respectively count the number of patents in the four technology fields of artificial intelligence (AI), smart chips, biomedicine and renewable energy that were valid on 1 January 2023. Among them, AI, biomedicine and renewable energy refer to the Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021) and smart chips refer to the Key Digital Technology Patent Classification System (2023). AI mainly includes fields of AI hardware platforms, general AI technology and AI technology; AI chips mainly include fields of graphics processing units, field-programmable gate arrays, application-specific integrated circuits, brain-inspired chips and neural processing units; biomedicine mainly includes fields of biopharmaceutical manufacturing, genetic engineering drug and vaccine manufacturing, chemical drug raw materials, and preparation manufacturing; renewable energy mainly includes fields of nuclear power, wind energy, solar energy, smart grids, biomass energy and other new energy industries. After data search, consolidation according to the Derwent patent family, data cleaning and processing, 403,586 patents in AI, 301,762 patents in smart chips, 487,279 patents in biomedicine, and 298,185 patents in renewable energy were obtained.
Data sources: Derwent Innovation patent database

10. Number of PCT patents

Definition: The report focuses on patent filing internationally published under the Patent Cooperation Treaty (PCT). This year's study statistically analysed PCT patent data published in 2023 in the four technology fields of artificial intelligence, smart chips, biomedicine and renewable energy.
This study relies on the Derwent Innovation patent data platform and refers to the patent classification systems in the 'Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021)' and the Key Digital Technology Patent Classification System (2023) to statistically analyse the patent performance of the four technology fields of AI, smart chips, biomedicine and renewable energy, as described above in the category of Total number of valid patents (per million people). The search discovered 17,382 PCT patents in the field of AI, 42,548 PCT patents in the field of smart chips, 23,737 PCT patents in the field of biomedicine and 9,908 PCT patents in the field of renewable energy.
Data sources: Derwent Innovation patent database.

11. Number of leading innovative companies

Definition: This study combined the top 2,500 companies in research and development (R&D) investment in 2022 published by the EU Industrial R&D Investment Scoreboard 2023, Derwent Top 100 Global Innovators 2023, and Fortune Global 500 2023 (only science and technology enterprises are included) to rank enterprises in evaluated cities as an indicator of the enterprises' ability to drive innovation and spillover effect to surrounding regions.
Data sources: The EU Industrial R&D Investment Scoreboard, 2023; Top 100 Global Innovators 2023 by Clarivate; Fortune Global 500, 2023.

12. Number of unicorn companies

Definition: Unicorn is the term used to refer to start-ups that are valued at $1 billion or more that have existed for a relatively short period of time (typically within a decade) and have not been listed. This study combined the Complete List of Unicorn Companies 2023 by CB Insights and the 2023 Hurun Global Unicorn List. By removing duplicated companies, 1,453 unicorn companies in the assessed cities have been included in the scope of this report.
Data sources: Complete List of Unicorn Companies published by CB Insights (https://www.cbinsights.com/research-unicorn-companies), data as of 29 April, 2024; 2023 Hurun Global Unicorn List (https://www.hurun.cn/zh-CN/Rank/HsRankDetails?pagetype=unicorn).

13. Market value of high-tech manufacturing companies

Definition: This study evaluates innovative companies by calculating the market capitalization of high-tech manufacturing companies in the 2024 Forbes Global 2000 list by cities/metropolitan areas. Forbes is one of the four most important magazines in the financial industry. The Forbes 2000 list is based on four indicators: sales, profit, assets and market value. This report classifies high-tech manufacturing enterprises according to the secondary industries of the Global Industry Classification Standard, divided into three categories: pharmaceutical and chemical enterprises, electronic information enterprises and high-end manufacturing enterprises. Pharmaceutical and chemical enterprises include chemistry, biomedicine, health-care equipment and services enterprises; electronic information enterprises include companies engaged in IT software and services, semiconductors, technology hardware and equipment and telecommunications; and high-end manufacturing companies include those engaged in aerospace and defence, materials and transportations.
Data sources: Forbes Website (https://www.forbes.com/lists/global2000)

14. Revenue of listed companies in new economy industries

Definition: The new economy industry is a forward-looking industry that has high human capital investment, high-tech investment, light assets, and sustainable and rapid growth. In this report, new economy industries refer to information technology, communication services and health-care industries. The specific industry codes and sub-industries are shown in the table below. The measurement indicator is 2023 operating incomes of the listed companies in new economy industries of the cities.

45 Information technology	4510 Software and services	451020	IT services
		451030	Software
	4520 Technical hardware and equipment	452010	Communications equipment
		452020	Technical hardware, storage and peripherals
		452030	Electronic equipment, instruments and parts
	4530 Semiconductors and semiconductor equipment	453010	Semiconductors and semiconductor equipment
50 Communication services	5010 Telecommunications services	501010	Diversified information services
		501020	Radio telecommunication services
35 Health care	3510 Health care equipment and services	351010	Health care equipment and supplies
		351020	Health care providers and services
		351030	Health care technology
	3520 Pharmaceuticals, biotechnology and life sciences	352010	Biotechnology
		352020	Pharmaceuticals
		352030	Life science tools and services

Data sources:
Osiris, an online database of publicly listed companies worldwide

15. GDP growth rate

Definition: This study uses the GDP growth rate in 2022 calculated from the purchasing power parity of 2015 for each city (using 2015 as the real GDP base). To eliminate the effect of differences in prices among countries on the purchasing power of different currencies and the effect of price changes on GDP, this study uses the GDP deflator of each country to convert nominal GDP into real GDP that takes 2015 as the base year. The GDP growth rate is then calculated using GDP time series data in US$ that are generated based on the constant prices and purchasing power in 2015. Due to missing data, the GDP growth rate for 2021 are used for Mexico City, Vienna, Helsinki, Lyon-Grenoble, Paris MA, Berlin MA, Cologne, Dusseldorf, Frankfurt, Hamburg, Heidelberg, Munich, Stuttgart, Dublin, Milan, Rome, Amsterdam MA, Eindhoven, Rotterdam, Oslo, Warsaw, Barcelona MA, Madrid, Göteborg, Stockholm, Basel, Geneva, Lausanne, Zurich, Mumbai, Kyoto–Osaka–Kobe, Nagoya MA, Seoul MA, and Sao Paulo; the GDP growth rates for 2020 are used for Montreal MA, Toronto MA, Vancouver MA, Bangkok,and Doha.

Data sources: GDP data are from statistics offices of countries and cities, such as the National Bureau of Statistics of China, the United States Bureau of Economic Analysis, Eurostat and the Organisation for Economic Co-operation and Development (OECD); purchasing power parities (PPP) index and GDP deflator are from the World Bank.

16. Labour productivity

Definition: The output per unit of labour, calculated as gross regional product (GRP) divided by the population of working age. The GDP used in this study is the GDP-PPP data for 2022 (based on 2015). The size of workforce refers to the population aged from 15 to 64 in each city. When no data is directly available, estimations are made based on the demographic structure of the country or state/province that the city is located in and the total population of the city.
Data sources: workforce data collected from departments of statistics for each country and city.

C. Innovation ecosystem

17. Paper co-authorship network centrality

Definition: Co-authorship of a paper means two or more researchers work together to write and publish a scientific paper. The paper co-authorship network centrality reflects the openness and internationalization of a city's scientific research and this study calculates the eigenvector centrality of each city to measure the importance of a node in the paper co-authorship network based on the 2023 intercity paper publication collaboration matrix of the 120 evaluated cities. The importance of a node in the eigenvector centrality depends on the number of neighbouring nodes (the degree of the node) and the importance of the neighbouring nodes, which provides a more accurate representation of the node's position in the network. The eigenvector centrality calculates the centrality of a node based on the centrality of neighboring nodes and the eigenvector centrality of node i is $Ax = \lambda x$ where A is the adjacency matrix of a graph G with the eigenvalue λ. For information about the calculation of the eigenvector centrality, see the following link: https://networkx.github.io/documentation/stable/reference/algorithms/generated/networkx.algorithms.centrality.eigenvector_centrality_numpy.html?highlight=eigenvector_centrality_numpy
Data sources: Digital Science – Dimensions

18. Patent collaboration network centrality

Definition: Patent collaboration is the joint filing of patent applications by two or more researchers or organizations. This study is based on the combination and deduplication of data of stock valid patents (2023) and PCT public patents. It has constructed the technology collaboration network of an assessed city on the basis of joint filing on artificial intelligence, intelligent chips, biomedicine and renewable energy, to examine the patent cooperation network centrality of metropolitan areas, and to reflect the range of cooperation of each GIH. It is calculated as shown below:

Appendix

$$C_i = \sum_{j=1}^{n} D_{ij}, D_{ij} = 0 \text{ or } 1$$

Data sources: Derwent Innovation patent database.

19. Foreign direct investment (FDI)

Definition: This study measures a city's attraction to foreign investment by its foreign direct investment (FDI) in greenfield projects in 2023. Greenfield investment refers to enterprises in which part or all of their assets are owned by foreign investors in accordance with the laws of the host country.
Data sources: fDi markets, an online database of cross-border greenfield investments (https://www.fdimarkets.com/).

20. Outward foreign direct investment (OFDI)

Definition: The total amount of Outward Foreign Direct Investment (OFDI) made by companies located in the assessed city in 2023, which measures the spillover effects of a city's capital.
Data sources: fDi markets, an online database of cross-border greenfield investments (https://www.fdimarkets.com/).

21. Venture capital investment (VC)

Definition: This study measures the venture capital (VC) activities by measuring the amount of venture capital investment received in 2023, defined as the total financing amount in seed, angel, series A and series B rounds in the early stages of a company's development.
Data sources: CB Insights (https://www.cbinsights.com/)

22. Private Equity (PE)

Definition: Private Equity (PE) refers to the growth capital received during the pre-initial public offering (IPO) period of a proposed public company. In this study, the investment activity is measured by the total amount of private equity investment in 2023. PE investment is calculated as the total of financing rounds from series C, series D, series E+, growth equity and private equity.
Data sources: CB Insights (https://www.cbinsights.com/)

23. Number of registered lawyers (per million people)

Definition: The number of registered lawyers per million people in an assessed city in 2022. In this study, the number of registered lawyers is used to evaluate a city's entrepreneurial ecosystem. When data is not directly available, we use data from the state or province where the city belongs. For Budapest, Jakarta, Jerusalem, Tel Aviv, Kuala Lumpur, Bangkok and Doha, the country/region-level data are used instead; for Toronto MA, Vancouver MA, Heidelberg, Eindhoven, Bengaluru, Central National Capital Region (Delhi), Chennai, Mumbai MA, Kyoto-Osaka-Kobe, Nagoya MA, Tokyo MA, Brisbane, Melbourne, Perth, Sydney, Buenos Aires and Sao Paulo, data from the state or province are used instead.
Data sources: lawyer associations in countries and cities; ministries of justice in countries.

24. Number of data centres (public clouds)

Definition: Data centre hosting is an outsourced data centre solution where small and medium-sized companies with limited corporate IT resources often choose to host data centres to expand their data centre capacity rather than build their own data centres to save costs. In this study, the number of colocation data centres in the city is used to measure the city's digital economy growth.
Data sources: Cloudscene (https://cloudscene.com) data as of 7 May 2024.

25. Broadband connection speed

Definition: Broadband connection speed refers to the maximum theoretical rate that can be achieved by a network broadband technology which uses the 'fixed broadband Internet speed' and 'mobile Internet speed' to measure the broadband transmission service capacity of a city. This study uses the average upload and download rates (Mbps).
Data sources: Speedtest (https://www.speedtest.net) on 6 May 2024.

26. Number of international flights (per million people)

Definition: The number of all direct flights departing from and arriving at the city in 2023.
Data sources: Official Aviation Guide, an aviation intelligence provider (https://www.oag.com/)

27. E-governance level

Definition: This study uses the E-Government Development Index (EGDI) published by the Department of Economic and Social Affairs at the United Nations to examine global development of e-government and to reflect the status of data governance. EGDI is based on a survey, which examines official websites in countries, including national portals, online service portals and e-participation portals. The 2022 Online Services Questionnaire consists of 180 yes/no questions about institutional framework, service provision, content provision, technology and e-participation.
Data sources: E-Government Development Index (EGDI) 2022 from the United Nations (https://publicadministration.un.org/egovkb/en-us/Reports/UN-E-Government-Survey-2022)

28. Professional talent inflow (per million people)

Definition: In this study, the professional talent inflow into the assessed city, as recorded on LinkedIn Talent Insights between May 2023 and May 2024 is used to measure the attraction of the city/metropolitan areas to talents. For Dublin, Moscow, Busan, Daejeon, Seoul MA, Dubai, Abu Dhabi and Doha, as the data is unavailable at the city level, the indicator is estimated using the proportion of citizens in the country/region and the talent inflow into that country/region. As LinkedIn shut down its China platform in October 2021, the data for mainland Chinese cities in 2023 is collected from Zhaopin.com.
Data sources: Zhaopin.com; LinkedIn Talent Insights (https://business.linkedin.com/talent-solutions/talent-insights), a dataset that is based on the integrated information submitted by LinkedIn

members voluntarily, and the accuracy of data is not committed by LinkedIn. Data as of 20 May 2024.

29. Residents' average years of schooling

Definition: The average years of schooling for people aged over 25 in an assessed city. The average years of schooling in 2021 from the Subnational Human Development Index (HDI) published by the United Nations Development Programme are used to measure a city's education quality and human resources.
Data sources: Global Data Lab

30. Number of public museums and libraries (per million people)

Definition: In this study, the number of public museums and libraries in a city/metropolitan area that were open in 2023 is used to measure the public service environment for arts and culture in a city.
Data sources: public museums: official museum directories, official tourism welcome pages, platforms for museum-goers and web maps; and public libraries: official statistical yearbooks or bulletins, official library websites, government websites, official tourism welcome pages and web maps (including the number of libraries open to the public excluding university libraries).

Appendix III: Data standardization

There are differences in the data dimensions of the GIHI indicators, so we need to standardize the raw data of all the indicators first. This report uses the Z-Score, with the formula shown as below:

$$y_{ij}^{s} = \frac{x_{ij} - \bar{x}_i}{Std(x_i)}$$

y_{ij}^{s} is the standardized value of the Z-Score for the i-th level-3 indicator for city j. x_{ij} is the raw data for the i-th level-3 indicator for city j. $\bar{x}_i$ is the mean of the raw data for the i-th level-3 indicator for all cities and $Std(x_i)$ is the standard deviation of the raw data for the i-th level-3 indicator for all cities. All indicators are turned dimensionless. The mean value of the treated indicators is 0 and the standard deviation is 1.

The Z-Score for each of the three levels of indicators are linearly weighted by the indicator weights to calculate the Z-Score for their level-1 indicators and the GIHI index Z-Scores. Since there are zero and negative values in the Z-Score, to make the final score clearer and more intuitive, this report uses min-max normalization on the basis of the Z-Score to map the evaluated cities' scores to the [0,1] range.

$$Y_{aj}^{n} = \frac{X_{aj} - X_{min}}{X_{max} - X_{min}}$$

Y_{aj}^{n} is the min-max normalized value of the Z-Score for the a-th level-1 indicator for city j. X_{aj} is the Z-Score for the a-th level-1 indicator for city j. X_{min} is the minimum Z-Score for the a-th level-1 indicator for all cities. X_{max} is the maximum Z-Score for the a-th level-1 indicator for all cities.

Based on this, this report sets the base score of the evaluated cities to 60 so that the combined score of the level-1 indicators and GIHI indicators is [60,100] i.e. the first-ranked city scores 100 points and the last-ranked city scores 60 points.

The scores for level-1 indicators are shown in the following formula and the final scores for the three level-1 indicators for city j (A, B and C) are as follows Y_{Aj}, Y_{Bj}, Y_{Cj}.

$$Y_{Aj} = 60 + Y_{Aj}^{n} * 40$$

$$Y_{Bj} = 60 + Y_{Bj}^{n} * 40$$

$$Y_{Cj} = 60 + Y_{Cj}^{n} * 40$$

The GIHI composite score is Y_j, which is the result of the min-max normalization of city j based on the weighted Z-Score of all level-3 indicators and mapped to [60,100]. The formula of Y_j is as follows:

$$Y_j^{s} = \sum_{i=1}^{n} w_i y_{ij}^{s}$$

$$Y_j = 60 + \left(\frac{Y_j^{s} - Y_{min}}{Y_{max} - Y_{min}}\right) * 40$$

Y_j^{s} is the GIHI Z-Score for the sum of city j's level-3 indicators. w_i is the weight of the i-th level-3 indicator. y_{ij}^{s} is the standardized value of the Z-Score for the i-th level-3 indicator of city j, where n=30, indicating the number of level-3 indicators; i=1 means starting from the first level-3 indicator.

Appendix IV: The GIH selection process

In this report, cities/metropolitan areas were selected via the following steps: first we counted the cities in the science cities in the Nature Index — Science Cities 2023, the 2023 Global Cities Index by Kearney, the WIPO Global Innovation Index 2023 and those in the Innovation Cities™ Index 2023 by 2thinknow. We then selected the top 50 cities/metropolitan areas and those that rank below 50 but feature in at least two of the four lists as the final 120 cities/metropolitan areas to be assessed. Among them, there were 12 cities/metropolitan areas with a population of less than 1 million and these were evaluated separately as mini-hubs. The remaining 108 cities/metropolitan areas were included in the main list for assessment.

These 120 cities/metropolitan areas are from 38 countries/regions in six continents, covering 374 major administrative cities. Among them, there are 44 Asian cities, 38 European cities, 31 North American cities, four Oceanian cities, two South American cities and one African city.

Appendix

Appendix V: **Scope of administrative divisions of GIHs**

No.	City/metropolitan area	Administrative division	Country/region
1	Montreal MA	Montréal	Canada
		Laval	Canada
		Longueuil	Canada
2	Toronto MA	Toronto	Canada
		Oshawa	Canada
		Vaughan	Canada
		Richmond Hill	Canada
		Burlington	Canada
		Markham	Canada
		Brampton	Canada
		Mississauga	Canada
		Oakville	Canada
		Milton	Canada
3	Vancouver MA	Vancouver	Canada
		Surrey	Canada
		Burnaby	Canada
		Richmond	Canada
		Delta	Canada
4	Mexico City	Mexico City	Mexico
5	Ann Arbor	Ann Arbor	United States
6	Atlanta MA	Sandy Springs	United States
		Atlanta	United States
		Athens	United States
7	Austin	Austin	United States
8	Baltimore-Washington	Baltimore	United States
		Washington D.C.	United States
		Arlington	United States
		Alexandria	United States
9	Boston MA	Lowell	United States
		Cambridge	United States
		Boston	United States
10	Boulder	Boulder	United States
11	Chapel Hill-Durham-Raleigh	Chapel Hill	United States
		Durham	United States
		Raleigh	United States
12	Chicago-Naperville-Elgin	Naperville	United States
		Chicago	United States
		Aurora	United States
		Joliet	United States
13	Cincinnati	Cincinnati	United States
14	Dallas-Fort Worth	Plano	United States
		Frisco	United States
		Irving	United States
		Arlington	United States
		Richardson	United States
		Fort Worth	United States
		Dallas	United States
		Denton	United States
		Lewisville	United States
		Carrollton	United States
		Mesquite	United States
15	Denver MA	Denver	United States
		Aurora	United States
		Lakewood	United States
		Arvada	United States
		Westminster	United States
		Centennial	United States
16	Detroit MA	Detroit	United States
		Warren	United States

17	Houston MA	Houston	United States
		Pearland	United States
		Pasadena	United States
18	Ithaca	Ithaca	United States
19	Las Vegas	Las Vegas	United States
20	Los Angeles-Long Beach-Anaheim	Torrance	United States
		Santa Ana	United States
		Rancho Cucamonga	United States
		Pomona	United States
		Pasadena	United States
		Orange	United States
		Los Angeles	United States
		Long Beach	United States
		Huntington Beach	United States
		Glendale	United States
		Fullerton	United States
		El Monte	United States
		Downey	United States
		Costa Mesa	United States
		Anaheim	United States
		Garden Grove	United States
		Ontario	United States
		Inglewood	United States
		Burbank	United States
21	Miami MA	Miami	United States
		Fort Lauderdale	United States
		Hollywood	United States
		Miramar	United States
		Pompano Beach	United States
		West Palm Beach	United States
		Davie	United States
		Pembroke Pines	United States
22	Minneapolis-Saint Paul	Minneapolis	United States
		Saint Paul	United States
23	New York MA	New York City	United States
		Staten Island	United States
		Paterson	United States
		Bridgeport	United States
		Edison	United States
		New Haven	United States
		Stamford	United States
		Brooklyn	United States
		The Bronx	United States
		Queens	United States
		Newark	United States
		Jersey City	United States
		Yonkers	United States
24	Philadelphia MA	Philadelphia	United States
25	Phoenix MA	Phoenix	United States
		Mesa	United States
		Chandler	United States
		Gilbert	United States
		Glendale	United States
		Scottsdale	United States
		Tempe	United States
26	Pittsburgh	Pittsburgh	United States

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27	Portland	Portland	United States
		Vancouver	United States
		Hillsboro	United States
28	San Diego MA	Vista	United States
		San Diego	United States
		Escondido	United States
		El Cajon	United States
		Chula Vista	United States
		Carlsbad	United States
29	San Francisco-San Jose	Berkeley	United States
		Concord	United States
		Antioch	United States
		San Jose	United States
		Fremont	United States
		Richmond	United States
		Santa Rosa	United States
		Oakland	United States
		Hayward	United States
		San Mateo	United States
		Vallejo	United States
		Santa Clara	United States
		San Francisco	United States
		Sunnyvale	United States
30	Seattle-Tacoma-Bellevue	Tacoma	United States
		Seattle	United States
		Renton	United States
		Kent	United States
		Everett	United States
		Bellevue	United States
31	St. Louis	St. Louis	United States
32	Vienna	Vienna	Austria
33	Brussels	Brussels	Belgium
34	Prague	Prague	Czech Republic
35	Copenhagen	Copenhagen	Denmark
36	Helsinki	Helsinki	Finland
		Espoo	Finland
		Vantaa	Finland
37	Lyon-Grenoble	Lyon	France
		Grenoble	France
		Villeurbanne	France
38	Paris MA	Paris	France
		Cergy-Pontoise	France
		Boulogne-Billancourt	France
		Saint-Quentin-en-Yvelines	France
39	Berlin MA	Berlin	Germany
		Potsdam	Germany
40	Cologne	Cologne	Germany
41	Dusseldorf	Dusseldorf	Germany
42	Frankfurt	Frankfurt	Germany
		Offenbach	Germany
43	Hamburg	Hamburg	Germany
44	Heidelberg	Heidelberg	Germany
45	Munich	Munich	Germany
46	Stuttgart	Stuttgart	Germany
47	Budapest	Budapest	Hungary
48	Dublin	Dublin	Ireland
49	Milan	Milan	Italy
		Monza	Italy
50	Rome	Rome	Italy

51	Amsterdam MA	Amsterdam	The Netherlands
		Hoofddorp	The Netherlands
		Haarlem	The Netherlands
		Almere Stad	The Netherlands
52	Eindhoven	Eindhoven	The Netherlands
53	Rotterdam	Rotterdam	The Netherlands
54	Oslo	Oslo	Norway
55	Warsaw	Warsaw	Poland
56	Lisbon	Lisbon	Portugal
		Amadora	Portugal
57	Moscow	Moscow	Russia
		Balashikha	Russia
		Korolev	Russia
58	Barcelona MA	Barcelona	Spain
		Badalona	Spain
59	Madrid	Madrid	Spain
		Móstoles	Spain
		Alcalá de Henares	Spain
		Fuenlabrada	Spain
		Leganés	Spain
		Getafe	Spain
		Alcobendas	Spain
60	Göteborg	Göteborg	Sweden
61	Stockholm	Stockholm	Sweden
		Sollentuna	Sweden
62	Basel	Basel	Switzerland
63	Geneva	Geneva	Switzerland
64	Lausanne	Lausanne	Switzerland
65	Zurich	Zurich	Switzerland
66	Cambridge	Cambridge	United Kingdom
67	London MA	London	United Kingdom
		Watford	United Kingdom
		Croydon	United Kingdom
		Enfield Town	United Kingdom
		Sutton	United Kingdom
68	Manchester	Manchester	United Kingdom
		Bolton	United Kingdom
		Stockport	United Kingdom
		Oldham	United Kingdom
69	Oxford	Oxford	United Kingdom
70	Beijing	Beijing	China
71	Changchun	Changchun	China
72	Changsha	Changsha	China
73	Chengdu	Chengdu	China
74	Chongqing	Chongqing	China
75	Dalian	Dalian	China
76	Fuzhou	Fuzhou	China
77	Guangdong-Hong Kong-Macao Greater Bay Area	Shenzhen	China
		Guangzhou	China
		Hong Kong	China
		Macao	China
		Zhuhai	China
		Foshan	China
		Huizhou	China
		Dongguan	China
		Zhongshan	China
		Jiangmen	China
		Zhaoqing	China
78	Hangzhou	Hangzhou	China
79	Harbin	Harbin	China

Appendix

80	Hefei	Hefei	China
81	Jinan	Jinan	China
82	Lanzhou	Lanzhou	China
83	Nanjing	Nanjing	China
84	Qingdao	Qingdao	China
85	Shanghai	Shanghai	China
86	Suzhou	Suzhou	China
87	Taipei	Taipei	China
88	Tianjin	Tianjin	China
89	Wuhan	Wuhan	China
90	Xiamen	Xiamen	China
91	Xi'an	Xi'an	China
92	Zhengzhou	Zhengzhou	China
93	Bengaluru	Bengaluru	India
94	Central National Capital Region Delhi MA	Delhi	India
		Faridabad	India
		Ghaziabad	India
		New Delhi	India
		Noida	India
		Greater Noida	India
		Gurgaon	India
95	Chennai MA	Chennai	India
96	Mumbai MA	Mumbai	India
		Navi Mumbai	India
		Kalyān	India
		Ulhasnagar	India
		Panvel	India
97	Jakarta	Jakarta	Indonesia
98	Jerusalem	Jerusalem	Israel
99	Tel Aviv	Tel Aviv	Israel
		Bnei Brak	Israel
		Ḥolon	Israel
		Ramat Gan	Israel
100	Kyoto-Osaka-Kobe	Kyoto	Japan
		Osaka	Japan
		Kobe	Japan
		Sakai	Japan
		Hirakata	Japan
		Toyonaka	Japan
		Takatsuki	Japan
		Suita	Japan
		Ibaraki	Japan
		Neyagawa	Japan
		Uji	Japan
		Izumi	Japan
		Moriguchi	Japan
		Matsubara	Japan
101	Nagoya MA	Nagoya	Japan
		Okazaki	Japan
		Inazawa	Japan
		Ichinomiya	Japan
		Anjō	Japan
		Kakamigahara	Japan
		Kasugai	Japan
		Komaki	Japan
		Gifu-shi	Japan
		Ōgaki	Japan
		Seto	Japan
		Toyota	Japan
		Kariya	Japan

102	Tokyo MA	Tokyo	Japan
		Asaka	Japan
		Zama	Japan
		Kamakura	Japan
		Chigasaki	Japan
		Hino	Japan
		Atsugi	Japan
		Fujisawa	Japan
		Noda	Japan
		Yokosuka	Japan
		Ichihara	Japan
		Kashiwa	Japan
		Chiba	Japan
		Sōka	Japan
		Saitama	Japan
		Koshigaya	Japan
		Abiko	Japan
		Ageoshimo	Japan
		Tokorozawa	Japan
		Kawasaki	Japan
		Matsudo	Japan
		Higashimurayama	Japan
		Musashino	Japan
		Sayama	Japan
		Yokohama	Japan
		Nagareyama	Japan
		Kawagoe	Japan
		Sakura	Japan
		Chōfu	Japan
		Machida	Japan
		Kawaguchi	Japan
		Isehara	Japan
		Kisarazu	Japan
		Hiratsuka	Japan
		Hachiōji	Japan
		Honchō	Japan
		Tama	Japan
103	Kuala Lumpur	Kuala Lumpur	Malaysia
		Klang	Malaysia
		Subang Jaya	Malaysia
		Petaling Jaya	Malaysia
		Shah Alam	Malaysia
		Sepang	Malaysia
104	Singapore	Singapore	Singapore
105	Busan	Busan	South Korea
106	Daejeon	Daejeon	South Korea
107	Seoul MA	Seoul	South Korea
		Osan	South Korea
		Seongnam-si	South Korea
		Guri-si	South Korea
		Goyang-si	South Korea
		Ansan-si	South Korea
		Suwon	South Korea
		Incheon	South Korea
		Hwaseong-si	South Korea
		Bucheon-si	South Korea
		Uijeongbu-si	South Korea
		Anyang-si	South Korea
		Hanam	South Korea
108	Bangkok	Bangkok	Thailand

109	Ankara	Ankara	Turkey
110	Istanbul	Istanbul	Turkey
		Maltepe	Turkey
111	Abu Dhabi	Abu Dhabi	United Arab Emirates
112	Dubai	Dubai	United Arab Emirates
113	Doha	Doha	State of Qatar
114	Brisbane	Brisbane	Australia
115	Melbourne	Melbourne	Australia
116	Perth	Perth	Australia
117	Sydney	Sydney	Australia
118	Buenos Aires	Buenos Aires	Argentina
119	Sao Paulo	Sao Paulo	Brazil
		São Bernardo do Campo	Brazil
		Santo André	Brazil
		Diadema	Brazil
		Barueri	Brazil
		São Caetano do Sul	Brazil
120	Johannesburg	Johannesburg	South Africa
		Soweto	South Africa
		Randburg	South Africa

Note: The 120 cities/metropolitan areas listed above are the major administrative cities in the geographic range which do not exactly overlap with the actual range of metropolitan areas. The GIHI generally adopts the same boundaries of metropolitan areas as the Nature Index.

Appendix VI: Measurement of development models

In order to reveal the characteristics of development patterns in different regions, and to comprehensively compare and evaluate the three level-1 indicators of cities/metropolitan areas this report measures development patterns. First, the Z-Score is used to standardize the raw data of the level-3 indicators and then the Z-Score of the level-1 indicators is obtained via linear weighting (see Appendix III for details). Second, to make the scores of the three level-1 indicators — research innovation, innovation economy and innovation ecosystem — comparable, the Z-Scores of the three level-1 indicators of the 108 evaluated cities were uniformly min-max normalized so that the scores of the evaluated cities were mapped to the [0,1] range. Finally, the score range of the level-1 indicators is set to [0,100] to calculate the scores of level-1 indicators for each evaluated city by taking the development patterns into consideration.

Appendix VII: Patent classification

1. Patent classification of AI technology

Field of technology	International patent classification	Description
Artificial intelligence	G06F40*, A61B5/0476, A61B5/0478	
	G05B15/02, G06K9/66, G07C9/00, G08B19/00, G08B25/10	Information system integration services such as AI systems for production areas and smart home systems
	G05D1/02, G05D1/08, G05D1/10, G05D1/12, G06F1/16	Wearable smart device manufacturing, intelligent unmanned aerial vehicle manufacturing, digital home intelligent terminal equipment, intelligent sensing and control equipment and other smart consumer device manufacturing, financial electronic application products
	G06F3/01	Wearable smart device manufacturing, intelligent unmanned aerial vehicle manufacturing, digital home intelligent terminal equipment, intelligent sensing and control equipment and other smart consumer device manufacturing, financial electronic application products, information system integration services such as AI systems for production areas and smart home systems, AI for operation system, AI middleware, artificial function library, development of application as computer vision and audition software, biometrics software
	G06F9/44, G06F9/455, G06N3/00, G06N3/04, G06N3/06, G06N3/063, G06N3/067, G06N3/10, G06N3/12, G06N5/00, G06N5/02, G06N5/04	AI for operating system, AI middleware, AI function library, development of application as computer vision and audition software, biometrics software
	G06K9/00, G06K9/62, G06N3/02, G06N3/08	Information system integration services such as AI systems for production areas and smart home systems, AI for operation system, AI middleware, AI function library, development of applications such as computer vision and audition software, biometrics software
	A61B5* (excluding A61B5/0476, A61B5/0478), G16H	Keywords of brain structures and brain diseases such as the human brain, amygdala, epilepsy

Source: China National Intellectual Property Administration, Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021)

2. Patent classification of smart chip technology

Field of technology		International patent classification	Description
Smart chip		G06K7*, G06K9*, G06K17*, G06K19*,G06N*, G06T1*, G06T3*,G06T5*, G06T7*, G06T11*, G06T15*, G06V*, G16B*, G16C*, G16H*, H01L21* , H01L23*, H01L25*, H01L27*, H05K1*, H05K3*	Graphic processing units (GPUs), field programmable gate arrays (FPGAs), application-specific integrated circuits (ASIC), security operations centres (SOCs), complex programmable logic devices (CPLDs), smart integrated circuits, smart chips, AI chips, smart single-chip computers, GPUs, FPGAs, ASICs, SOC chips, neuro-inspired computing chips, etc.
	GPU	G06T1*, G06T3*, G06T5*, G06T7*, G06T11*, G06T15*	GPU, image processor, visual processor, display card chip, display chip, etc.
	FPGA	G05B19*	FPGAs, Field-programmable logic device, field-programmable logic gate array, etc.
	ASIC	G06F*, H01L21*, H01L23*, H01L25*, H01L27*, H03K*, H05K1*, H05K3*	ASIC, application-specific integrated circuit, application-specific large-scale integrated circuit, application-specific integrated chip, application-specific chip, etc.

Source: China National Intellectual Property Administration, Key Digital Technology Patent Classification System (2023)

3. Patent classification of renewable energy

Field of technology	International patent classification	Description
Nuclear power industry	G21C5*, G21C17/013, G21C17/017, G21C19*, G21C21*, G21C23*, G21D3*	
	E04G21*, E04H5*	Nuclear power transmission equipment engineering, nuclear power plant construction
	G21C1*, G21C9*, G21C11*, G21C13*, G21C15*, G21C17* (excluding G21C17/013, G21C17/017), G21D1*, G21D5*	Complete sets of equipment for advanced pressurized water reactor nuclear power plants with million-kilowatt capacity, fast neutron reactor and high temperature gas-cooled reactor nuclear power plants etc., nuclear power boilers and auxiliary equipment, emergency protection arrangements structurally associated with the reactor
	G21C3*, G21C7*, G21G1*	Processing of nuclear fuel, manufacturing of special equipment for uranium purification and conversion, uranium enrichment, etc.
Wind energy industry	F03D1*, F03D3*, F03D5*, F03D7*, F03D17*	
	E02D27*, F03D13*	Offshore wind turbine construction, offshore wind power equipment installation, wind farm construction
	F03D9*, F03D15*, F03D80*	Manufacturing of wind energy prime movers; manufacturing of generators and generator sets, such as onshore and offshore wind turbines
	H02J3/38, H02J3/44, H02J3/46, H02J3/48, H02J3/50	Wind power
Solar energy industry	F03G6* (excluding F03G6/00, F03G6/04, F03G6/06), F24S10*, F24S25* (excluding F24S25/00, F24S25/20, F24S25/30, F24S25/617, F24S25/70), F24S30*, F24S40*, F24S50*, F24S60*, F24S80*, F24S90*, H02J7/35, H02S10*, H02S20*, H02S30*, H02S40* (excluding H02S40/10, H02S40/12), H02S50*	
	C01B33/02	Silicon (forming single crystals or homogeneous polycrystalline material with defined structure)
	H01G9/042, H01G9/045, H01G9/052, H01G9/055, H01G9/06, H01G9/08, H01G9/10, H01G9/12, H01G9/20, H01L27/14, H01L51/42, H01L51/44, H01L51/46, H01L51/48	Perovskite, silane, high light use, heat-absorbing coating material, photovoltaic conductive glass, glass tubing for sealing with metal, graphite material for solar energy, getter, photovoltaic cell encapsulation material, cadmium telluride, special silver paste, photovoltaic cell material
	H01G9/04	Solar cell production equipment; Stirling generators; organic Rankine cycle power generation equipment; manufacturing of light and heat equipment and its components; manufacturing of solar power generation protection and control devices and equipment; manufacturing of photovoltaic equipment and components; solar batteries; solar battery charge and discharge controllers, solar energy storage materials and products, organic polymer electrodes

Appendix

Field of technology	International patent classification	Description
Solar energy industry	H01L31*	Solar energy prime movers, sliding parameter steam turbines, coating equipment for solar heat absorbing coatings, large-scale coating machines etc., manufacturing of pumps and vacuum equipment, high-strength curved mirrors, concentrators, concentrator field control devices, reducers for concentrators, controllers
	H02M7*	Sterling generators, organic Rankine cycle power generation equipment, multi-megawatt or tens megawatt-scale concentrated solar power systems and equipment, manufacturing of solar thermal equipment and components, manufacturing of protective control devices and equipment for solar power generation, battery charge and discharge controllers for solar energy
Biomass energy and other new energy industries	C10L5/44, F03B13/12, F03B13/14, F03B13/16, F03B13/18, F03B13/20, F03B13/22, F03B13/24, F03B13/26	
	A01F29*, F03B13/00, F03G4*, F23C10*, H02N11*	Equipment manufacturing for furnaces such as biomass combustion boilers, geothermal water treatment equipment, generators and generator sets for new energy sources such as geothermal or hydrogen energy equipment
	C10B53*	Equipment for the degradation and conversion of biomass, heating with biomass fuels, manufacturing and supply of bio-gas
	C10J3*	Equipment for producing hydrogen from biomass and microorganisms, biomass electricity generation, heating with biomass fuels, manufacturing and supply of bio-gas
	E02B3*, E02B9*(excluding E02B9/08)	Engineering of power transmission equipment for biomass and other new energy power generation, construction of biomass energy generation projects, other new energy construction projects, geothermal power generation and heat use projects, and hydrogen energy projects
	E02B9/08	Tide or wave power plants (water-pressure machines, tide or wave motors)
	F23G5*	Equipment manufacturing for furnaces such as biomass combustion boilers, heating with biomass fuels
	G01R31*(excluding G01R31/00, G01R31/08, G01R31/10, G01R31/11, G01R31/12, G01R31/14, G01R31/327, G01R31/333, G01R31/34, G01R31/36, G01R31/364, G01R31/367, G01R31/371, G01R31/374, G01R31/378, G01R31/379, G01R31/382, G01R31/3828, G01R31/3832, G01R31/3835, G01R31/3842, G01R31/385, G01R31/387, G01R31/388, G01R31/389, G01R31/392, G01R31/396, G01R31/40, G01R31/42, G01R31/50, G01R31/52, G01R31/54, G01R31/55, G01R31/56, G01R31/58, G01R31/62)	Maintenance of biomass power generation equipment, consulting services for biomass energy and other new energy sources, power generation project management, power generation project supervision, construction engineering surveys, technical promotion services, research and experimental development on engineering and technology such as biomass energy and other new energy sources, engineering design activities such as the design of biomass power generation construction projects

Field of technology	International patent classification	Description
Smart grid industry	G01R19*, G01R21*(excluding G01R21/127), G01R22*, G01R23*(excluding G01R23/173, G01R23/175, G01R23/177), G01R25*, G01R27*(excluding G01R27/12), G01R29*, G01R31/00, G01R31/08, G01R31/10, G01R31/11, G01R31/12, G01R31/14, G01R31/327, G01R31/333, G01R31/36, G01R31/364, G01R31/367, G01R31/371, G01R31/374, G01R31/378, G01R31/379, G01R31/382, G01R31/3828, G01R31/3832, G01R31/3835, G01R31/3842, G01R31/385, G01R31/387, G01R31/388, G01R31/389, G01R31/392, G01R31/396, G01R31/40, G01R31/42, G01R31/50, G01R31/52, G01R31/54, G01R31/55, G01R31/56, G01R31/58, G01R31/62, G01R33/00, H01B3*(excluding H01B3/02, H01B3/30), H01B5*(excluding H01B5/04), H01B7*(excluding H01B7/20, H01B7/24, H01B7/282, H01B7/32), H01B9*, H01B13*(excluding H01B13/016, H01B13/28), H01B17*(excluding H01B17/04, H01B17/12, H01B17/16, H01B17/18, H01B17/32, H01B17/46, H01B17/48, H01B17/54), H01B19*, H01F17*, H01F19*, H01F21*, H01F27*(excluding H01F27/18), H01F29*(excluding H01F29/08, H01F29/14), H01F30*, H01F36*, H01F37*, H01F38/20, H01F38/22, H01F38/24, H01F38/26, H01F38/28, H01F38/30, H01F38/32, H01F38/34, H01F38/36, H01F38/38, H01F38/40, H01F41/00, H01F41/02, H01F41/04, H01F41/06, H01F41/061, H01F41/063, H01F41/064, H01F41/066, H01F41/068, H01F41/069, H01F41/07, H01F41/071, H01F41/073, H01F41/074, H01F41/076, H01F41/077, H01F41/079, H01F41/08, H01F41/082, H01F41/084, H01F41/086, H01F41/088, H01F41/092, H01F41/096, H01F41/098, H01F41/10, H01F41/12	Manufacturing of transformers, rectifiers and inductors such as intelligent large-scale, DC converter transformers and intelligent reactors, manufacturing of intelligent power distribution systems, facilities and other power distribution switch control equipment, cross-linked polyethylene insulated power cables and cable accessories
	H01H31*, H01H33*, H01H45*, H01H47*, H01H50*, H01H51*, H01H57*, H01H59*, H01H61*, H01H69*, H01H71*(excluding H01H71/58), H01H73*, H01H75*, H01H77*, H01H79*, H01H81*, H01H83*, H01H85*(excluding H01H85/42), H01H87*, H01H89*, H02B1*(excluding H02B1/06), H02G1*, H02G7*(excluding H02G7/06), H02G9*(excluding H02G9/00), H02G13*, H02G15*(excluding H02G15/072), H02H1*, H02H3*(excluding H02H3/13), H02H5*, H02H6*, H02H7*, H02H9*, H02H11*, H02P1*, H02P3*(excluding H02P3/16), H02P5/00, H02P5/46, H02P5/49, H02P5/50, H02P5/505, H02P5/51, H02P5/52, H02P5/54, H02P5/56, H02P5/74, H02P5/747, H02P5/753, H02P6*, H02P13*(excluding H02P13/12), H02P21*, H02P23*, H02P25*(excluding H02P25/064, H02P25/12), H02P27*(excluding H02P27/06), H02P29*	Manufacture of power electronic components such as metal oxide semiconductor field effect transistors, insulated-gate bipolar transistor chips and modules
	H02B3*, H02B5*, H02B7*, H02B11*, H02B13*, H02B15*(excluding H02B15/04), H02J1*, H02J3*(excluding H02J3/38, H02J3/40, H02J3/42, H02J3/44, H02J3/46, H02J3/48, H02J3/50), H02J4*, H02J5*, H02J9*, H02J11*, H02J13*, H02J15*, H02J50*, H02M3*, H02M5*(excluding H02M5/297), H02M11*	Power supply: 750 kV or higher-class AC transmission, large-scale power grid protection and defence systems, and intelligent dispatching systems

Source: China National Intellectual Property Administration, Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021)

Appendix

4. Patent classification of biomedicine

Field of technology	International patent classification	Description
Biomedicine	A61K31*, A61K38*, A61K39*, A61K47*, A61K48*	Biological drug manufacturing, genetic engineering drug and vaccine manufacturing, pharmaceutical excipient and packaging material manufacturing, pharmaceutical special equipment manufacturing, medical device research, large-scale cultivation of vaccine antigens, basic research on vaccine antigen purification technology and other medical research and experimental development, laboratory equipment and reagent testing and monitoring services, biological laboratory and pharmaceutical production workshop design services, biological resource collection, preservation and utilization services for animals, technology promotion such as drug information, biological treatment services for severe and incurable diseases, genetic testing services
	A61K33*, C07J*	Manufacture of chemical raw materials and preparations
	A61K9*, C07K*	Biological drug manufacturing, genetic engineering drug and vaccine manufacturing
	A61P*, C07C*(excluding C07C1*, C07C2/00, C07C2/30, C07C4/02, C07C4/12, C07C4/22, C07C5/333, C07C6/04, C07C7/13, C07C7/177, C07C9/10, C07C9/21, C07C9/22, C07C11*, C07C13/12, C07C13/20, C07C13/50, C07C13/68, C07C15*, C07C21/14, C07C27*, C07C29*, C07C31*, C07C35/28, C07C35/36, C07C37/18, C07C37/84, C07C39/23, C07C41/28, C07C41/40, C07C41/44, C07C43*, C07C45/49, C07C47/02, C07C49/00, C07C49/205, C07C49/258, C07C49/573, C07C49/713, C07C51*, C07C55/12, C07C59/00, C07C59/11, C07C61/13, C07C63/24, C07C63/38, C07C67*, C07C69*, C07C71/00, C07C203/00, C07C205/05, C07C209/22, C07C209/44, C07C211*, C07C215*, C07C217/14, C07C217/30, C07C217/76, C07C219/08, C07C219/10, C07C229/68, C07C231*, C07C233*, C07C235*, C07C237/32, C07C245/14, C07C251/20, C07C251/22, C07C253*, C07C255/20, C07C255/55, C07C269/02, C07C271/02, C07C271/68, C07C275/06, C07C275/10, C07C309*, C07C311/06, C07C311/49, C07C313/28, C07C319*, C07C323/41, C07C333/20, C07C403/16, C07C409/08, C07C409/12), C07D*(excluding C07D201*, C07D207/335, C07D209/76, C07D211*, C07D213*, C07D215*, C07D223*, C07D235*, C07D239*, C07D243/04, C07D249*, C07D251/38, C07D255/04, C07D277/84, C07D279/32, C07D293/12, C07D295/037, C07D295/10, C07D301*, C07D307*, C07D311/26, C07D311/68, C07D313*, C07D317*, C07D319*, C07D329*, C07D333/10, C07D333/78, C07D341/00, C07D401/00, C07D405*, C07D413/02, C07D421/14, C07D487*, C07D495/08)	Biological drug manufacturing, genetic engineering drug and vaccine manufacturing, manufacture of chemical raw materials and preparations, pharmaceutical excipient and packaging material manufacturing, pharmaceutical special equipment manufacturing, medical device research, large-scale cultivation of vaccine antigens, basic research on vaccine antigen purification technology, and other medical research and experimental development, laboratory equipment and reagent testing and monitoring services, biological laboratory and pharmaceutical production workshop design services, biological resource collection, preservation and utilization services for animals, technology promotion such as drug information, biological treatment services for severe and incurable diseases, genetic testing services
	C12Q1/68, C12Q1/70	Genetic testing services

Source: China National Intellectual Property Administration, Classification of Strategic Emerging Industries and International Patent Classification Cross-Reference Table (2021)

Global Innovation Hubs Index, GIHI

The Global Innovation Hubs Index (GIHI), developed by the Center for Industrial Development and Environmental Governance (CIDEG) at Tsinghua University, with data services and translation support from Nature Research Intelligence, has been tracking and analysing year-on-year changes and the latest trends in global innovation since 2020. The GIHI is an index system that applies scientific, objective, independent and impartial principles in evaluating GIHs by their innovation capability and growth potentials, providing a reference for public policy-makers and innovation practitioners.

About us

The Center for Industrial Development and Environmental Governance (CIDEG) founded in 2005 at Tsinghua University, is a leading think tank in China. We focus on public policy research and academic exchanges in the areas of industrial development, environmental governance, and institutional change. Our mission is to improve the quality of research and education on public policy and governance in China, and to foster communication, understanding, and coordination among academics, industrial communities, non-governmental organizations, and government departments.

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