Global Innovation Hubs Index 2023

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Executive Summary

Global innovation and development in 2023 was clouded by uncertainties. The digital economy is one of the few economic sectors that is booming in an ever-changing world. Innovation, however, remains an important engine for economic growth. In a time of rapid change, global innovation hubs (GIHs) have shown new characteristics. 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 GIHI2023 continues to apply scientific, objective, independent and impartial principles in evaluating 119 GIHs by three indicators known as research innovation, innovation economy, and innovation ecosystem, providing a reference for policy-makers, entrepreneurs, and practitioners.

The GIHI2023 has expanded its assessment scope in the following ways:

First, the number of evaluated cities has increased from 100 to 119, which includes 108 global innovation hubs and 11 mini-hubs. Although accounting for only 11.28% of the world's total population, these 119 cities/metropolitan areas are home to the top innovation resources in the world, boasting 134 world-leading universities, 150 of the top 200 world-class research institutions, 1,373 unicorn companies (which are individually valued at more than US$1 billion), and 1,847 leading innovative enterprises. They have attracted 280 winners of top scientific awards including Nobel prizes, the Turing Award and the Fields Medal.

Second, the GIHI2023 has added two sections on discipline hubs and artificial intelligence patents. Focusing on discipline hubs further explores the concept of knowledge creation in research innovation to better capture the knowledge creation capability and characteristics of the dominant disciplines of GIHs. In the artificial intelligence patents, the number of valid invention patents, the number of high-quality patents and technological strengths are used to compare GIHs in AI innovation capabilities and analyse their competitive edge.

The GIHI2023 comprehensively evaluates the GIHs using three dimensions – research innovation, innovation economy and innovation ecosystem. The assessment results are as follows:

The GIHI2023 top 20 cities/metropolitan areas overall are San Francisco-San Jose, New York MA, Beijing, London MA, Boston MA, Guangdong-Hong Kong-Macao Greater Bay Area, Tokyo MA, Baltimore-Washington, Paris MA, Shanghai, Seoul MA, Singapore, Los Angeles-Long Beach-Anaheim, Chicago-Naperville-Elgin, Seattle-Tacoma-Bellevue, Dallas-Fort Worth, Munich, San Diego MA, Chapel Hill-Durham-Raleigh and Zurich.

Overall, the GIHI2023 has drawn the following conclusions:

First, the international innovation landscape continues to move towards multipolarity, with European and American cities still taking the lead and Asian cities catching up rapidly to disrupt the previous bipolarity. The development characteristics of bay areas and mini-hubs are even more distinct. The innovation capability of Asian cities continues to improve and more Asian cities are included in the GIHI shortlist, highlighting the increasing multipolarity of the GIHs. More Chinese cities have become GIHs, with a total of 23 Chinese cities/metropolitan areas on the list in 2023, up by four from 2022. Bay area cities hold prominent advantages in innovation resource integration, with four of the top ten cities/metropolitan areas overall being bay areas. Each bay area displays its own innovation patterns, for example, San Francisco Bay Area is a strong performer in innovation economy and innovation ecosystem. New York Bay Area excels in research innovation owing to its profound research strength. Guangdong-Hong Kong-Macao Greater Bay Area and Tokyo Bay Area rank sixth and seventh and are seen as exemplars of Asia's innovation system. Mini-hubs with a population of less than one million are small and refined. The number of mini-hubs has increased to 11 in 2023, all of which are in Europe and North America except for Jerusalem in Asia.

Second, GIHs have strong agglomeration and spillover effects. San Francisco-San Jose, New York MA and Beijing exert strong agglomeration and spillover effects, which are embodied in the active flow of innovation resources. Large-scale aggregation of innovation resources provide solid support while spillover effects facilitate innovation and empowerment. As capital cities, London MA, Tokyo MA, Baltimore-Washington, Paris MA, and Seoul MA have stronger spillover effects than agglomeration capacity and they support and amplify innovation activities and results of other cities/metropolitan areas. Cities/metropolitan areas including Boston MA, Shanghai, and Singapore have demonstrated stronger agglomeration capacity than spillover effects, gathering a large amount of high-end innovation resources around the world and playing key roles in the global innovation network.

Third, Europe and the United States still lead the world in research innovation but Asian cities/metropolitan areas are gaining a competitive edge while trying to catch up. The top 20 includes 13 cities/metropolitan areas in Europe and the United States which have maintained their edge. The performance of the top 20 cities/metropolitan areas in research innovation are varied by each indicator. For example, New York MA ranks first and is leading in research innovation owing to its advantages in science

Executive Summary

and technology human resources and research institutions. Beijing, ranking second, has invested hugely in scientific infrastructure and is far ahead of other cities/metropolitan areas for this indicator. Boston MA and San Francisco-San Jose focus on the synergetic development of science and technology human resources and knowledge creation. Guangdong-Hong Kong-Macao Greater Bay Area has made major investments in research institutions in recent years and its performance in this single indicator is outstanding, placing it top in the world.

Fourth, in innovation economy, GIHs help strengthen global economic resilience despite the COVID-19 pandemic and the complex international landscape, serving as an important engine of global innovation. Overall, the 80-20 rule is even more evident in GIHs. The top 20 GIHs, including San Francisco-San Jose, Tokyo MA and New York MA are mostly located in the United States and Asia. Compared to the performance in last year's index, Dallas-Fort Worth and Chicago-Naperville-Elgin have made a leap in innovation capability thanks to their economic growth.

Fifth, in innovation ecosystem, cities across Europe and the United States lead the world with their well-established infrastructure, services and innovation culture, but Asian cities are gaining momentum by supporting emerging industries with incentive policies. Geographically, about 78% of the top 50 cities for innovation ecosystem are in Europe or the United States. European cities are on a par with American cities in innovation ecosystem. The former boast a rich innovation culture while the latter stay ahead in their support for start-ups and in openness and cooperation. Asian cities, such as Seoul MA, Guangdong-Hong Kong-Macao Greater Bay Area, Singapore, Dubai, Beijing and Shanghai, are among the top 20 and are rapidly rising in the global innovation ecosystem. These cities play an active role in the global network of openness and cooperation, provide support for start-ups and facilitate the expansion of the innovation ecosystem network. Overall, top GIHs usually have a good innovation ecosystem. Most cities, such as Dubai, London MA and Paris MA have recovered from the COVID-19 pandemic and rapid recovery of the aviation market has led to a boom in innovation.

Finally, the GIHI2023 features two new special focus sections: discipline hubs and artificial intelligence patents.

The global discipline hubs are primarily located in North America, East Asia and Western Europe. Cities in North America and Western Europe have comparative advantages in discipline-sourcing capability and discipline excellence. Regarding discipline-sourcing capability, San Francisco-San Jose, Boston MA and New York MA in the United States are in the top ten across all 22 disciplines. Notably, New York MA ranks first in eight disciplines. The discipline excellence of cities/metropolitan areas in North America and Western Europe is close to or above the global benchmark of 1%. Although the performance of emerging cities in East Asia still lag behind the global benchmark, these places are experiencing a period of quantitative change to qualitative change and stand out in some areas in discipline-sourcing capability. For example, Beijing is in the top ten in 15 disciplines and sits at the top in seven disciplines. Regarding disciplinary characteristics, cities in North America and Western Europe have relatively stronger discipline-sourcing capabilities in medicine, humanities, arts and social sciences, while cities in East Asia have made breakthroughs in science, technology, and engineering.

As AI technology continues to flourish, the frontier fields face the most intense competition. AI has seen explosive growth since 2020, with an average annual growth rate of 75.9%. Chinese cities, such as Beijing and Guangdong-Hong Kong-Macao Greater Bay Area, lead the world in the total number of valid invention patents, accounting for 14 spots in the top 20, and have become the main driving force of global AI technology. Tokyo MA is far ahead in high-quality patents. The percentage of high-quality patents is high in Europe and the United States. High-quality patents in cities/metropolitan areas, such as Tokyo MA, San Francisco-San Jose, Guangdong-Hong Kong-Macao Greater Bay Area, New York MA and Seoul MA, are highly concentrated, with large high-tech enterprises playing a leading role. As for the hottest fields within AI, neural networks and genetic algorithms, machine learning and computer vision technologies are booming and cities/metropolitan areas, such as Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, San Francisco-San Jose, Seoul MA and New York MA, have become the main driving forces. Technical advantages in AI vary widely across GIHs. For example, Tokyo MA and San Francisco-San Jose possess critical basic technologies in AI and are making progress on all fronts. Chinese cities are important drivers for neural networks and genetic algorithms, image recognition and speech recognition.

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Contents

Introduction

Scientific and technological innovation does not occur in a vacuum and although it has been affected by the intensification of geopolitical tensions around the world, the technology sector is seeing continued growth. Digital technologies, such as artificial intelligence, cloud computing, 5G and virtual reality are developing quickly and have become key driving forces of scientific and technological innovation, reshaping the global innovation landscape.

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 global innovation value and provides information for policy-makers about the development of GIHs.

We continue to uphold the principles of being scientific, objective, independent and impartial that we established when developing the GIHI2020 report, while taking into account the feedback and suggestions of industry experts, media and the public. Some adjustments have been made to the assessment scope, the index system, and data samples as follows:

First, we have expanded the scope of our assessment to include more cities. To better reveal the latest trends and changes in cities' innovation patterns, the number of cities evaluated has increased from 100 in 2022 to 119 in 2023, including 108 global innovation hubs (GIHs) and 11 mini-hubs, resulting in a significant increase in the scope of administrative divisions, percentage of the global population, as well as the number of world-leading research institutions, scientists and leading innovation enterprises included in the assessment.

Second, we have added two focus sections – discipline hubs and artificial intelligence (AI) patents, to reveal the latest trends in the world's scientific and technological development. In the discipline hubs, based on the conceptual model of the GIHI, the concept of knowledge creation in research innovation is further explored to better capture the discipline-sourcing capability, overall performance in academic research and disciplinary characteristics of assessed cities. In AI patents, the number of valid invention patents and the number of high-quality patents – defined as patent cooperation treaty (PCT) patents and triadic patents (those filed in patent offices in the United States, Japan and Europe) – are used to compare AI innovation capabilities and competitive edge in different GIHs.

Third, the index system has been optimized to improve its scientific rigor. We have deleted the duplicated indicator of the 'percentage of highly cited scientists' to improve the assessment of research innovation and replaced percentage-based indicators with value/scale-based indicators. For example, the 'percentage of highly cited papers' has been replaced with the 'number of highly cited papers' and the 'proportion of papers cited in patents, policy reports and clinical trials' has been replaced with 'total citations in patents, policy reports and clinical trials'. We have also created a separate ranking for 'mini-hubs' that have a population of less than one million to reflect their distinct development patterns. Due to data availability, the 'number of creative talent (per million people)' has been replaced with 'residents' average years of schooling'. See Appendix I for a more detailed explanation of the adjustments to the indicators.

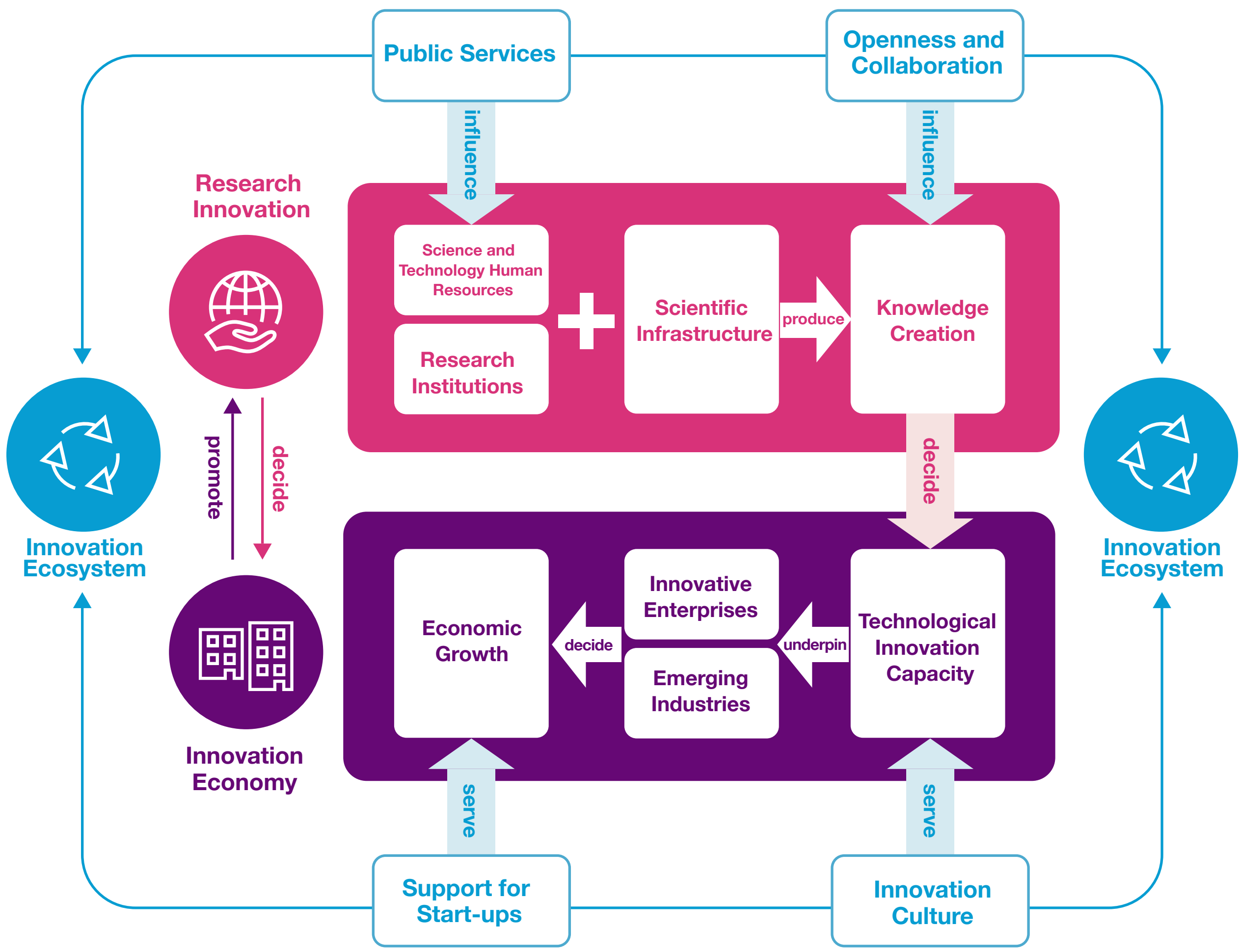
1. The index system

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 not only global science hubs, but also clusters 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 GIHI assessment is shown in Figure 1.

FIGURE 1

A conceptual model for GIHI 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 indicators	Level-1 indicator weight	Level-2 indicators	Level-2 indicator weight	Level-3 indicators
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 2022 Science Cities, the 2022 Global Cities Index by Kearney, the World Intellectual Property Organization (WIPO) Global Innovation Index 2022 and the Innovation Cities™ Index 2022 by 2ThinkNow. Cities/metropolitan areas with strong innovation capabilities were evaluated, which totaled 119 cities/metropolitan areas. Among these, 11 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 119 cities/metropolitan areas are from 37 countries in six continents, covering 373 major administrative divisions. Among them, there are 43 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 11.28% of the world's total population, these cities/metropolitan areas boast 134 world-leading universities, 150 of the top 200 world-class research institutions, 1,373 unicorn companies valued at more than US$1 billion and 1,847 leading innovative enterprises. They have attracted 280 winners of top scientific awards, including Nobel prizes, the Turing Award or the Fields Medal.

2. Overall GIHI ranking

2.1 Ranking results

The GIHI2023 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	93.43	4	100.00	1	100.00	1
New York MA	88.65	2	100.00	1	75.89	3	91.49	3
Beijing	83.18	3	94.66	2	75.74	4	79.24	11
London MA	82.11	4	84.68	6	68.31	17	98.80	2
Boston MA	81.13	5	94.41	3	70.92	7	80.08	8
Guangdong - Hong Kong - Macao Greater Bay Area	80.25	6	84.55	7	75.19	5	81.81	6
Tokyo MA	78.58	7	74.68	12	82.55	2	75.98	24
Baltimore - Washington	76.01	8	86.57	5	67.03	19	77.81	15
Paris MA	75.90	9	79.98	8	68.72	14	82.39	4
Shanghai	73.98	10	77.25	9	68.69	15	79.03	13
Seoul MA	73.92	11	70.61	17	71.50	6	82.10	5
Singapore	72.49	12	70.15	21	69.50	12	80.89	7
Los Angeles - Long Beach - Anaheim	71.86	13	75.88	10	66.59	22	76.69	20
Chicago - Naperville - Elgin	71.54	14	74.40	13	66.80	20	76.98	19
Seattle - Tacoma - Bellevue	70.72	15	68.80	29	69.61	11	76.24	23
Dallas - Fort Worth	70.33	16	65.25	57	70.40	8	77.80	16
Munich	70.26	17	70.59	18	66.66	21	77.26	17
San Diego MA	70.08	18	70.18	20	68.47	16	74.27	28
Chapel Hill - Durham - Raleigh	69.97	19	75.11	11	65.18	29	73.35	31
Zurich	69.28	20	72.50	14	64.99	32	74.32	27
Toronto MA	69.12	21	68.56	31	64.48	42	79.11	12
Austin	68.80	22	65.15	59	67.65	18	77.00	18
Amsterdam MA	68.41	23	68.25	32	63.23	77	79.03	14
Stockholm	68.36	24	70.52	19	64.81	36	73.73	30
Dublin	68.32	25	65.21	58	69.74	10	72.01	39
Phoenix MA	68.24	26	64.05	68	65.63	25	79.51	10
Kyoto - Osaka - Kobe	68.20	27	69.53	24	68.93	13	67.89	66
Taipei	67.82	28	66.59	44	70.22	9	67.96	65
Copenhagen	67.81	29	69.61	22	65.14	31	72.38	37
Atlanta MA	67.42	30	69.41	26	65.26	28	71.09	47
Houston MA	67.34	31	68.69	30	65.18	30	71.82	41

City/metropolitan area	Overall		Research innovation		Innovation economy		Innovation ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Helsinki	67.19	32	65.42	55	64.39	46	76.28	22
Philadelphia MA	66.97	33	69.25	27	64.94	34	70.26	50
Sydney	66.96	34	69.57	23	63.19	79	72.58	36
Pittsburgh	66.57	35	68.97	28	64.53	40	69.87	53
Denver MA	66.54	36	63.40	72	65.42	27	74.80	26
Nanjing	66.48	37	71.18	15	64.47	43	67.09	73
Vancouver MA	66.43	38	66.83	41	63.96	57	72.77	34
Melbourne	66.37	39	70.71	16	62.58	91	70.23	51
Oslo	66.20	40	66.48	45	63.62	67	72.94	32
Montreal MA	66.20	41	67.83	34	63.63	65	71.35	46
Madrid	66.07	42	65.54	50	61.80	102	76.39	21
Berlin MA	66.06	43	66.84	40	63.04	84	72.92	33
Miami MA	65.95	44	62.11	87	64.98	33	75.01	25
Kuala Lumpur	65.66	45	67.80	35	63.30	76	70.06	52
Hangzhou	65.62	46	65.88	47	66.20	23	67.57	69
Manchester	65.56	47	65.67	48	63.79	61	71.39	45
Rome	65.45	48	67.75	37	61.42	106	72.34	38
Minneapolis - Saint Paul	65.43	49	65.45	53	64.71	38	69.76	54
Wuhan	65.37	50	69.51	25	64.33	48	65.47	81
Brisbane	65.33	51	66.70	42	62.20	97	71.93	40
Tel Aviv	65.13	52	64.16	67	64.28	50	70.90	48
Frankfurt	65.12	53	63.23	75	62.87	87	74.17	29
Milan	65.11	54	67.23	38	62.71	89	69.74	56
Daejeon	65.09	55	67.79	36	64.85	35	65.66	80
Dubai	65.06	56	60.00	108	61.63	103	79.62	9
Perth	64.97	57	64.39	63	65.53	26	68.13	61
Lyon - Grenoble	64.95	58	65.05	61	64.41	45	69.05	57
Abu Dhabi	64.78	59	60.42	105	65.86	24	71.57	43
Barcelona MA	64.75	60	67.22	39	60.88	107	71.40	44
Hamburg	64.56	61	62.93	79	62.85	88	72.64	35
St. Louis	64.39	62	65.51	51	64.02	56	67.24	71
Nagoya MA	64.33	63	65.42	56	63.70	63	67.62	68
Lisbon	64.16	64	63.15	78	63.32	75	70.29	49
Moscow	64.10	65	65.43	54	63.74	62	66.79	75

2.Overall GIHI ranking

City/metropolitan area	Overall		Research innovation		Innovation economy		Innovation ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Chengdu	64.06	66	66.65	43	64.33	49	64.29	85
Dusseldorf	63.78	67	61.26	101	63.02	85	71.64	42
Portland	63.71	68	62.05	88	64.14	53	68.72	58
Hefei	63.69	69	66.09	46	64.10	54	64.03	87
Cincinnati	63.68	70	62.19	86	64.38	47	68.08	62
Bengaluru	63.56	71	61.48	97	64.53	41	68.27	60
Xi'an	63.55	72	68.12	33	62.55	92	63.63	90
Rotterdam	63.53	73	63.83	69	62.46	94	68.67	59
Vienna	63.47	74	65.59	49	61.88	100	67.36	70
Brussels	63.31	75	63.63	71	64.22	52	65.41	82
Tianjin	63.25	76	65.10	60	63.53	69	64.59	83
Warsaw	63.10	77	62.86	80	63.49	71	66.73	76
Göteborg	63.02	78	63.76	70	62.41	95	67.11	72
Cologne	63.02	79	63.40	73	62.10	99	68.01	64
Central National Capital Region Delhi MA	63.02	80	61.68	91	64.07	55	66.89	74
Suzhou	62.94	81	62.66	83	64.70	39	64.52	84
Las Vegas	62.92	82	60.11	107	64.26	51	68.08	63
Detroit MA	62.91	83	61.47	98	64.43	44	66.22	77
Mexico City	62.91	84	61.60	96	63.35	74	67.75	67
Changsha	62.89	85	65.48	52	63.20	78	63.44	91
Sao Paulo	62.88	86	64.33	64	60.00	108	69.76	55
Jinan	62.41	87	64.47	62	63.55	68	62.40	97
Prague	62.33	88	62.80	81	63.79	60	63.70	89
Busan	62.21	89	61.03	102	63.45	72	65.87	78
Stuttgart	62.20	90	61.65	93	63.08	83	65.70	79
Istanbul	62.18	91	61.63	95	64.71	37	63.10	94
Buenos Aires	62.13	92	62.37	85	63.38	73	64.14	86
Qingdao	61.87	93	61.64	94	63.85	59	63.37	92
Bangkok	61.65	94	61.76	90	63.64	64	62.80	95
Budapest	61.60	95	61.67	92	63.93	58	62.29	99
Chongqing	61.56	96	62.62	84	63.09	82	62.39	98
Xiamen	61.55	97	63.15	77	63.13	80	61.64	101
Harbin	61.50	98	64.18	66	61.58	104	62.72	96
Dalian	61.47	99	63.30	74	62.96	86	61.49	104
Ankara	61.32	100	61.37	100	63.62	66	62.20	100

2.2
Overall analysis

San Francisco-San Jose has been named the top ranked GIH for the fourth consecutive year, scoring much higher than other cities/ metropolitan areas; New York MA ranks second again with a score of 88.65; Beijing comes in third place with a score of 83.18; London MA and Boston MA rank fourth and fifth, respectively. Other cities/metropolitan areas in the top 20 are Guangdong-Hong Kong-Macao Greater Bay Area, Tokyo MA, Baltimore-Washington, Paris MA, Shanghai, Seoul MA, Singapore, Los Angeles-Long Beach-Anaheim, Chicago-Naperville-Elgin, Seattle-Tacoma-Bellevue, Dallas-Fort Worth, Munich, San Diego MA, Chapel Hill-Durham-Raleigh and Zurich.

Among the top 30 cities/metropolitan areas, five have risen significantly: Chicago-Naperville-Elgin is up ten places; Dallas-Fort Worth has moved up 13 places; Phoenix MA up by 15; and Taipei is up by 22 places. Comparing the GIHI assessment results of 2021 to 2023, it is found that San Francisco-San Jose, New York MA, Beijing, London MA and Boston MA still remain in the top five, highlighting the stable and strong innovation capability of these cities.

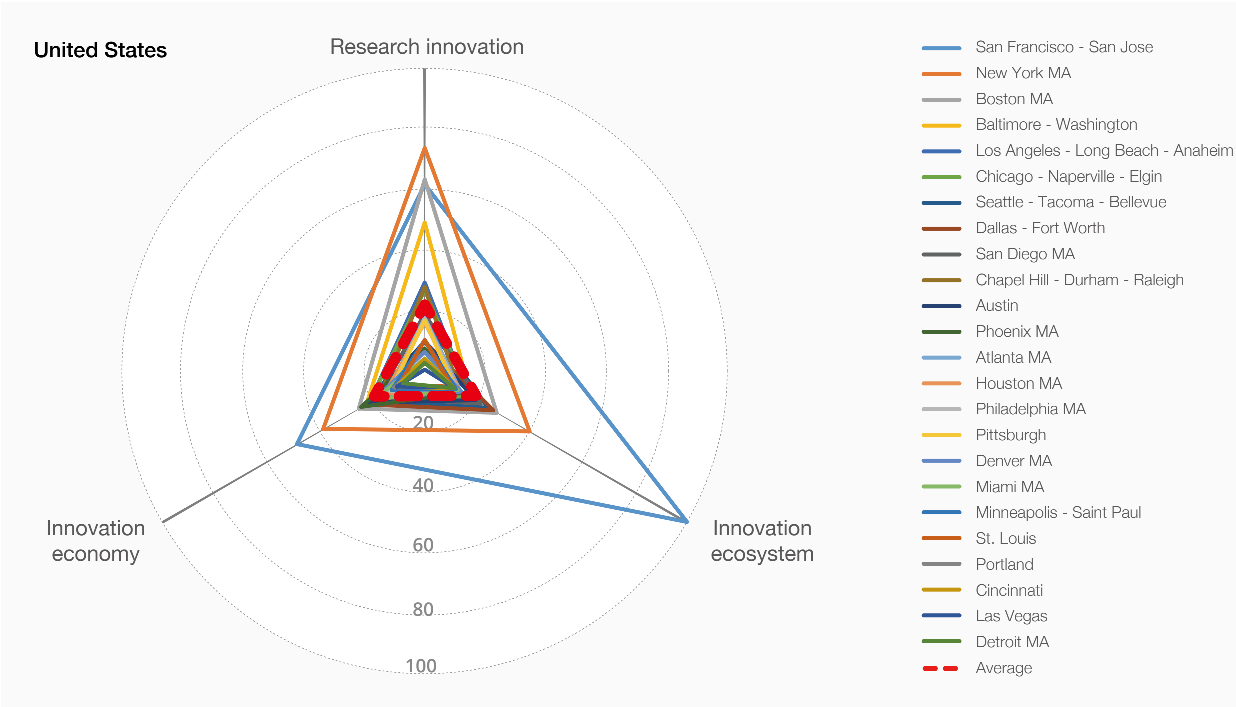
TABLE 3 A comparison of the top 20 GIHs in overall ranking between 2021-2023

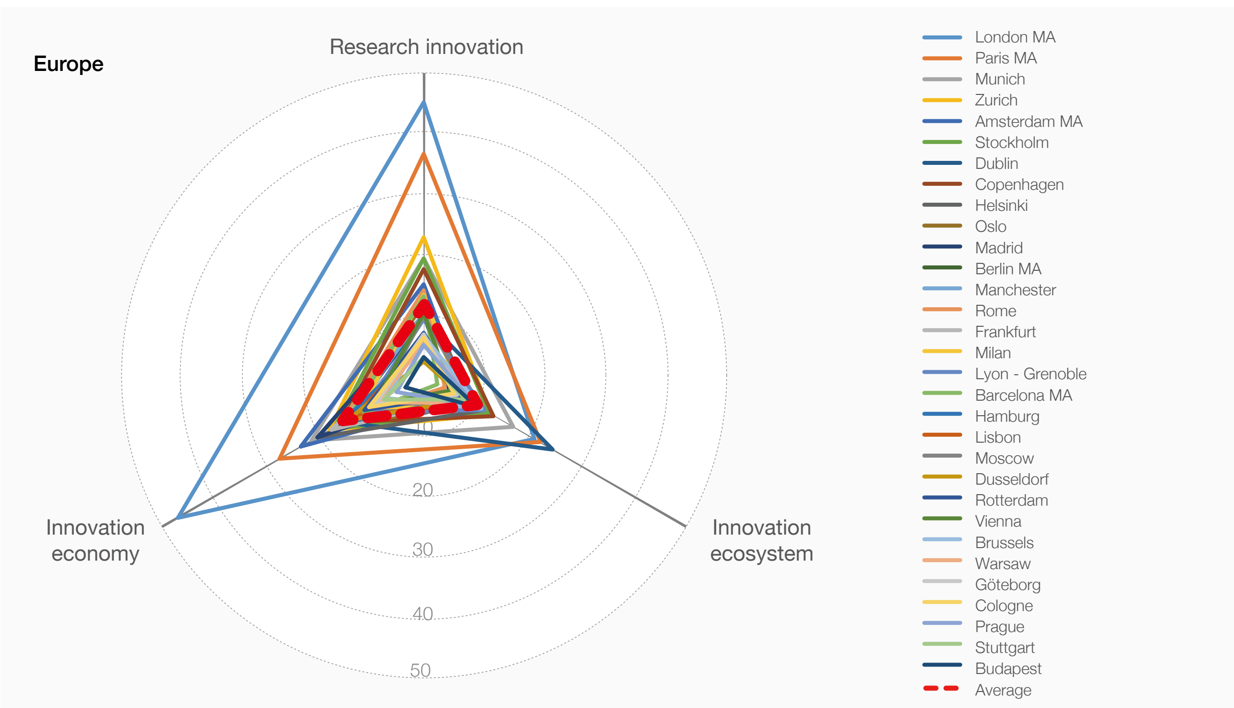
City/metropolitan area	Rank 2023	Rank 2022	Rank 2021
San Francisco - San Jose	1	1	1
New York MA	2	2	2
Beijing	3	3	4
London MA	4	4	3
Boston MA	5	5	5
Guangdong - Hong Kong - Macao Greater Bay Area	6	6	7
Tokyo MA	7	7	6
Baltimore - Washington	8	15	10
Paris MA	9	9	8
Shanghai	10	10	14
Seoul MA	11	12	21
Singapore	12	13	13
Los Angeles - Long Beach - Anaheim	13	16	12
Chicago - Naperville - Elgin	14	24	17
Seattle - Tacoma - Bellevue	15	11	9
Dallas - Fort Worth	16	29	19
Munich	17	14	11
San Diego MA	18	18	15
Chapel Hill - Durham - Raleigh	19	27	18
Zurich	20	20	N/A

2.Overall GIHI ranking

FIGURE 2

Development patterns of GIHs in the United States, Europe and China





Innovation towards multipolarity

Geographically, developed countries, represented by Europe and the United States, continue to lead in global innovation in 2023. Asian cities are edging up, driving the global innovation landscape towards multipolarity where multiple countries perform well simultaneously. Among the top 50 cities/metropolitan areas, 19 are in the United States, 14 in Europe and 12 in Asia. With Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, Tokyo MA, Shanghai, Seoul MA and Singapore entering the top 20, Asian cities/metropolitan areas have become one of the most productive regions for innovation in the world.

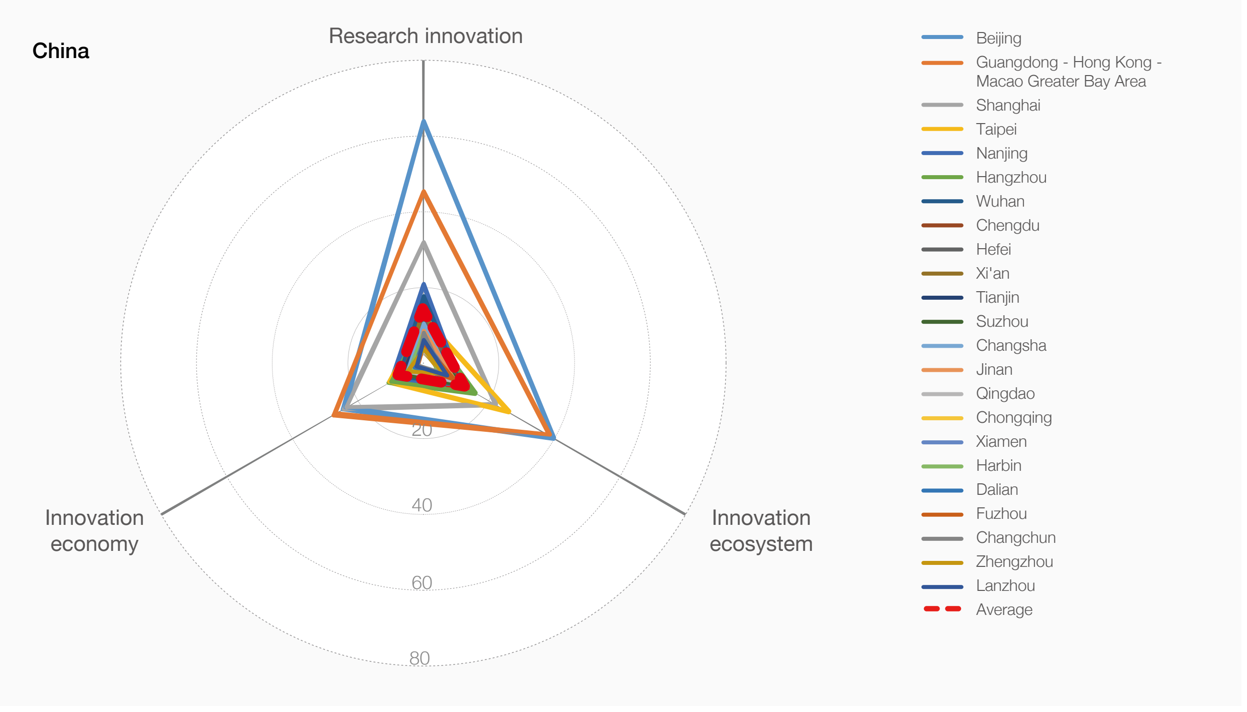
The overall innovation capability of Chinese cities continues to improve, occupying 23 spots in 2023, with Xiamen, Fuzhou, Zhengzhou and Lanzhou entering the list for the first time and Beijing, Guangdong-Hong Kong-Macao Greater Bay Area and Shanghai retaining top ten positions. In general, the distribution of Chinese cities on the list is relatively scattered. Beijing, Shanghai and Guangdong-Hong Kong-Macao Greater Bay Area have become the regional centres facilitating the development of surrounding cities.

Integrated innovation resources of bay areas

Bay areas have prominent advantages in innovation resource integration. Four out of the top ten cities/metropolitan areas are bay areas, with each following distinct innovation paths. For example, San Francisco bay area not only excels in innovation economy and innovation ecosystem, but also sits at the top in overall performance. The New York bay area plays a dominant role in innovation owing to its solid research strengths and scores significantly higher than others in research innovation. Guangdong-Hong Kong-Macao Greater Bay Area and Tokyo bay area rank sixth and seventh and have become the main pillars of Asia's innovation system.

Development patterns

GIHs show distinctive regional development characteristics (see Appendix VI for measurement methodology). In addition to San Francisco-San Jose, which boasts the world's most influential innovation economy, and New York MA, which outperforms in research innovation, other cities/metropolitan areas in the United States have relatively similar performance in research innovation and innovation ecosystem. GIHs in the United States have active interactions in research innovation, innovation economy and innovation ecosystem, following comprehensive and balanced development patterns. European cities/metropolitan areas perform well in research innovation and innovation ecosystem, providing a favourable environment for regional innovation and development that is driven by dual forces. Chinese cities/metropolitan areas have relatively balanced performance in research innovation and innovation economy, with top cities particularly standing out in research innovation. Nevertheless, there is still room for improvement in innovation ecosystem. The development patterns of GIHs in the United States, Europe and China are shown in Figure 2.



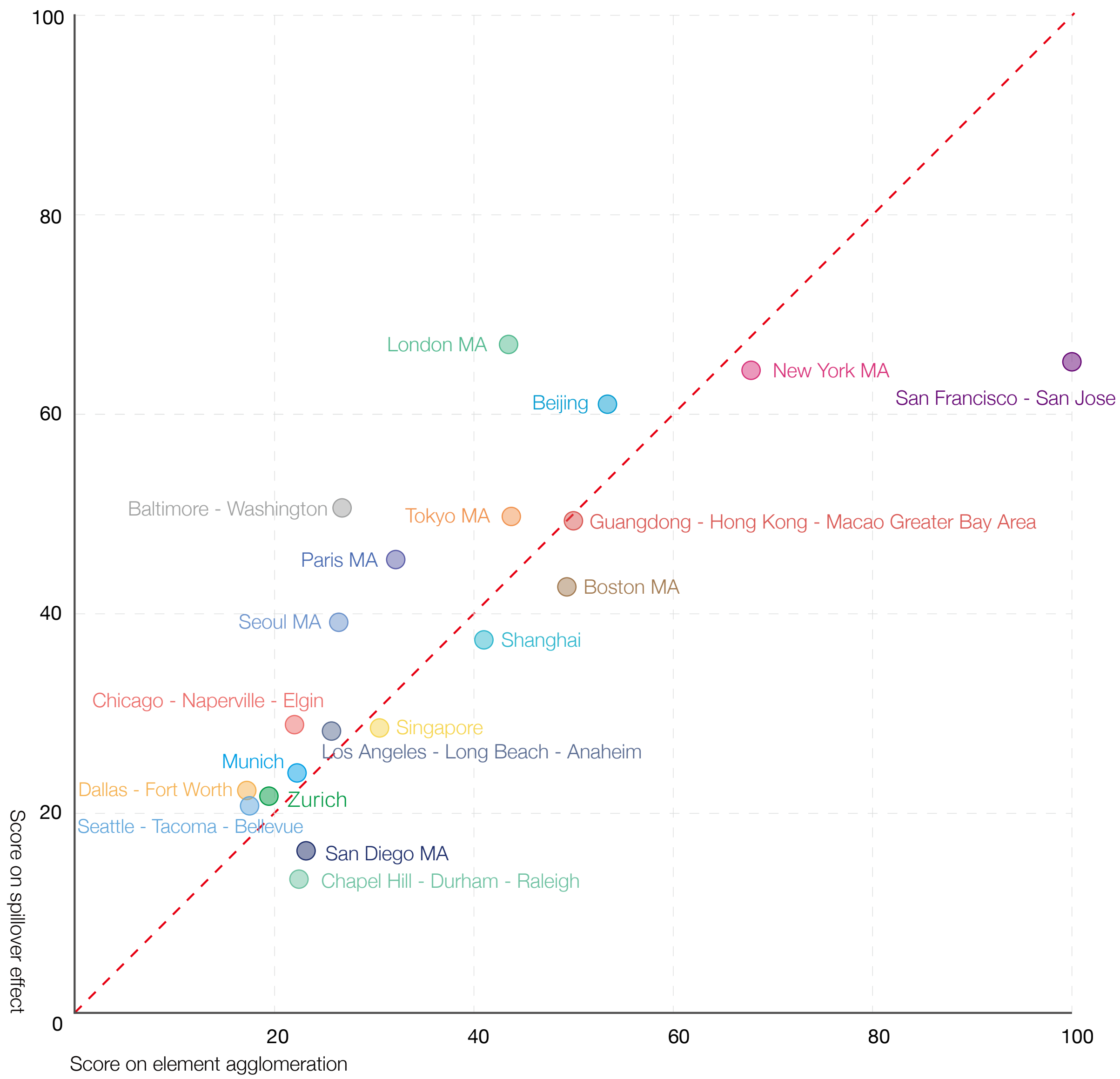
2.Overall GIHI ranking

Agglomeration and spillover effects

The GIHI2023 measured element agglomeration and spillover effect of GIHs (see Appendix VII for measurement methodology) and has identified a strong relation between their abilities in agglomerating elements and the spillover effect that draws innovation elements to the leading cities. San Francisco-San Jose, New York MA and Beijing demonstrate high levels of element agglomeration and strong spillover effect. The innovation resources flow intensively in these cities/metropolitan areas, resulting in large-scale agglomeration of innovative resources and spillover effect. Among the top 20 cities/metropolitan areas, capitals such as London MA, Tokyo MA, Baltimore-Washington, Paris MA and Seoul MA have much stronger spillover effect than element agglomeration capacity. This kind of empowerment could support and enhance innovation in other cities/metropolitan areas. Boston MA, Shanghai, and Singapore boast stronger agglomeration capacity than spillover effect. They manage to stay dominant in the global innovation network by gathering a large amount of high-end innovation resources around the world.

FIGURE 3

Performance in element agglomeration and spillover effect for the top 20 GIHs in overall ranking



2.3 Mini-hubs

The GIHI indicator system assesses the innovation of the world's cities primarily on scale indicators. Some cities are small in population but strong in innovation, which makes them significantly different from most of the other cities in this report and unsuitable for inclusion in the overall ranking. Therefore, GIHI2023 has evaluated mini-hubs with a population of less than one million separately.

As seen in Table 4, a total of 11 mini-hubs are included in GIHI2023, with Basel, Eindhoven, Ithaca and Jerusalem new inclusions for 2023. Apart from Jerusalem, the mini-hubs are in Europe and North America. As shown in the overall ranking, Cambridge and Geneva have strong innovation strengths and are the top two mini-hubs, followed by Boulder, Ann Arbor, Oxford and Basel.

Cambridge excels in research innovation. As home to the University of Cambridge, it benefits from an abundance of human resources in science and technology, a large number of research institutions, well-developed scientific infrastructure and remarkable knowledge creation. As the second largest city in the Swiss Confederation, Geneva is a global city with many international institutions and an open innovation ecosystem, whereas Boulder has a vibrant environment for start-ups.

Mini-hubs mainly follow two development models: one is led by innovative industries and enterprises, such as Eindhoven and Basel; the other is led by top universities, such as Cambridge, Oxford and Ithaca.

TABLE 4 The GIHI2023 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	86.76	2	82.00	4
Geneva	94.82	2	86.62	5	78.87	5	100.00	1
Boulder	86.15	3	79.96	8	82.17	4	89.76	2
Ann Arbor	85.90	4	87.75	4	73.29	6	84.57	3
Oxford	85.65	5	95.31	2	65.07	9	79.15	5
Basel	79.53	6	76.79	9	100.00	1	65.08	7
Ithaca	77.71	7	91.51	3	62.54	10	71.01	6
Lausanne	71.28	8	84.46	6	72.59	7	60.00	11
Jerusalem	64.10	9	75.77	10	68.49	8	62.82	9
Heidelberg	63.61	10	80.00	7	60.00	11	62.55	10
Eindhoven	60.00	11	60.00	11	86.67	3	63.54	8

2.Overall GIHI ranking

Among mini-hubs led by enterprises and industries, Eindhoven, home to top semiconductor companies such as ASML and NXP, ranks fifth in the number of PCT patents in integrated circuits. Basel is the industrial centre of the chemical and pharmaceutical industries and home to a science and technology park known as the BioValley. The park is located near the borders of France, Germany and Switzerland, and pharmaceutical giants Roche and Novartis have their headquarters there. It also has a number of start-ups in the pharmaceutical, biological and chemical industries. The total market value of its Forbes 2000 pharmaceutical and chemical companies is second only to New York MA.

Among mini-hubs led by research institutes and universities is Ithaca, a small city in New York state which is home to Cornell University. Cambridge and Oxford are both world-renowned university towns. Cambridge boasts 10 winners of Nobel prizes, Fields Medals or Turing Awards, and enjoys advantages in science and technology human resources, scientific infrastructure and knowledge creation. Oxford performs well in knowledge creation and has set a model for the transformation of scientific and technological achievements in universities with its world-famous Oxford model.

Mini-hubs have populations under 1 million and feature innovation and development paths distinct from those of GIHs.

FIGURE 4

Development patterns of mini-hubs in research innovation

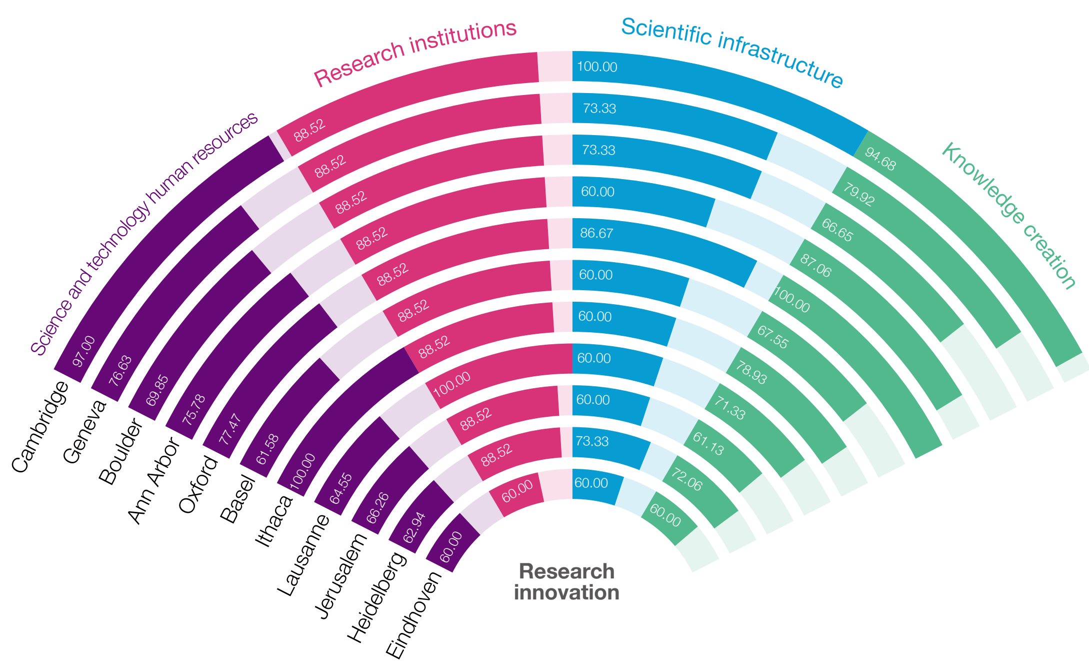
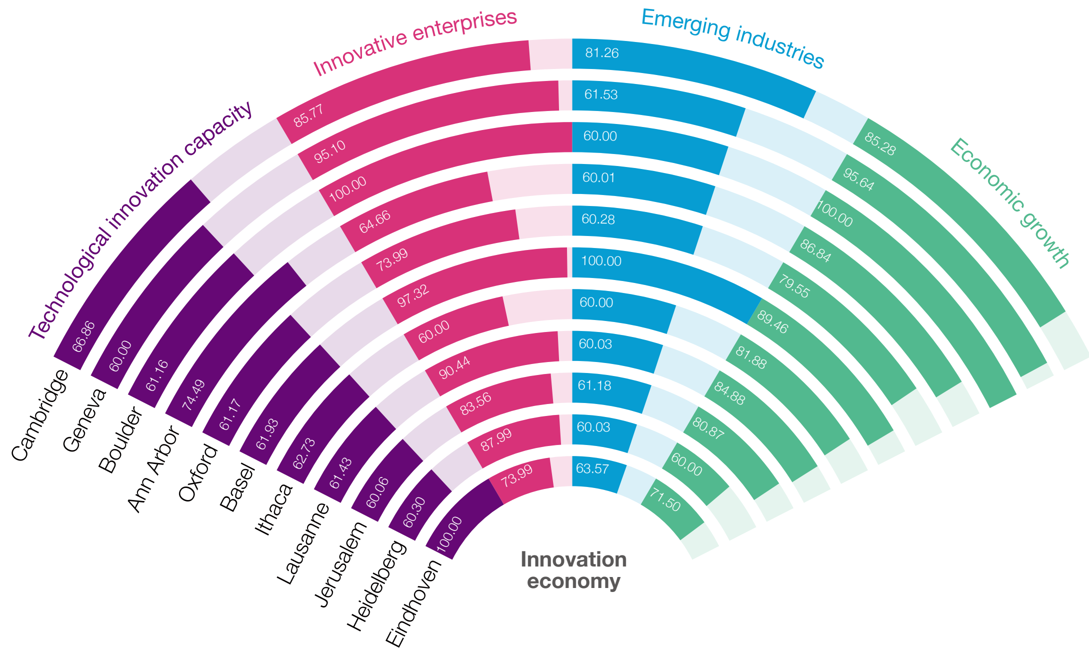
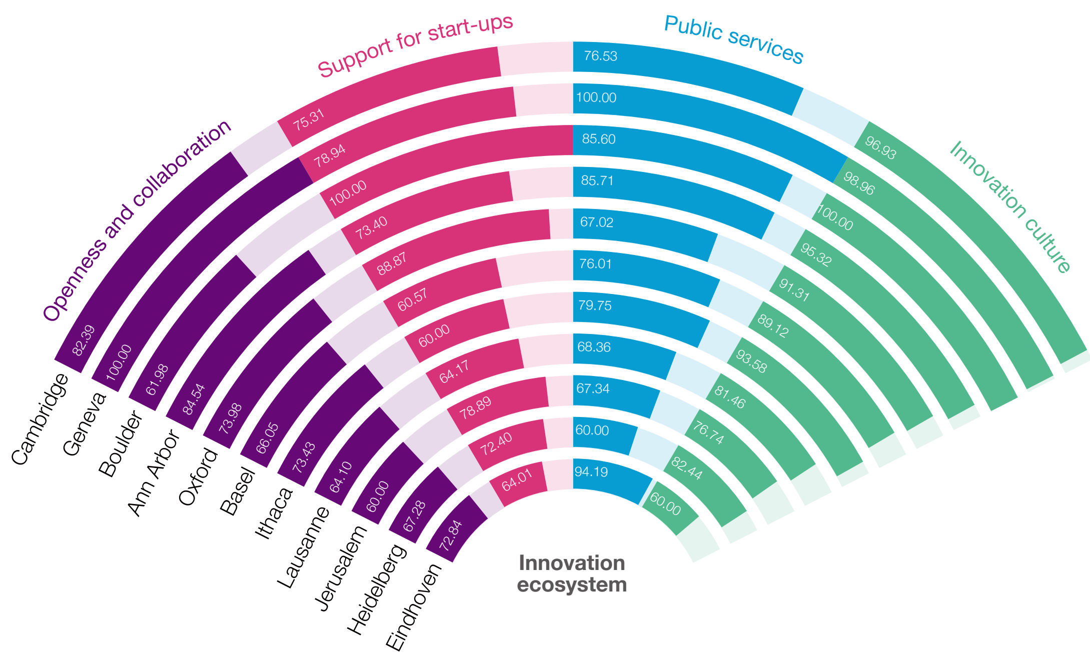


FIGURE 4

Development patterns of mini-hubs in innovation economy



Development patterns of mini-hubs in innovation ecosystem



3. Research innovation

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Cities/metropolitan areas in Europe and the United States are relatively ahead in research innovation, accounting for 13 spots in the top 20. Asian cities/metropolitan areas are catching up and rising up significantly in the rankings. Thirty-three cities/metropolitan areas have become global discipline hubs, the foremost being San Francisco-San Jose, Boston MA, New York MA, London MA, Baltimore-Washington and Beijing. New York MA and Beijing have demonstrated absolute strengths in disciplines.

3.1

A comprehensive analysis of research innovation

The GIHI2023 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	90.61	97.88	68.59	100.00
2	Beijing	94.66	81.46	92.27	100.00	86.24
3	Boston MA	94.41	100.00	78.32	61.79	97.77
4	San Francisco - San Jose	93.43	96.51	77.45	81.22	91.03
5	Baltimore - Washington	86.57	84.95	72.34	68.00	93.76
6	London MA	84.68	75.41	81.31	64.87	90.18
7	Guangdong - Hong Kong - Macao Greater Bay Area	84.55	64.82	100.00	74.96	77.34
8	Paris MA	79.98	74.12	80.44	70.88	76.83
9	Shanghai	77.25	67.78	85.92	69.24	70.70
10	Los Angeles - Long Beach - Anaheim	75.88	70.49	78.32	60.00	75.71
11	Chapel Hill - Durham - Raleigh	75.11	79.04	72.34	60.00	71.33
12	Tokyo MA	74.68	66.78	70.22	88.21	71.94
13	Chicago - Naperville - Elgin	74.40	71.94	72.34	66.16	73.52
14	Zurich	72.50	77.23	70.22	61.24	67.43
15	Nanjing	71.18	72.37	72.34	60.60	66.62
16	Melbourne	70.71	68.08	70.22	60.00	71.73
17	Seoul MA	70.61	65.22	69.35	66.71	72.19
18	Munich	70.59	71.44	70.22	62.43	67.18
19	Stockholm	70.52	68.69	70.22	68.00	67.26
20	San Diego MA	70.18	71.22	67.23	63.08	68.93
21	Singapore	70.15	66.94	70.22	65.51	68.95
22	Copenhagen	69.61	71.41	68.10	60.00	67.63
23	Sydney	69.57	67.10	68.10	61.84	70.83
24	Kyoto - Osaka - Kobe	69.53	68.76	70.22	66.76	64.99
25	Wuhan	69.51	66.75	72.34	62.48	66.57
26	Atlanta MA	69.41	65.31	70.22	60.60	70.55
27	Philadelphia MA	69.25	67.70	65.11	60.00	73.09
28	Pittsburgh	68.97	70.62	68.10	60.00	66.62
29	Seattle - Tacoma - Bellevue	68.80	67.78	65.11	60.60	71.53
30	Houston MA	68.69	64.90	71.09	60.60	68.11
31	Toronto MA	68.56	66.88	65.11	62.43	70.94
32	Amsterdam MA	68.25	66.82	65.98	65.51	67.99

3.Research innovation

Rank	City/metropolitan area	Research innovation	Science and technology human resources	Research institutions	Scientific infrastructure	Knowledge creation
33	Xi'an	68.12	66.05	72.34	61.24	63.97
34	Montreal MA	67.83	66.87	68.10	61.19	66.54
35	Kuala Lumpur	67.80	80.28	60.00	60.00	62.17
36	Daejeon	67.79	74.89	62.12	65.56	62.82
37	Rome	67.75	69.21	65.11	61.79	66.78
38	Milan	67.23	66.49	62.99	66.21	68.15
39	Barcelona MA	67.22	66.63	65.11	60.60	68.27
40	Berlin MA	66.84	66.87	62.12	64.32	68.36
41	Vancouver MA	66.83	67.73	65.11	61.19	65.91
42	Brisbane	66.70	68.05	65.11	60.00	65.75
43	Chengdu	66.65	62.87	70.22	64.32	63.71
44	Taipei	66.59	73.51	62.12	60.00	63.20
45	Oslo	66.48	69.09	62.99	64.92	64.16
46	Hefei	66.09	64.23	67.23	67.45	62.51
47	Hangzhou	65.88	65.74	65.11	62.98	64.45
48	Manchester	65.67	66.36	65.11	60.00	64.56
49	Vienna	65.59	67.07	62.99	61.19	65.20
50	Madrid	65.54	67.58	60.00	61.24	67.51
51	St. Louis	65.51	66.01	65.11	60.00	64.44
52	Changsha	65.48	65.05	67.23	60.60	62.94
53	Minneapolis - Saint Paul	65.45	64.79	65.11	60.60	65.17
54	Moscow	65.43	67.69	62.99	64.18	62.92
55	Helsinki	65.42	67.51	62.99	61.84	64.07
56	Nagoya MA	65.42	65.99	65.11	65.51	61.87
57	Dallas - Fort Worth	65.25	64.43	65.11	60.60	64.96
58	Dublin	65.21	67.49	62.99	62.48	63.22
59	Austin	65.15	65.11	65.11	62.39	63.30
60	Tianjin	65.10	64.07	67.23	60.60	62.84
61	Lyon - Grenoble	65.05	66.21	62.99	62.43	64.03
62	Jinan	64.47	63.92	67.23	60.00	61.49
63	Perth	64.39	66.19	62.99	60.00	63.25
64	Sao Paulo	64.33	64.89	62.99	61.19	63.82
65	Changchun	64.29	63.52	67.23	60.00	61.37
66	Harbin	64.18	64.20	65.11	61.24	61.98

Rank	City/metropolitan area	Research innovation	Science and technology human resources	Research institutions	Scientific infrastructure	Knowledge creation
67	Tel Aviv	64.16	63.29	65.11	61.24	62.78
68	Phoenix MA	64.05	62.78	65.11	60.60	63.25
69	Rotterdam	63.83	64.40	62.99	60.00	63.42
70	Göteborg	63.76	64.74	62.99	60.60	62.65
71	Brussels	63.63	63.40	62.99	60.60	63.58
72	Denver MA	63.40	65.10	60.00	60.60	64.25
73	Cologne	63.40	64.84	62.99	60.00	61.82
74	Dalian	63.30	63.13	64.24	61.24	61.43
75	Frankfurt	63.23	63.10	62.99	62.39	62.02
76	Lanzhou	63.16	65.72	62.12	61.24	60.67
77	Xiamen	63.15	62.92	65.11	60.00	60.91
78	Lisbon	63.15	66.29	60.00	60.00	62.70
79	Hamburg	62.93	64.13	60.00	63.03	62.85
80	Warsaw	62.86	65.67	60.00	61.24	61.96
81	Prague	62.80	65.78	60.00	60.00	62.22
82	Fuzhou	62.69	62.49	64.24	60.00	60.89
83	Suzhou	62.66	60.90	65.11	60.60	61.21
84	Chongqing	62.62	60.81	64.24	61.24	61.77
85	Buenos Aires	62.37	65.35	60.00	61.24	60.92
86	Cincinnati	62.19	64.10	60.00	60.00	62.14
87	Miami MA	62.11	63.08	60.00	60.00	62.87
88	Portland	62.05	63.39	60.00	60.00	62.42
89	Zhengzhou	61.95	62.18	62.12	60.00	61.23
90	Bangkok	61.76	63.39	60.00	60.00	61.62
91	Central National Capital Region Delhi MA	61.68	61.01	60.00	60.60	63.43
92	Budapest	61.67	63.00	60.00	60.60	61.49
93	Stuttgart	61.65	63.04	60.00	60.60	61.40
94	Qingdao	61.64	63.20	60.00	60.00	61.49
95	Istanbul	61.63	61.11	60.00	63.72	61.86
96	Mexico City	61.60	63.00	60.00	60.00	61.56
97	Bengaluru	61.48	61.05	62.12	60.00	61.00
98	Detroit MA	61.47	62.24	60.00	60.00	61.93
99	Chennai MA	61.40	63.06	60.00	60.00	60.97
100	Ankara	61.37	62.63	60.00	60.00	61.27

3.Research innovation

The United States continues to lead in research innovation, with New York MA, Boston MA and San Francisco-San Jose all in the top five for three consecutive years, ranking first, third, and fourth, respectively, this year. Beijing has entered the top three for the first time and ranks second globally. Paris MA and Shanghai have entered the top ten for the first time, whereas Tokyo MA, Nanjing, Melbourne and Seoul MA have entered the top 20 for the first time.

Geographically, cities/metropolitan areas in Europe and the United States still maintain a considerable edge, accounting for 13 spots in the top 20. Asian cities/metropolitan areas are active in research innovation, with a total of six cities/metropolitan areas in the top 20. Asian cities such as Nanjing, Seoul MA, Tokyo MA and Shanghai have all risen significantly in research innovation.

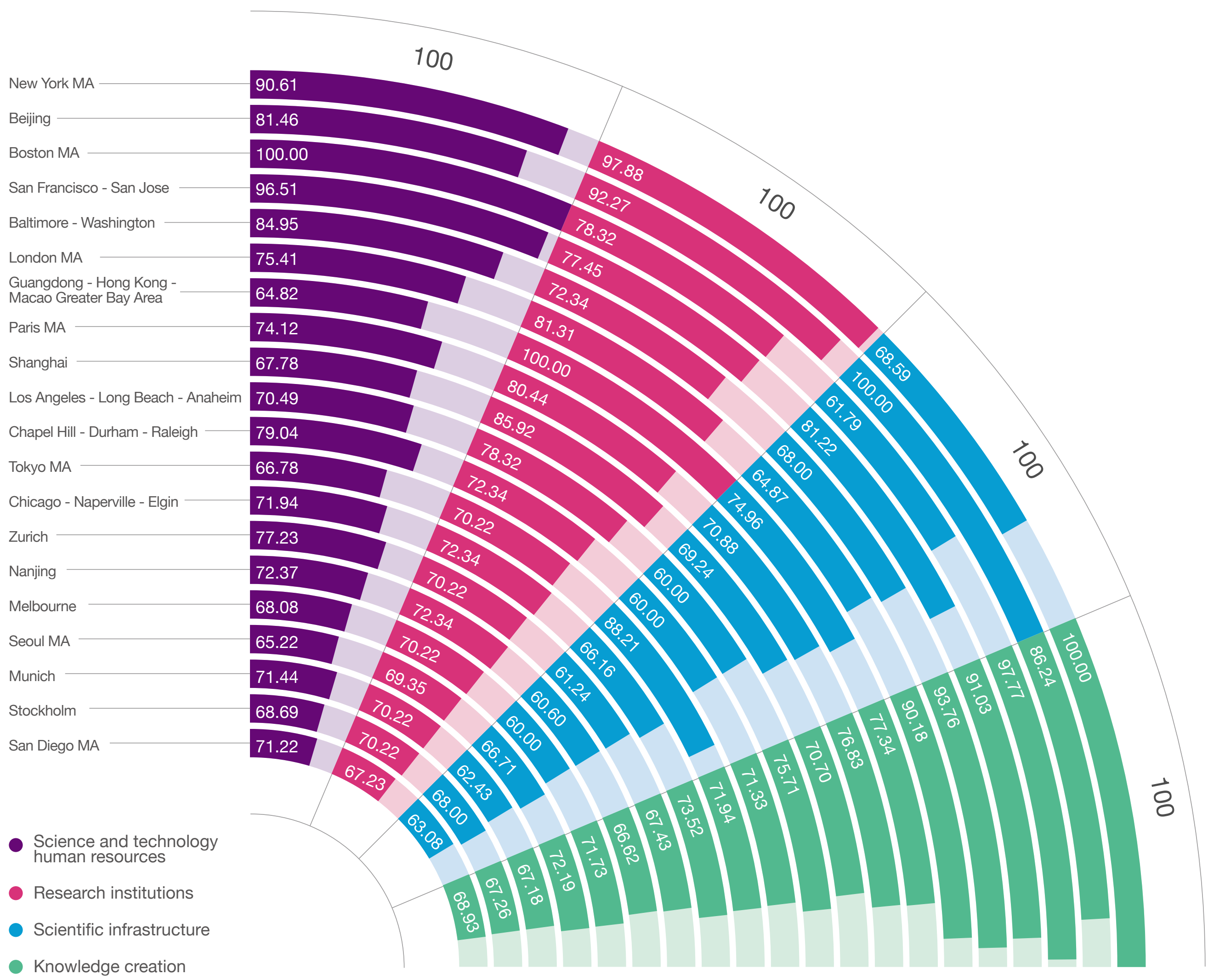
TABLE 6 A comparison of the top 20 GIHs in research innovation between 2021-2023

City/metropolitan area	Rank 2023	Rank 2022	Rank 2021
New York MA	1	1	1
Beijing	2	4	6
Boston MA	3	3	2
San Francisco - San Jose	4	2	3
Baltimore - Washington	5	10	4
London MA	6	8	5
Guangdong - Hong Kong - Macao Greater Bay Area	7	5	10
Paris MA	8	16	11
Shanghai	9	25	24
Los Angeles - Long Beach - Anaheim	10	11	9
Chapel Hill - Durham - Raleigh	11	14	7
Tokyo MA	12	39	27
Chicago - Naperville - Elgin	13	17	12
Zurich	14	13	N/A
Nanjing	15	59	31
Melbourne	16	28	N/A
Seoul MA	17	55	36
Munich	18	31	17
Stockholm	19	20	15
San Diego MA	20	15	13

The GIHI top 20 cities/metropolitan areas in research innovation have varied performance across each sub-indicator. New York MA, which leads the list, has outstanding performance in knowledge creation, relying on its comparative advantages in science and technology human resources and research institutions. Second is Beijing, which has a more balanced performance across all four indicators. It has invested heavily in scientific infrastructure, outperforming other cities/metropolitan areas. Boston MA and San Francisco-San Jose follow closely with synergetic development in both science and technology human resources as well as knowledge creation. Guangdong-Hong Kong-Macao Greater Bay Area has put more effort into building research institutions in recent years, and its performance in this single indicator stands out, ranking first in the world. Shanghai, London MA and Paris MA are strong in research institutions, while Tokyo MA has always placed great emphasis on scientific infrastructure. Development of the GIHI top 20 cities/metropolitan areas in research innovation is shown in Figure 5.

FIGURE 5

Development patterns of the top 20 GIHs in research innovation



3.2
Science and technology human resources

Scientific and technological talent is the foundation of innovation. Considering key factors such as the distribution of scientific talent, their mobility and the time period required for scientific output, the GIHI2023 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. Figure 6 shows the number of active researchers (per million people) for the top 20 cities/metropolitan areas in science and technology human resources.

Cities/metropolitan areas in North America and Europe have continued to take the lead globally in science and technology human resources, accounting for 15 spots in the top 20. Asian cities are also catching up and continue to invest in these resources, with a total of five cities in the top 20, including Beijing, Kuala Lumpur, Daejeon, Taipei and Nanjing.

FIGURE 6 Number of active researchers (per million people) for the top 20 GIHs in science and technology human resources

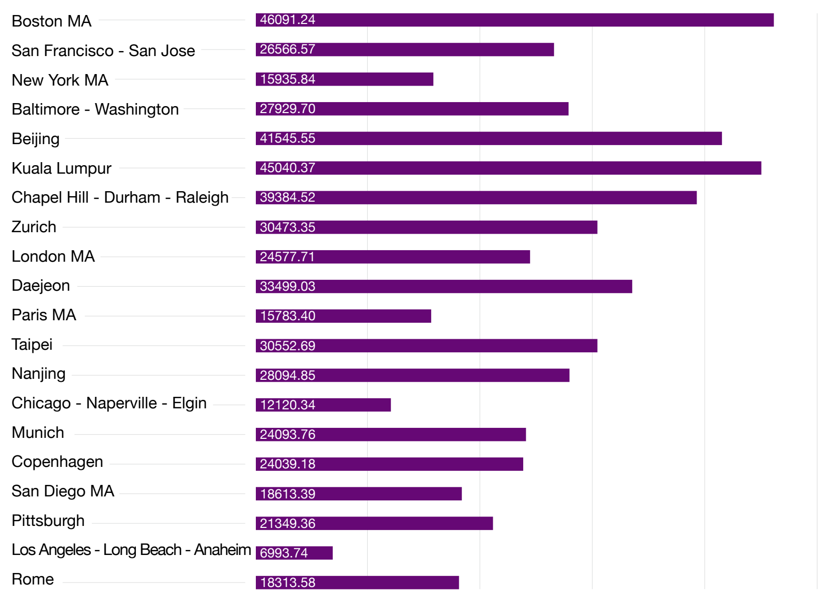


FIGURE 7 Number of winners of top scientific awards for the top 20 GIHs in science and technology human resources

The number of active researchers per million people in the top Asian cities has increased significantly and the scale of research talent has expanded rapidly. Kuala Lumpur has as many as 45,040 active researchers per million people, an increase of 23.03% over the previous year, followed by Beijing with 41,546, an increase of 18.40%. By comparison, Kuala Lumpur and Beijing rank second and third only to Boston MA which has 46,091 active researchers per million people. Chapel Hill-Durham-Raleigh and Daejeon rank fourth and fifth, respectively. Factors such as the supporting systems of research institutes, the introduction and training of talent, the comprehensive supporting systems and the local population base continue to affect the performance of cities/metropolitan areas on this indicator.

Among the top 20 cities in science and technology human resources, cities/metropolitan areas in North America boast 217 top scientific award winners, far ahead of other regions. It is followed by Europe with 41 and Asia with six top scientific award winners. Top scientific and technological talent not only serves as a solid foundation for innovation, but it is also an important indicator of well-established high-quality research teams.

3.3
Research institutions

Research institutions are the key entities of innovation. This report measures the performance of universities and research institutions in a city by the number of research institutions in the Nature Index top 200 by publications and world-leading universities. The strengths of a research institution in basic research, technology application and cutting-edge innovation depend not only on long-term knowledge accumulation, but also on strategic planning, resource investment and policies. To be a source of original innovation and disruptive technology, it is necessary to dynamically adjust strategies, resources and policies. As a result, the ranking of research institutions remains relatively stable.

In terms of research institutions, Guangdong-Hong Kong-Macao Greater Bay Area comes out on top with nine top 200 research institutions (one more than the runner-up, New York MA) and seven leading universities. Chinese cities/metropolitan areas outperform other places with three spots among the top five. Besides Guangdong-Hong Kong-Macao Greater Bay Area, Beijing comes third with 11 top 200 research institutions and three leading universities; and Shanghai ranks fourth with eight top 200 research institutions and three leading universities. Wuhan, Xi'an, Nanjing and Chengdu are in the top 20 for this indicator thanks to the strong momentum and excellent performance of universities and research institutions in these cities.

FIGURE 8

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 material basis for innovation. The discovery of new theories, major knowledge transformation and key technological iterations rely on large-scale and complex scientific facilities or systems. The GIHI measures the development of scientific infrastructure by the numbers of large scientific facilities and top 500 supercomputers in a city/ metropolitan area.

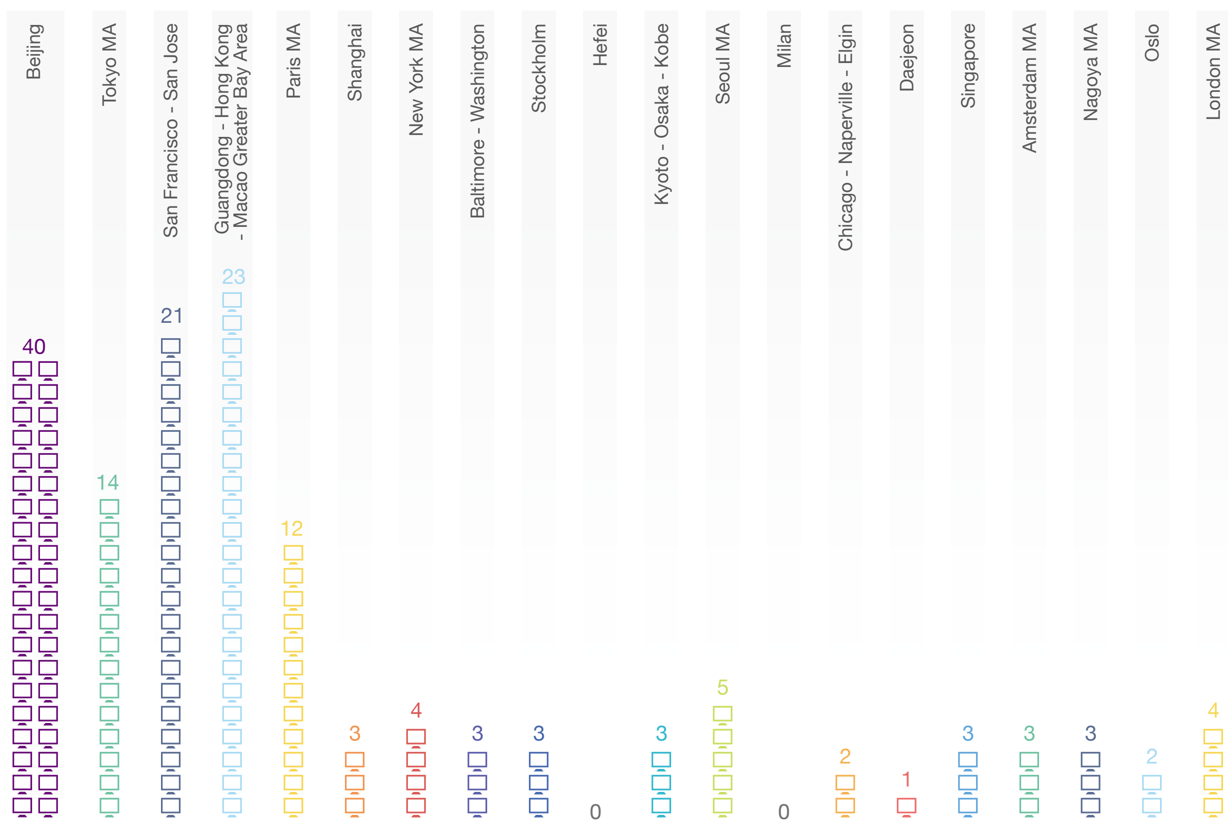
Among the top 20 cities for scientific infrastructure, Beijing and Tokyo MA rank first and second with a significant edge, followed by San Francisco-San Jose, Guangdong-Hong Kong-Macao Greater Bay Area and Paris MA. Large scientific facilities are of prominent strategic importance and extremely difficult to build. They have value in engineering and research, helping to realize research goals, promote interdisciplinary development and break bottlenecks. Large scientific facilities tend to cluster geographically and the top ten cities possess nearly half of the total scientific infrastructure in the world.

Regarding the number of top 500 supercomputers, as shown in Figure 9, Beijing prevails in the top 20 cities in scientific infrastructure with 40 units. It is followed by Guangdong-Hong Kong-Macao Greater Bay Area and San Francisco-San Jose, with 23 and 21 units, respectively. Tokyo MA and Paris MA rank fourth and fifth with 14 and 12 units each.

According to the list published by the international organization TOP500, as of November 2022, China remains in the leading position for the number of supercomputers. Frontier, the supercomputer owned by the United States, topped the list in computing power and is the world's first E-class supercomputer. China's Sunway TaihuLight and Tianhe-2 have made great progress by entering the top ten, ranking seventh and tenth, respectively.

Figure 9

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



3.5
Knowledge creation

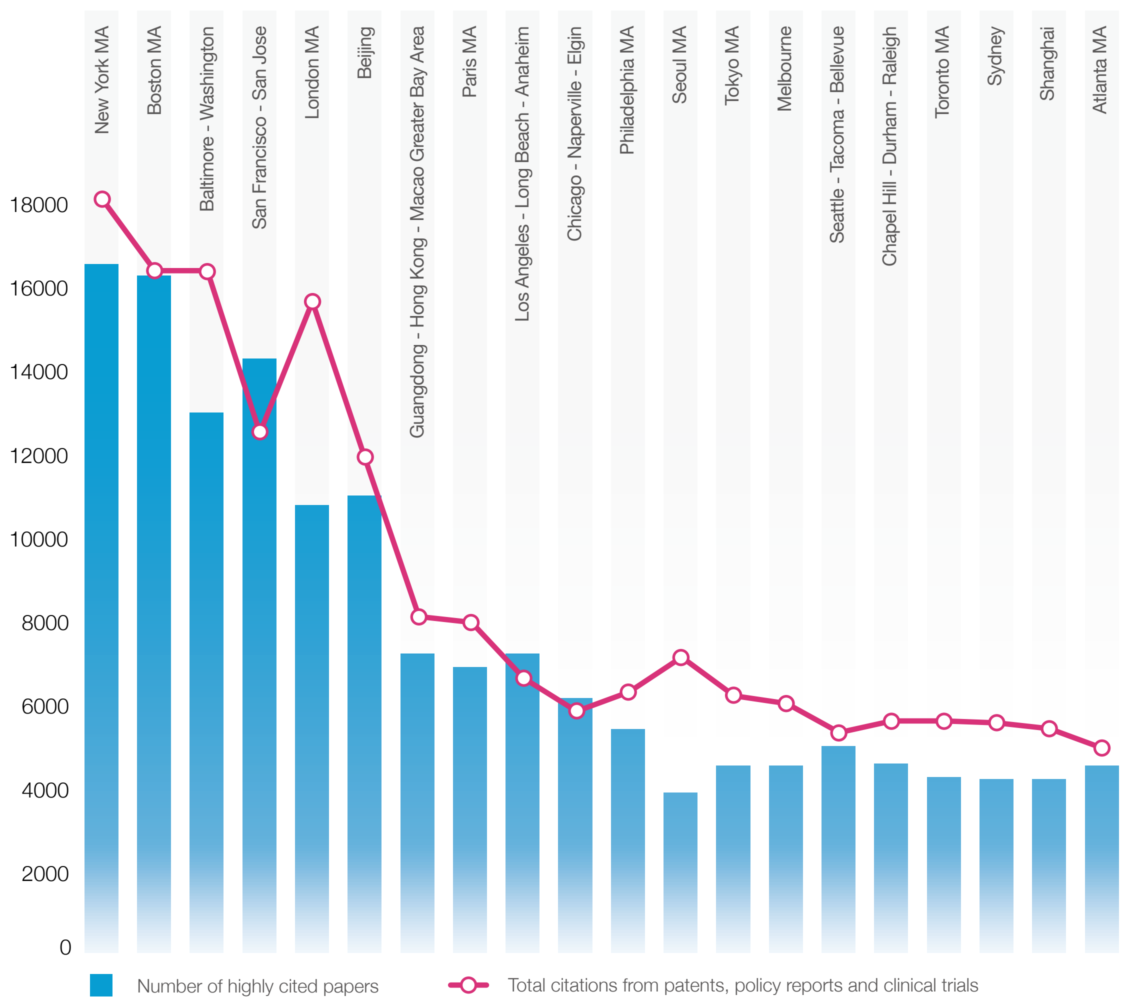
Knowledge is the source of innovation. This report uses the number of highly cited papers published by a city to measure its overall academic impact. It uses the total citations from patents, policy reports and clinical trials to measure the application potential of the publications in industries and wider society.

The United States enjoys a profound advantage in knowledge creation, with 11 cities/metropolitan areas in the top 20 for knowledge creation. New York MA, Boston MA, Baltimore-Washington and San Francisco-San Jose are in the top four. In the top 20, five cities/metropolitan areas are in Asia – Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, Seoul MA, Tokyo MA, and Shanghai – and two cities – Melbourne and Sydney – are in Oceania. When ranking the top 20 for scientific research institutions and knowledge creation, it is found that cities with greater investment in scientific research institutions also have a considerable advantage in knowledge creation.

By single indicators, the evaluated cities/metropolitan areas have similar performance in the number of highly cited papers and the total citations from patents, policy reports and clinical trials. New York MA, Boston MA, Baltimore-Washington and San Francisco-San Jose are all in the top five for both indicators, revealing that cities/metropolitan areas of academic influence are making significant contributions to society and industry.

Figure 10

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

DISCIPLINE HUBS

Discipline hubs refer to the sources, planning centres and hubs of innovation in a discipline or academic field. For a city/metropolitan area within discipline hubs, its knowledge creation paves the way for research in specific disciplines, covering a wide range of frontiers and hotspots with far-reaching influence in the world.

Peer-reviewed academic papers are the products of scientific knowledge creation and academic exchange. The citation of papers reflected in references objectively record the inheritance and dissemination of knowledge. For a given discipline, the top 1% of highly cited papers in the world in the same year of publication (referred to as 'highly cited papers') represent the key achievement of knowledge creation in the discipline. In this report, the number of highly cited papers is used to evaluate a city's **discipline-sourcing capabilities**. The percentage of highly cited papers is used to assess a city's **disciplinary excellence**. The papers of each discipline as a percentage of the total papers published by a city are used to examine a city's **disciplinary characteristics**. The assessment period spans from 2012 to 2021. A total of 119 cities/metropolitan areas are evaluated in the GIHI2023 and their scope of administrative divisions are shown in Appendix V.

To be included in the **list of global discipline hubs**, a city must have at least one discipline in the top ten. The list shows the standard scores and rankings by the number of highly cited papers in 22 disciplines of assessed cities, as well as the comparison of the percentage of highly cited papers in each discipline of the city with the global benchmark. A city's **overall ranking** depends on the number of disciplines in the top ten list of the number of highly cited papers, which is the main basis of the ranking. If the number of disciplines in the top ten is the same for more than one city, these cities are then ranked based on the average percentage of highly cited papers in 22 disciplines. The measurement methods are shown in Appendix VIII.

TABLE 7 The ranking of global discipline hubs

Overall ranking	City/metropolitan area	01 Mathematical Sciences			02 Physical Sciences			03 Chemical Sciences			04 Earth Sciences			05 Environmental Sciences			06 Biological Sciences			07 Agricultural, Veterinary And Food Sciences			08 Information And Computing Sciences			09 Engineering			10 Health Sciences			11 Biomedical And Clinical Sciences		
		STEM – Science, Technology, Engineering, and Mathematics																																
		R	S		R	S		R	S		R	S		R	S		R	S		R	S		R	S		R	S		R	S		R	S	
1	San Francisco - San Jose	2	89.20	★	2	98.49	☆	4	76.66	★	4	75.90	★	3	85.45	★	2	92.15	★	3	79.08	★	2	95.13	★	5	74.52	★	5	80.51	★	5	84.02	★
2	Boston MA	4	86.88	★	3	98.19	☆	10	70.10	★	5	74.59	★	9	76.03	★	1	100.00	★	7	72.72	★	6	76.44	★	7	72.27	★	2	95.48	★	2	97.32	★
3	New York MA	1	100.00	★	1	100.00	☆	8	70.69	★	3	79.45	★	3	85.45	★	3	90.86	☆	4	78.76	★	4	81.76	★	9	70.38	★	4	88.16	☆	1	100.00	☆
4	London MA	6	79.55	★	11	75.17	☆	24	64.80	☆	10	71.48	★	5	80.74	★	6	76.64	☆	8	71.86	★	7	76.11	★	12	67.95	★	1	100.00	★	3	90.85	★
5	Baltimore - Washington	8	73.76	☆	4	87.25	☆	14	67.08	☆	2	88.52	★	2	95.15	★	4	88.47	☆	2	84.26	★	11	71.48	★	15	66.80	☆	3	92.35	☆	4	89.92	★
6	Beijing	3	87.52	☆	5	87.09	☆	1	100.00	★	1	100.00	☆	1	100.00	☆	7	75.92	☆	1	100.00	☆	1	100.00	☆	1	100.00	☆	22	67.15	☆	24	67.54	☆
7	Guangdong - Hong Kong - Macao Greater Bay Area	11	72.35	☆	23	71.02	☆	2	79.57	★	12	70.44	☆	7	77.91	☆	15	69.55	☆	6	73.48	☆	3	89.81	★	2	82.48	★	21	67.28	☆	22	68.24	☆
8	Oxford	14	70.93	★	22	71.09	☆	38	63.61	★	23	65.41	★	22	70.51	★	13	69.86	★	30	66.90	★	24	66.01	★	57	62.11	★	8	74.76	★	20	68.66	★
9	Chicago - Naperville - Elgin	17	69.65	☆	8	80.83	★	12	69.35	★	56	62.35	★	49	64.04	★	14	69.78	☆	43	64.53	★	30	65.17	★	21	65.81	★	15	70.61	☆	9	72.91	☆
10	Los Angeles - Long Beach - Anaheim	7	74.66	★	7	84.38	☆	19	65.91	★	6	73.33	★	32	67.27	★	9	72.28	☆	44	64.31	★	16	69.36	★	13	66.88	★	11	72.25	☆	8	74.22	★
11	Paris MA	5	82.25	☆	6	84.91	☆	31	63.96	☆	7	72.90	☆	14	73.87	★	11	71.26	☆	5	76.28	★	15	69.48	☆	20	65.89	☆	23	66.82	☆	6	77.06	★
12	Philadelphia MA	38	65.40	☆	24	70.94	★	26	64.64	★	75	61.42	☆	57	63.64	★	16	69.33	☆	40	64.96	☆	28	65.29	★	32	63.61	★	14	70.69	☆	7	74.60	☆
13	Sydney	56	63.86	☆	56	65.58	☆	35	63.73	★	16	67.65	★	6	79.39	★	31	66.45	☆	15	69.38	★	9	71.78	★	19	66.26	★	7	75.13	☆	19	68.80	☆
14	Melbourne	21	69.00	★	32	68.68	☆	36	63.70	☆	27	64.21	☆	19	71.31	★	22	67.55	☆	18	68.73	★	20	68.34	★	18	66.44	★	6	75.70	☆	14	71.10	★
15	Shanghai	10	73.25	☆	27	70.42	☆	3	78.56	☆	21	66.12	☆	17	71.45	☆	25	67.32	☆	27	67.22	☆	8	71.90	☆	3	75.04	☆	49	63.37	☆	45	64.76	☆
16	Singapore	42	64.89	☆	49	66.49	☆	5	73.38	★	81	61.20	☆	35	66.73	★	39	64.89	☆	36	65.61	★	5	78.39	★	4	74.57	★	35	64.85	☆	48	64.58	☆
17	Amsterdam MA	19	69.26	★	26	70.57	★	68	61.38	★	29	64.04	★	28	68.35	★	35	65.57	☆	45	64.20	★	50	63.29	★	90	60.71	★	18	68.55	★	16	70.25	★
18	Cambridge	8	73.76	★	13	73.51	★	22	65.25	★	30	63.99	★	20	70.91	★	5	78.65	★	33	66.25	★	37	64.54	★	43	62.62	★	17	68.80	★	23	67.74	★
19	Toronto MA	44	64.63	☆	29	69.89	★	43	63.09	★	35	63.50	★	64	63.37	☆	26	67.28	☆	50	63.56	★	25	65.98	★	34	63.36	★	10	73.16	☆	10	71.86	★
20	Nanjing	16	70.29	☆	44	66.57	☆	7	70.99	☆	13	69.56	☆	12	74.41	☆	64	62.46	☆	12	70.67	☆	10	71.63	☆	6	72.90	☆	92	60.70	☆	82	61.51	☆
21	Zurich	12	71.70	★	14	73.06	★	39	63.51	★	9	72.02	★	11	75.62	★	24	67.39	☆	10	71.43	★	21	67.03	★	27	64.43	★	53	63.21	★	43	64.90	★
22	Seattle - Tacoma - Bellevue	29	67.20	★	18	72.30	★	51	62.37	★	17	67.43	★	16	71.85	★	10	71.94	★	48	63.77	★	12	71.21	★	51	62.37	★	9	74.64	★	11	71.81	★
23	Berlin MA	25	68.49	☆	21	71.17	☆	21	65.41	★	13	69.56	★	8	76.57	★	19	68.45	☆	18	68.73	★	35	64.63	★	37	63.07	★	40	64.52	★	30	66.79	★
24	Brisbane	67	63.09	★	97	61.13	☆	33	63.80	★	48	62.73	★	10	75.89	★	29	66.75	☆	23	68.30	★	48	63.38	★	39	62.99	★	16	69.33	☆	49	64.54	☆
25	Wuhan	22	68.87	☆	53	65.74	☆	6	72.28	★	11	71.09	☆	30	67.41	☆	47	63.83	☆	13	70.46	☆	19	68.49	☆	10	69.92	☆	64	62.14	☆	53	64.08	☆
26	Seoul MA	35	65.92	☆	16	72.53	☆	9	70.45	☆	37	63.44	☆	37	66.60	☆	39	64.89	☆	25	67.76	☆	13	70.85	☆	8	70.46	☆	44	63.74	☆	33	66.36	☆
27	Boulder	71	62.96	★	44	66.57	☆	70	61.29	★	8	72.73	★	35	66.73	★	60	62.62	★	52	63.45	★	89	60.99	★	81	61.11	★	95	60.58	☆	102	60.50	★
28	San Diego MA	40	65.02	★	53	65.74	☆	34	63.75	★	22	65.52	★	45	64.71	★	8	72.97	★	52	63.45	★	30	65.17	★	48	62.54	★	30	65.59	☆	21	68.47	★
29	Vienna	62	63.47	☆	56	65.58	☆	74	61.20	☆	18	66.78	★	12	74.41	★	37	65.16	☆	18	68.73	★	56	62.63	☆	72	61.59	☆	68	61.69	☆	46	64.67	★
30	Copenhagen	56	63.86	☆	41	66.94	☆	57	61.97	☆	24	65.14	★	21	70.64	★	16	69.33	☆	16	69.16	★	52	62.99	★	56	62.12	★	25	66.66	★	28	66.98	★
31	Munich	17	69.65	★	10	77.81	☆	47	62.88	☆	39	63.28	★	42	65.52	★	21	67.66	☆	31	66.68	★	26	65.86	★	40	62.86	☆	56	62.75	☆	36	65.89	☆
32	Hangzhou	33	66.17	☆	84	62.11	☆	15	66.89	☆	51	62.57	☆	37	66.60	☆	55	63.30	☆	9	71.64	★	23	66.31	☆	17	66.49	☆	80	61.15	☆	77	61.66	☆
33	Tokyo MA	19	69.26	☆	9	80.08	☆	16	66.68	☆	15	68.20	☆	43	65.39	☆	27	66.86	☆	37	65.50	☆	32	65.14	☆	24	65.24	☆	48	63.45	☆	26	67.17	☆

Note: Column R indicates ranking of disciplines; Column S indicates standard scores of the number of highly cited papers; A golden solid ☆ indicates that the percentage of highly cited papers is higher than the global benchmark, otherwise it's lower than the global benchmark.

60 100

3.Research innovation

TABLE 7 The ranking of global discipline hubs

Overall ranking	City/metropolitan area	HASS – Humanities, Arts, and Social Sciences																																
		12 Built Environment And Design			13 Education			14 Economics			15 Commerce, Management, Tourism And Services			16 Human Society			17 Psychology			18 Creative Arts And Writing			19 Language, Communication And Culture			20 Law And Legal Studies			21 History, Heritage And Archaeology			22 Philosophy And Religious Studies		
		R	S		R	S		R	S		R	S		R	S		R	S		R	S		R	S		R	S		R	S		R	S	
1	San Francisco - San Jose	2	97.12	★	2	99.64	★	3	83.51	★	8	79.63	★	5	88.11	★	4	86.03	★	6	78.91	★	5	84.38	★	5	85.57	★	4	86.67	★	6	80.18	★
2	Boston MA	4	78.82	★	6	94.55	★	1	100.00	★	1	100.00	★	2	98.20	★	2	93.93	★	2	97.09	★	4	86.25	★	2	92.13	★	2	96.67	☆	2	92.21	★
3	New York MA	10	74.12	☆	3	97.82	☆	2	88.30	★	4	88.71	★	1	100.00	☆	1	100.00	☆	1	100.00	☆	1	100.00	★	2	92.13	☆	3	87.50	☆	1	100.00	☆
4	London MA	5	78.04	★	5	95.64	★	4	78.83	★	2	94.20	★	4	91.83	☆	3	88.10	☆	3	93.45	☆	2	95.00	★	1	100.00	☆	1	100.00	☆	4	88.32	☆
5	Baltimore - Washington	18	68.10	☆	7	90.55	☆	6	77.98	☆	6	82.37	★	3	93.63	☆	5	83.34	☆	4	79.64	★	3	86.56	★	4	91.48	☆	5	85.83	☆	5	84.07	★
6	Beijing	1	100.00	☆	19	72.73	☆	5	78.19	★	5	83.64	☆	6	78.62	★	19	67.29	☆	42	64.36	☆	19	69.06	☆	6	80.33	★	10	79.17	☆	26	65.66	☆
7	Guangdong - Hong Kong - Macao Greater Bay Area	3	96.86	★	1	100.00	★	8	69.68	★	3	91.87	★	25	67.69	☆	21	67.06	☆	47	63.64	☆	9	75.00	☆	13	70.49	☆	42	65.00	☆	24	66.02	☆
8	Oxford	53	63.92	★	15	75.27	★	13	65.74	★	31	66.97	★	7	76.22	★	9	71.67	★	8	76.00	★	8	75.94	★	9	75.74	★	6	84.17	☆	3	89.03	★
9	Chicago - Naperville - Elgin	30	66.27	★	11	80.00	★	7	76.17	★	9	78.05	★	8	72.01	☆	14	69.29	☆	10	75.27	★	7	77.19	★	13	70.49	☆	20	69.17	☆	8	73.45	☆
10	Los Angeles - Long Beach - Anaheim	17	68.37	★	12	78.55	☆	11	66.06	☆	16	72.14	★	10	70.69	☆	6	75.36	☆	16	70.91	☆	11	74.06	★	46	63.93	☆	14	72.50	☆	9	73.10	☆
11	Paris MA	20	67.84	☆	48	64.73	★	10	68.62	☆	11	74.99	★	12	69.73	☆	30	65.53	☆	19	68.73	☆	16	69.69	☆	25	66.56	☆	7	83.33	☆	10	72.04	☆
12	Philadelphia MA	50	64.44	★	8	81.82	★	9	69.04	★	7	81.42	★	15	69.49	☆	8	71.90	☆	4	79.64	★	9	75.00	★	39	64.59	☆	17	71.67	☆	13	69.91	☆
13	Sydney	9	75.95	★	9	80.73	☆	17	64.89	☆	13	73.83	★	23	68.05	☆	11	70.21	☆	7	76.73	☆	13	73.13	☆	9	75.74	☆	24	68.33	☆	16	68.14	☆
14	Melbourne	8	76.73	★	4	96.00	★	15	65.21	☆	10	75.30	★	9	70.81	☆	12	69.75	☆	17	69.45	☆	21	68.44	☆	11	75.08	☆	25	67.50	☆	7	74.87	★
15	Shanghai	6	77.25	☆	52	64.00	☆	27	63.51	☆	17	71.50	☆	45	63.96	☆	45	63.53	☆	51	62.91	☆	60	62.50	☆	28	65.90	☆	63	62.50	☆	66	61.77	☆
16	Singapore	7	76.99	★	30	68.73	☆	24	63.72	☆	15	72.45	★	37	65.17	☆	35	64.15	☆	19	68.73	★	15	70.00	★	22	67.87	☆	49	64.17	☆	36	63.89	☆
17	Amsterdam MA	66	62.09	☆	26	70.55	★	30	62.98	☆	36	66.12	★	22	68.17	☆	7	72.67	★	8	76.00	★	6	78.75	★	46	63.93	☆	42	65.00	☆	11	71.68	★
18	Cambridge	52	64.18	☆	43	65.82	☆	19	64.04	★	49	64.85	★	16	69.25	★	13	69.67	★	22	68.00	★	16	69.69	★	12	71.15	☆	8	80.83	☆	16	68.14	☆
19	Toronto MA	24	67.06	★	24	71.27	☆	24	63.72	☆	20	70.34	★	23	68.05	☆	10	71.21	☆	12	71.64	☆	26	66.88	☆	28	65.90	☆	20	69.17	☆	12	70.27	☆
20	Nanjing	12	69.67	☆	66	62.91	★	34	62.77	☆	37	65.80	☆	64	62.16	☆	90	60.77	☆	84	60.73	☆	69	61.88	☆	39	64.59	★	94	60.00	☆	75	61.06	☆
21	Zurich	11	73.59	★	60	63.27	★	14	65.32	★	32	66.75	★	18	68.89	★	34	64.53	☆	17	69.45	★	11	74.06	★	15	69.84	★	25	67.50	☆	32	64.25	☆
22	Seattle - Tacoma - Bellevue	25	66.80	★	16	74.55	★	45	62.13	☆	26	67.92	★	27	67.45	★	25	66.68	☆	12	71.64	★	14	70.31	★	17	68.52	★	42	65.00	☆	18	67.43	★
23	Berlin MA	25	66.80	★	37	67.27	★	15	65.21	★	22	68.97	★	17	69.13	☆	27	66.45	☆	22	68.00	☆	16	69.69	★	8	76.39	★	17	71.67	☆	15	68.50	☆
24	Brisbane	16	68.63	★	9	80.73	☆	56	61.70	☆	12	74.04	★	25	67.69	☆	20	67.22	☆	12	71.64	☆	30	66.25	☆	16	69.18	☆	25	67.50	☆	28	65.31	☆
25	Wuhan	14	68.89	☆	50	64.36	☆	38	62.45	☆	41	65.49	☆	68	62.04	☆	59	62.23	★	84	60.73	☆	49	63.75	★	33	65.25	★	94	60.00	☆	75	61.06	☆
26	Seoul MA	12	69.67	☆	24	71.27	★	31	62.87	☆	18	70.87	☆	54	62.76	☆	47	63.30	☆	25	67.27	☆	33	65.94	☆	17	68.52	★	94	60.00	☆	36	63.89	☆
27	Boulder	70	61.83	☆	30	68.73	★	79	60.74	☆	71	62.74	★	58	62.52	☆	58	62.38	★	27	66.55	★	35	65.63	★	73	61.31	☆	49	64.17	☆	70	61.42	☆
28	San Diego MA	59	62.88	★	45	65.45	☆	21	63.94	★	67	63.27	★	42	64.08	☆	16	68.06	☆	47	63.64	☆	42	64.38	☆	28	65.90	★	42	65.00	☆	42	63.54	☆
29	Vienna	34	66.01	★	52	64.00	★	19	64.04	★	52	64.75	★	20	68.41	★	60	62.15	☆	12	71.64	★	28	66.56	★	7	78.36	★	11	76.67	★	20	66.73	☆
30	Copenhagen	18	68.10	★	52	64.00	★	41	62.34	☆	25	68.02	★	29	67.21	★	47	63.30	☆	51	62.91	☆	42	64.38	☆	28	65.90	☆	8	80.83	★	20	66.73	★
31	Munich	58	63.40	☆	30	68.73	★	28	63.30	☆	37	65.80	★	54	62.76	☆	31	65.45	☆	27	66.55	☆	24	67.19	★	39	64.59	☆	14	72.50	★	24	66.02	☆
32	Hangzhou	35	65.75	☆	76	61.82	☆	65	61.28	☆	67	63.27	☆	78	61.32	☆	75	61.46	☆	62	62.18	☆	60	62.50	☆	87	60.66	☆	63	62.50	★	94	60.35	☆
33	Tokyo MA	35	65.75	☆	59	63.64	☆	35	62.55	☆	56	64.01	☆	49	63.24	☆	35	64.15	☆	36	65.09	☆	42	64.38	☆	50	63.28	☆	38	65.83	☆	26	65.66	☆

Note: Column R indicates ranking of disciplines; Column S indicates standard scores of the number of highly cited papers; A golden solid ☆ indicates that the percentage of highly cited papers is higher than the global benchmark, otherwise it's lower than the global benchmark.

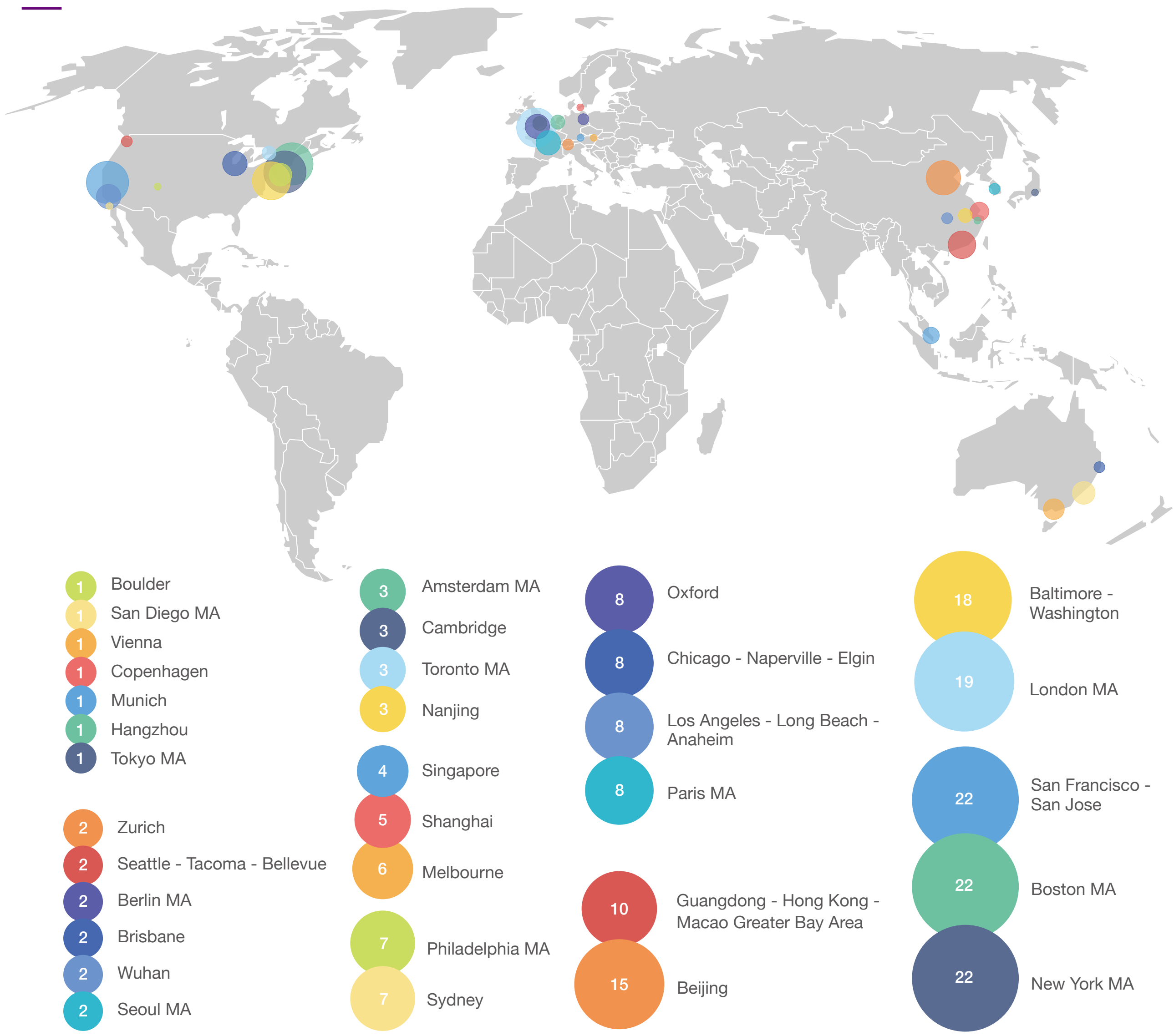
60 100

Based on the number of highly cited papers by discipline, a total of 33 cities/metropolitan areas are defined as global discipline hubs (Figure 11). They are mainly located in North America, Western Europe and East Asia, with about ten cities/metropolitan areas in each region. The United States and China enjoy comparative advantages with ten cities and six cities in the list, respectively. The United Kingdom and Australia both have three cities in the list, Germany has two and the remaining nine countries each have one city in the list.

Six of the top ten global discipline hubs are in the United States, with San Francisco-San Jose, Boston MA and New York MA in the top three, and Baltimore-Washington, Chicago-Naperville-Elgin and Los Angeles-Long Beach-Anaheim ranking fifth, ninth and tenth, respectively. London MA and Oxford in the UK rank fourth and eighth. Beijing and Guangdong-Hong Kong-Macao Greater Bay Area in China rank sixth and seventh.

FIGURE 11

Distribution of global discipline hubs



Note: The bubble size indicates the number of disciplines in the top 10, ranging from 1 to 22.

3.Research innovation

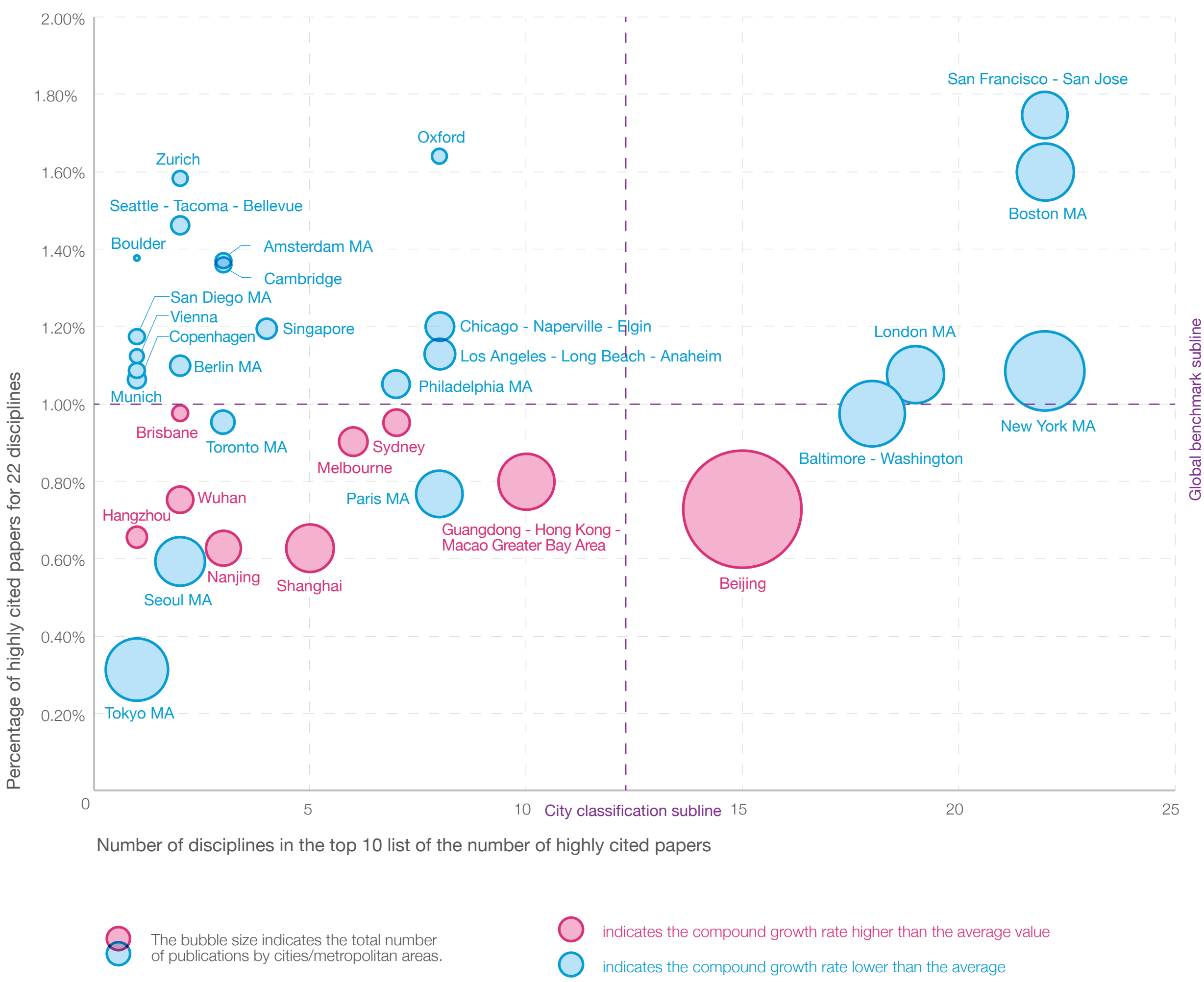
Superstar cities

Based on the number of disciplines in the top ten list by the number of highly cited papers for each city, six cities boast at least 15 disciplines in the top ten, including San Francisco-San Jose, Boston MA, New York MA, London MA, Baltimore-Washington and Beijing. These are the superstar cities of global discipline hubs. The remaining 27 cities/metropolitan areas lag significantly behind compared to the superstar cities.

Geographically, superstar cities represent the 'three poles' of global discipline-sourcing capabilities – North America, Western Europe and East Asia (the right side of the vertical dotted line in Figure 11). There are four superstar cities/metropolitan areas in the United States, with San Francisco-San Jose, Boston MA and New York MA in the top ten across all 22 disciplines. London MA, as the representative of Western Europe, has 19 disciplines in the top 10. Beijing, as the representative of East Asia, has 15 disciplines in the top 10.

FIGURE 12

Overall performance of global discipline hubs



By looking at the number of highly cited papers in each discipline published by each city, New York MA and Beijing rank first in eight disciplines and seven disciplines, respectively. New York MA ranks first in five of 11 disciplines in the humanities, arts and social sciences and Beijing ranks first in six of 11 disciplines in science, technology, engineering and medicine.

Champion cities

Among the 22 discipline champion cities, New York MA and Beijing lead in eight disciplines and seven disciplines, respectively, showing their absolute strengths. New York MA ranks first in biomedical and clinical sciences as well as two disciplines in science, technology, engineering and medicine (STEM), namely mathematical sciences and physical sciences. It also ranks first in five disciplines in the humanities, arts and social sciences (HASS). Beijing only ranks first in built environment and design in HASS, but it is leading in six disciplines in STEM, accounting for more than half of the total 11 disciplines in STEM. In addition, Boston MA and London MA each rank first in three disciplines and Guangdong-Hong Kong-Macao Greater Bay Area are leading in one discipline.

City of disciplinary excellence

This report measures disciplinary excellence using the percentage of highly cited papers in the discipline. According to the definition, highly cited papers in a given discipline account for 1% of the total number of papers published in that discipline globally and this value is set as the global benchmark. The average percentage of highly cited papers in the 22 disciplines published by the global discipline hubs represents the overall disciplinary excellence of a hub. An average percentage of highly cited papers higher than the global benchmark indicates a high level of disciplinary excellence.

Except for some individual cities/metropolitan areas, the average percentage of highly cited papers in cities/metropolitan areas in North America and Western Europe is mostly close to or higher than the global benchmark of 1% and the overall disciplinary excellence is high. For example, as a superstar city/metropolitan area, San Francisco-San Jose has an average percentage of highly cited papers of 1.75%, ranking first among 33 cities. Oxford follows with 1.64%, and Boston MA ranks third with an average of 1.60%. Except for a few cities, the average percentage of highly cited papers for cities/metropolitan areas in East Asia is below the global benchmark of 1% and the overall disciplinary excellence is still far behind that of cities in North America and Europe. Notably, the percentage of highly cited papers is a proportional indicator, where the performance of a city is positively affected by the numerator, known as the number of highly cited papers, but negatively affected by the denominator, known as the total number of publications. With the number of highly cited papers being similar, cities with a small total number of publications tend to perform better in this indicator. Cities with extremely large number of publications are more likely to be close to the global benchmark.

3.Research innovation

Emerging science city

The development of disciplines varies from city to city. The nature of a mature city/metropolitan area implies that the total number of annual publications remains at a certain level and the increase is slow, highly cited papers account for a decent share of the total and the overall disciplinary excellence reaches or exceeds the global benchmark. For emerging science cities/metropolitan areas, the total number of annual papers published and the number of highly cited papers are both increasing rapidly, but the proportion of highly cited papers is relatively small and below the global benchmark.

The size and colour of bubbles in Figure 12 indicate the total number of papers and the compound annual growth rates of the 33 discipline hubs in the list. A total of nine cities were identified as emerging science cities (red bubbles below the horizontal baseline). Among the top ten cities by the number of published papers over ten years, there are five superstar cities and the top three are Beijing, New York MA and Baltimore-Washington, followed by Tokyo MA, London MA, Boston MA, Guangdong-Hong Kong-Macao Greater Bay Area, Seoul MA, Shanghai and Paris MA. The one with the least publications among superstar cities is San Francisco-San Jose, ranking 11th. The average compound annual growth rate (CAGR) of papers published by cities in the list over ten years is 6.1%. A total of nine emerging science cities have higher growth rates than the average and

China's emerging cities are experiencing a period of movement from quantitative change to qualitative change: the total number of published papers has grown rapidly and the number of highly cited papers has exploded in some disciplines. It is gradually moving towards a mature stage that features a small increase in total number of publications and a high level of overall excellence.

the top six cities/metropolitan areas are all in China, namely Guangdong-Hong Kong-Macao Greater Bay Area, Nanjing, Wuhan, Hangzhou, Shanghai and Beijing, with an average CAGR of more than 10%, with Guangdong-Hong Kong-Macao Greater Bay Area having the highest growth rate and Beijing the lowest growth rate. Melbourne, Sydney and Brisbane rank seventh to ninth, with a CAGR of about 8%. For these nine cities, the percentage of highly cited papers is below the global benchmark of 1%, indicating that there is still much room for growth. It is expected that if the development environment remains unchanged, Chinese and Australian cities will be further improved in discipline-sourcing capabilities and overall excellence as discipline hubs.

Regional agglomeration of disciplines

To explore the disciplinary characteristics of the cities in the list, this report uses the agglomerative hierarchical clustering algorithm to carry out bottom-up clustering iteration on the approximation degree (Euclidean distance) of the discipline share distribution of each city using the number of papers in 22 disciplines published by each city as a percentage of the total number of papers published by the city. The calculation results are shown in Figure 13 and the development characteristics of each city are shown in Figure 14.

Global discipline hubs display distinct characteristics by region and cities from the same country tend to perform similarly in given discipline clusters (Figure 14). The hubs can be divided into three levels with different disciplinary characteristics (Figure 14): papers in engineering, information and computing science and chemistry account for a large share of the total papers published in East Asian cities; papers in biomedicine and clinical medicine, biological science, humanities, arts and social sciences account for a large share of the total papers published in cities in North America and Western Europe. Although the disciplinary characteristics of cities in North America and Western Europe are similar overall, the latter features a higher share of basic disciplines, such as mathematics, physics and chemistry in overall publications.

FIGURE 13

Agglomerative hierarchical clustering of discipline characteristics of global discipline hubs

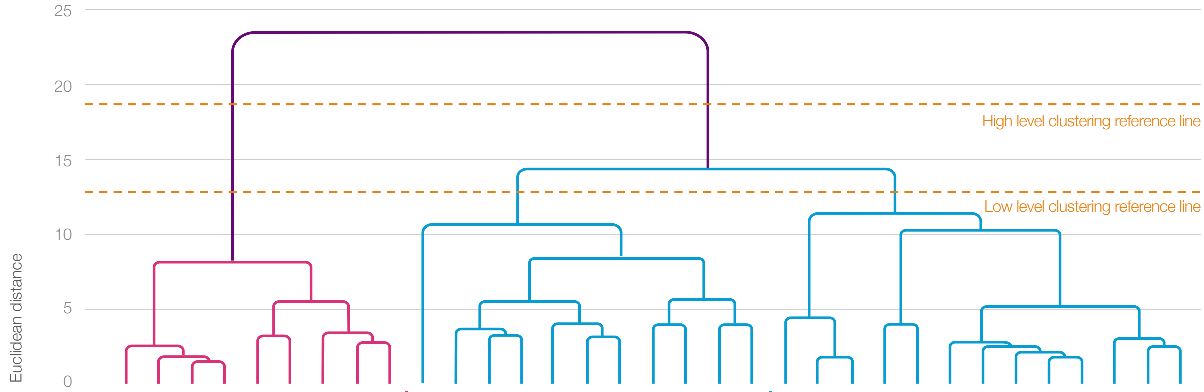
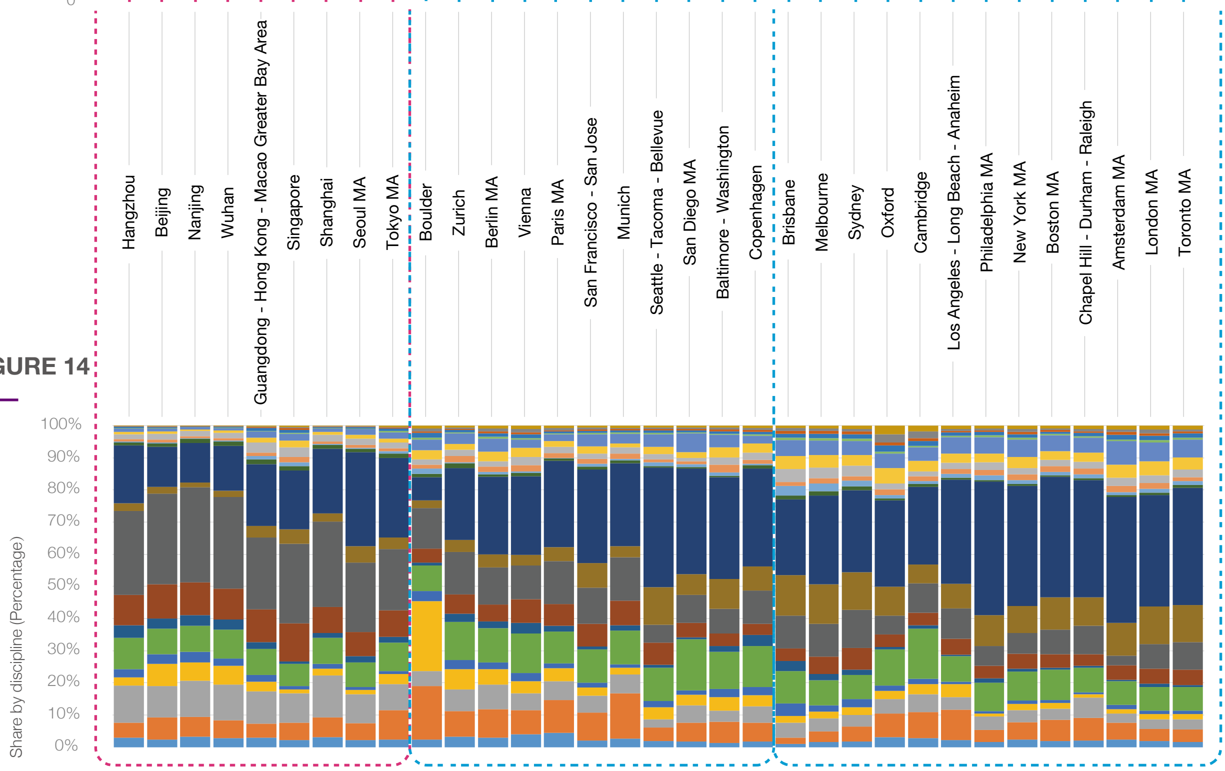


FIGURE 14



Share of publications by each discipline in the total publications for the global discipline hubs

- 01. Mathematical Sciences
- 02. Physical Sciences
- 03. Chemical Sciences
- 04. Earth Sciences
- 05. Environmental Sciences
- 06. Biological Sciences
- 07. Agricultural, Veterinary And Food Sciences
- 08. Information And Computing Sciences
- 09. Engineering
- 10. Health Sciences
- 11. Biomedical And Clinical Sciences
- 12. Built Environment And Design
- 13. Education
- 14. Economics
- 15. Commerce, Management, Tourism And Services
- 16. Human Society
- 17. Psychology
- 18. Creative Arts And Writing
- 19. Language, Communication And Culture
- 20. Law And Legal Studies
- 21. History, Heritage And Archaeology
- 22. Philosophy And Religious Studies

4. Innovation economy

In innovation economy, despite the impact of non-economic factors such as geopolitical conflicts and natural disasters, the 80-20 rule – that 80% of growth results from 20% of all cities – is more evident in GIHs driving resilient growth in the global economy. Since 2020, global patents for AI technology have grown explosively. The focus section explores the quantity, quality, trends and technology segments of AI patents.

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4.1

A comprehensive analysis of innovation economy

The GIHI2023 innovation economy ranking is shown in Table 8.

TABLE 8

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	86.64	100.00	100.00	99.17
2	Tokyo MA	82.55	100.00	72.42	76.96	72.91
3	New York MA	75.89	64.42	77.44	73.31	87.64
4	Beijing	75.74	68.79	78.67	72.33	79.95
5	Guangdong - Hong Kong - Macao Greater Bay Area	75.19	67.47	75.62	75.24	79.53
6	Seoul MA	71.50	70.59	65.31	72.58	77.63
7	Boston MA	70.92	63.62	71.95	62.80	89.19
8	Dallas - Fort Worth	70.40	65.02	61.77	73.44	84.68
9	Taipei	70.22	74.97	61.88	65.44	81.89
10	Dublin	69.74	61.87	61.94	68.71	93.15
11	Seattle - Tacoma - Bellevue	69.61	62.49	62.82	68.19	90.96
12	Singapore	69.50	64.22	61.97	61.49	100.00
13	Kyoto - Osaka - Kobe	68.93	79.10	63.84	62.62	70.33
14	Paris MA	68.72	63.53	65.16	64.30	87.03
15	Shanghai	68.69	62.93	71.93	62.76	78.71
16	San Diego MA	68.47	67.39	63.72	62.52	85.42
17	London MA	68.31	60.90	67.24	63.20	87.00
18	Austin	67.65	66.33	62.21	61.16	87.46
19	Baltimore - Washington	67.03	63.84	63.30	62.00	84.69
20	Chicago - Naperville - Elgin	66.80	60.95	63.29	63.63	85.12
21	Munich	66.66	69.94	61.62	60.32	79.37
22	Los Angeles - Long Beach - Anaheim	66.59	61.58	64.85	60.98	84.71
23	Hangzhou	66.20	63.01	65.77	61.40	78.34
24	Abu Dhabi	65.86	60.08	60.15	61.44	90.32
25	Phoenix MA	65.63	62.86	61.00	62.07	82.63
26	Perth	65.53	60.06	60.00	60.08	91.13
27	Denver MA	65.42	60.41	61.06	61.49	85.95
28	Atlanta MA	65.26	60.89	61.30	61.02	84.76
29	Chapel Hill - Durham - Raleigh	65.18	61.34	60.85	60.13	85.87
30	Houston MA	65.18	61.85	60.93	60.91	83.74
31	Copenhagen	65.14	60.08	60.94	60.26	87.17
32	Zurich	64.99	61.10	60.61	60.05	85.78

4.Innovation economy

Rank	City/metropolitan area	Innovation economy	Technological innovation capacity	Innovative enterprises	Emerging industries	Economic growth
33	Miami MA	64.98	60.20	61.13	60.20	85.90
34	Philadelphia MA	64.94	60.16	62.17	60.56	83.43
35	Daejeon	64.85	67.44	60.08	60.08	76.66
36	Stockholm	64.81	62.08	61.93	61.33	79.15
37	Istanbul	64.71	60.06	60.38	60.23	85.95
38	Minneapolis - Saint Paul	64.71	60.48	60.86	60.26	84.46
39	Suzhou	64.70	61.57	62.48	60.28	80.05
40	Pittsburgh	64.53	60.82	60.39	60.25	83.86
41	Bengaluru	64.53	60.13	62.83	61.13	79.28
42	Toronto MA	64.48	60.65	61.52	61.89	79.28
43	Nanjing	64.47	63.23	60.99	60.54	78.53
44	Detroit MA	64.43	61.57	60.31	60.00	82.77
45	Lyon - Grenoble	64.41	60.66	60.08	60.00	84.39
46	Helsinki	64.39	60.68	61.08	61.13	80.75
47	Cincinnati	64.38	60.38	60.23	60.09	84.26
48	Wuhan	64.33	61.64	61.01	60.97	79.43
49	Chengdu	64.33	63.41	61.53	60.71	76.34
50	Tel Aviv	64.28	60.34	62.13	60.16	80.45
51	Las Vegas	64.26	60.49	60.23	60.02	83.55
52	Brussels	64.22	60.19	60.47	60.46	82.70
53	Portland	64.14	60.32	60.23	60.02	83.22
54	Hefei	64.10	61.76	60.93	60.30	79.23
55	Central National Capital Region Delhi MA	64.07	60.04	61.72	61.17	78.86
56	St. Louis	64.02	60.32	60.16	60.15	82.49
57	Vancouver MA	63.96	60.57	61.15	60.98	78.79
58	Budapest	63.93	60.03	60.08	60.14	82.62
59	Qingdao	63.85	60.87	60.77	60.05	79.93
60	Prague	63.79	60.04	60.15	60.00	81.93
61	Manchester	63.79	60.18	60.23	60.03	81.55
62	Moscow	63.74	60.10	60.23	60.54	80.58
63	Nagoya MA	63.70	63.54	61.25	60.17	74.22
64	Bangkok	63.64	60.03	60.22	60.55	80.21
65	Montreal MA	63.63	60.27	60.85	60.96	78.09
66	Ankara	63.62	60.02	60.08	60.01	81.20

Rank	City/metropolitan area	Innovation economy	Technological innovation capacity	Innovative enterprises	Emerging industries	Economic growth
67	Oslo	63.62	60.51	60.69	60.20	79.13
68	Jinan	63.55	61.02	60.39	60.28	78.45
69	Tianjin	63.53	60.74	60.77	60.65	77.47
70	Fuzhou	63.51	60.54	60.47	60.13	79.01
71	Warsaw	63.49	60.01	60.08	60.38	79.95
72	Busan	63.45	60.74	60.00	60.02	79.43
73	Buenos Aires	63.38	60.00	60.15	60.10	79.70
74	Mexico City	63.35	60.00	60.37	61.42	77.07
75	Lisbon	63.32	60.02	60.08	60.00	79.69
76	Kuala Lumpur	63.30	60.24	60.15	60.63	78.11
77	Amsterdam MA	63.23	60.71	61.69	60.94	73.94
78	Changsha	63.20	60.96	60.77	60.33	75.98
79	Sydney	63.19	60.34	60.61	60.28	77.17
80	Xiamen	63.13	60.91	60.78	60.23	75.84
81	Jakarta	63.12	60.00	60.67	60.93	76.17
82	Chongqing	63.09	60.41	60.77	60.34	76.18
83	Stuttgart	63.08	62.07	60.39	60.02	74.89
84	Berlin MA	63.04	60.68	61.79	60.08	74.21
85	Dusseldorf	63.02	60.01	60.31	60.04	77.66
86	Dalian	62.96	60.50	60.16	60.00	76.96
87	Frankfurt	62.87	60.15	60.70	60.00	76.05
88	Hamburg	62.85	61.28	60.70	60.01	74.32
89	Milan	62.71	60.38	60.62	60.59	74.10
90	Lanzhou	62.64	60.18	60.00	60.01	76.03
91	Melbourne	62.58	60.03	60.77	60.88	73.22
92	Xi'an	62.55	61.37	60.39	60.67	72.11
93	Chennai MA	62.52	60.00	60.23	60.25	74.92
94	Rotterdam	62.46	60.05	60.08	60.19	74.88
95	Göteborg	62.41	60.34	60.47	60.00	73.83
96	Zhengzhou	62.22	60.30	60.23	60.04	73.20
97	Brisbane	62.20	60.02	60.38	60.03	73.30
98	Changchun	62.17	60.43	60.31	60.06	72.59
99	Cologne	62.10	60.00	60.23	60.04	73.01
100	Vienna	61.88	60.16	60.38	60.13	71.29

4.Innovation economy

The top city in innovation economy is San Francisco-San Jose, well ahead of Tokyo MA and New York MA at second and third. Among the top 20, nine cities/metropolitan areas are in the United States, eight in China and three in Europe.

As shown by the trends, San Francisco-San Jose and Tokyo MA have ranked first and second for three consecutive years. The livability and innovation capabilities of these two cities/metropolitan areas have attracted many innovative enterprises. These cities have gathered global top talent with their internationalization, incubated many emerging industries with an open economic structure and driven high-level economic development by providing resources efficiently. New York MA has risen over the years and entered the top three in 2023. In addition, in the top 20 cities, Dallas-Fort Worth and Chicago-Naperville-Elgin have recorded the most significant increase, up by seven and eight spots, respectively. Dallas-Fort Worth has made the top ten for the first time. In recent years, Texas has taken off in economy with its preferential tax and real estate policies. The overall economic strength has driven the rapid transformation of Dallas-Fort Worth, supporting the development of its financial markets and technology industries. Chicago-Naperville-Elgin's fast growth is also largely due to its economic development. As one of the most important economic and financial centres in the United States, Chicago-Naperville-Elgin has gathered high-end service industries, which have high labour productivity and help speed its GDP growth.

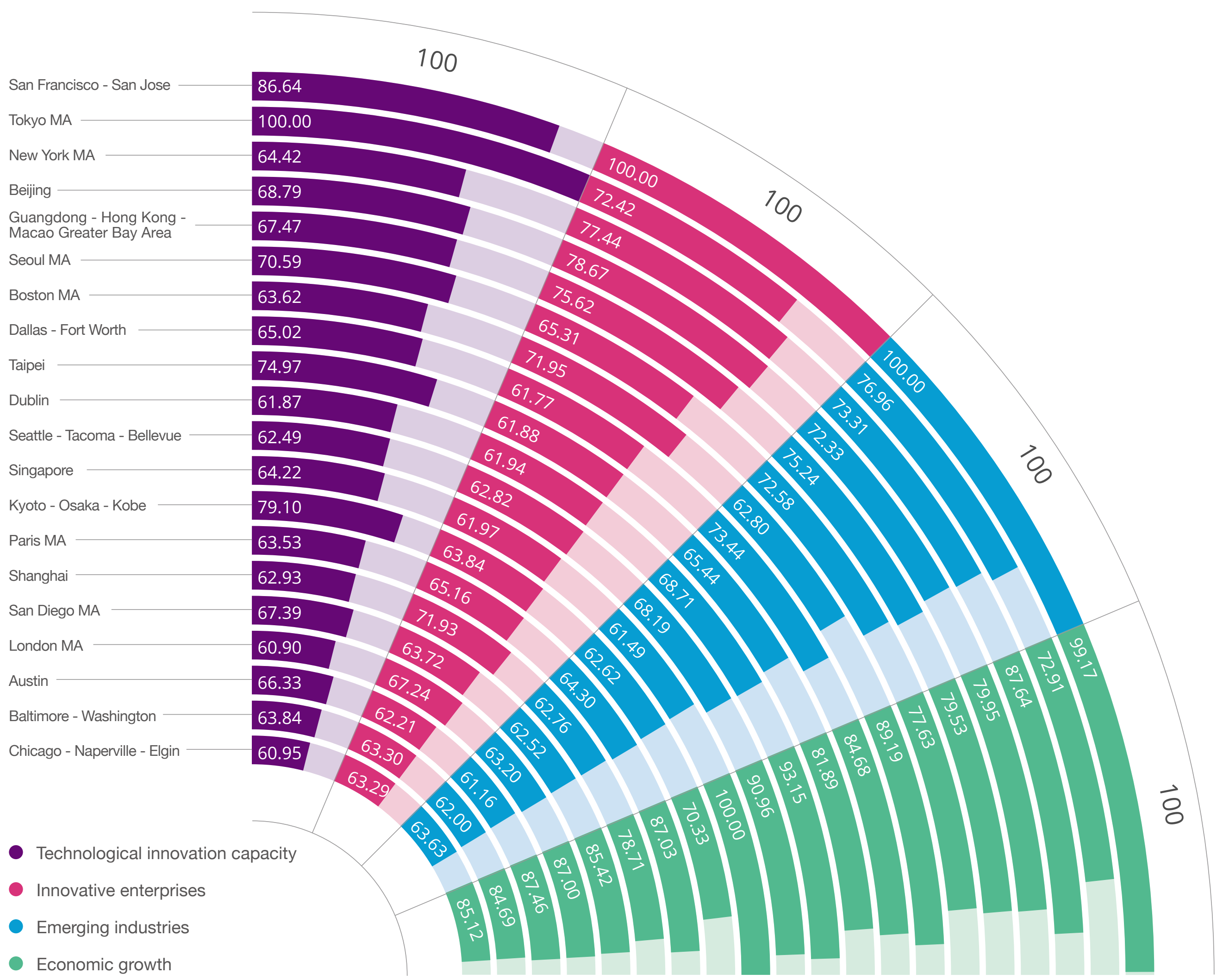
TABLE 9 A comparison of the top 20 GIHs in innovation economy between 2021-2023

City/metropolitan area	Rank 2023	Rank 2022	Rank 2021
San Francisco - San Jose	1	1	1
Tokyo MA	2	2	2
New York MA	3	4	5
Beijing	4	3	3
Guangdong - Hong Kong - Macao Greater Bay Area	5	7	4
Seoul MA	6	6	6
Boston MA	7	11	8
Dallas - Fort Worth	8	15	12
Taipei	9	9	N/A
Dublin	10	8	11
Seattle - Tacoma - Bellevue	11	12	9
Singapore	12	17	16
Kyoto - Osaka - Kobe	13	5	7
Paris MA	14	18	15
Shanghai	15	13	13
San Diego MA	16	14	14
London MA	17	20	17
Austin	18	16	10
Baltimore - Washington	19	32	27
Chicago - Naperville - Elgin	20	28	25

The top 20 cities/metropolitan areas in innovation economy have diverse advantages in each sub-indicator. San Francisco-San Jose ranks first overall and stands out across four level-2 indicators, leading both in innovative enterprises and emerging industries. It ranks second in economic growth after Singapore and second in technological innovation capacity after Tokyo MA. Apart from San Francisco-San Jose, Asian cities such as Tokyo MA, Kyoto-Osaka-Kobe and Taipei have much stronger technological innovation capacity than others. Tokyo MA, Beijing, New York MA, Guangdong-Hong Kong-Macao Greater Bay Area and Seoul MA outperform in the emerging industries and innovative enterprises. Singapore, Dublin, Seattle-Tacoma-Bellevue, Boston MA, New York MA and Austin stand out in economic growth.

FIGURE 15

Development patterns of the top 20 GIHs in innovation economy



4.2
Technological innovation capacity

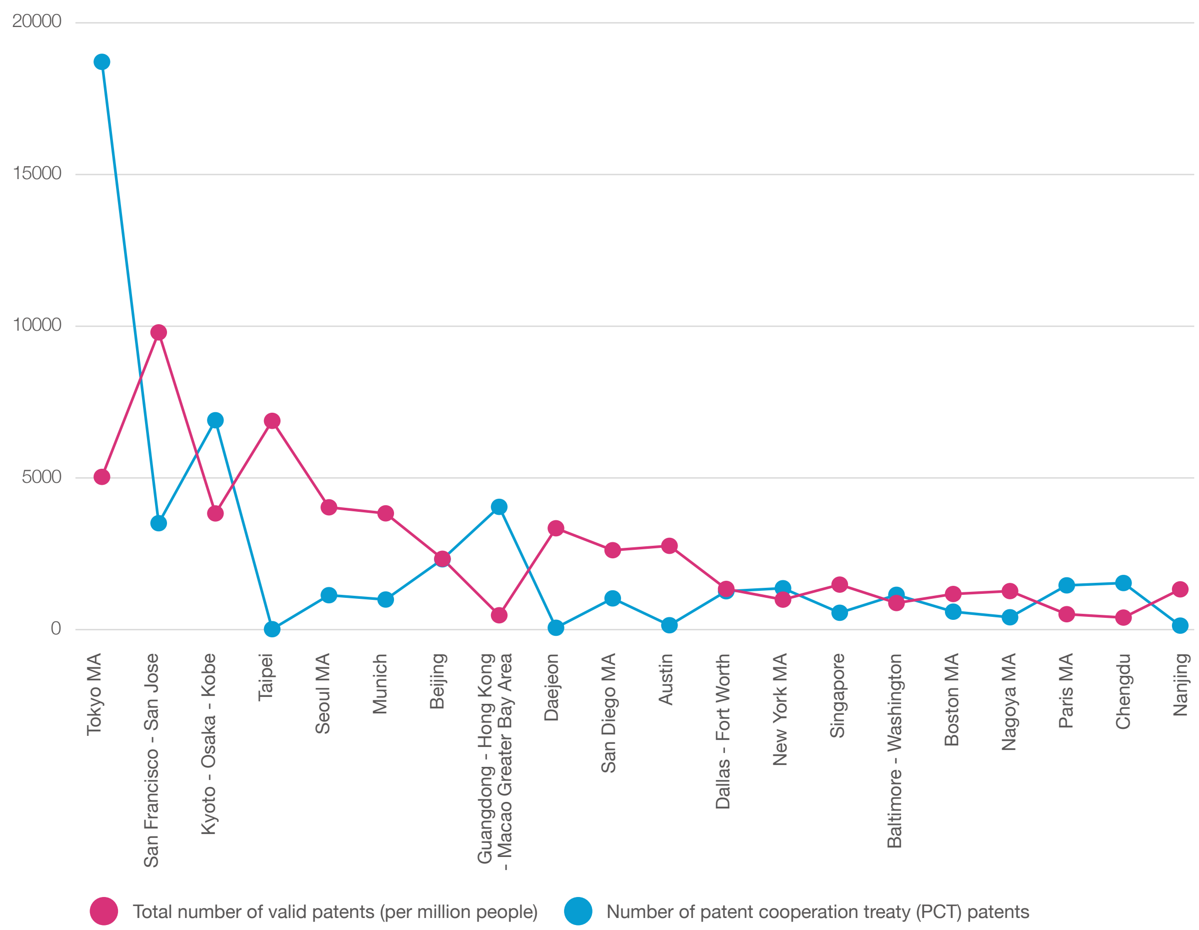
Patents are an important indicator of technological innovation capacity. The number and quality of patents reflect the level of technological innovation of a city/metropolitan area. This report evaluates technological innovation capacity using the number of valid invention patents (per million people) and patent cooperation treaty (PCT) patents for artificial intelligence (AI), integrated circuit (IC) and renewable energy technology.

The top five cities/metropolitan areas in technological innovation capacity are Tokyo MA, San Francisco-San Jose, Kyoto-Osaka-Kobe, Taipei and Seoul MA. Among the top 20, 11 cities are in Asia, seven in the United States and two in Europe.

For the number of valid invention patents (per million people), there are six cities/metropolitan areas that have more than 3,500 patents per million people, which are San Francisco-San Jose, Taipei, Tokyo MA, Seoul MA, Munich and Kyoto-Osaka-Kobe. In recent years, high-quality talent and resources have moved toward science centres at a faster pace. Take San Francisco-San Jose as an example, it ranks first with 9,835 valid invention patents per million people. Japan has systematically implemented its national intellectual property (IP) strategy since 2002, putting in place a complete system for formulating, implementing and evaluating IP strategies. As a result, Tokyo MA is far ahead of other cities/metropolitan areas with 18,742 PCT patents, and ranks first in the fields of AI, IC and renewable energy. Kyoto-Osaka-Kobe comes in second with 6,942 PCT patents. Across East Asia, Guangdong-Hong Kong-Macao Greater Bay Area ranks third with 4,090 PCT patents and Beijing and Chengdu rank fifth and sixth, respectively.

FIGURE 16

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



4.3
Innovative enterprises

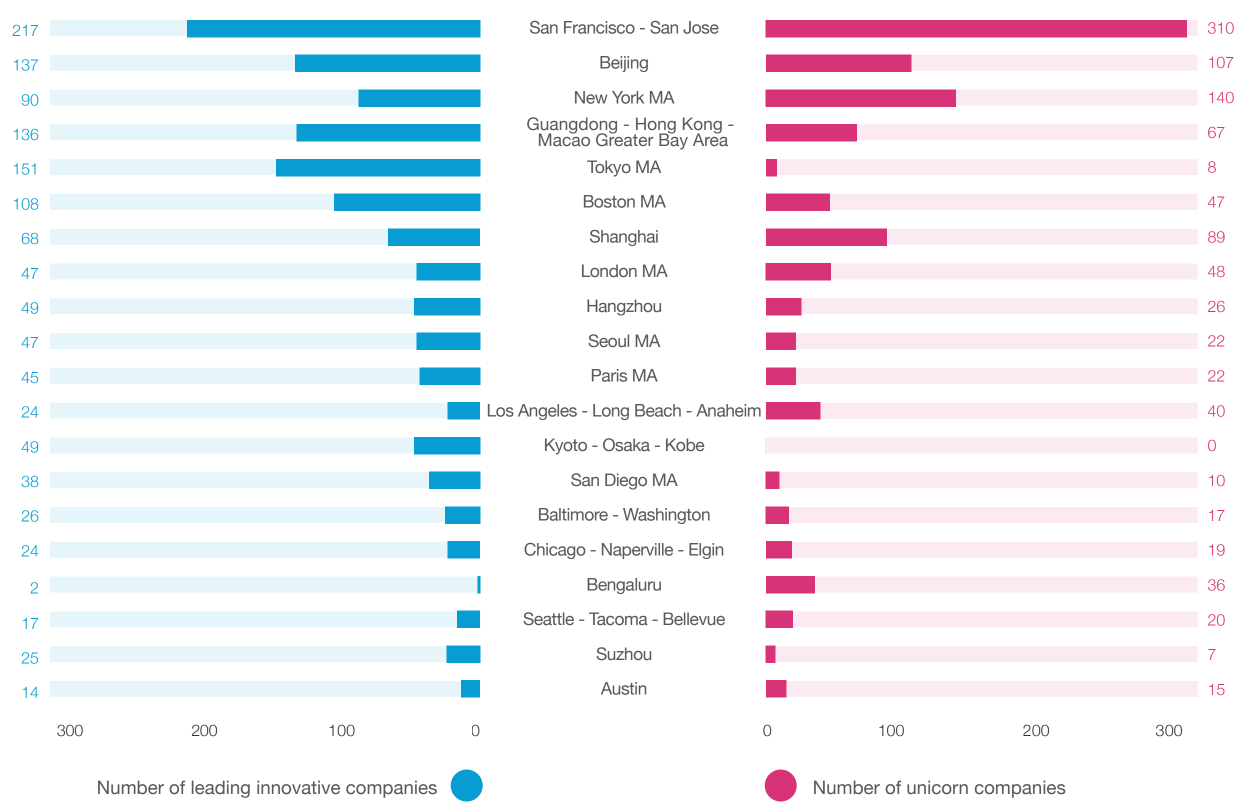
Enterprises are the major actors of technological innovation. This report uses the number of leading innovative companies and the number of unicorn companies to measure the scale and vitality of innovative companies. The top five cities/metropolitan areas in innovative enterprises are San Francisco-San Jose, Beijing, New York MA, Guangdong-Hong Kong-Macao Greater Bay Area and Tokyo MA. Asian cities account for nine spots in the top 20 list.

San Francisco-San Jose is far ahead with 217 leading innovative companies and is in a good position to support innovative talent and start-ups with its high-end human resources, abundant venture capital and diversified culture. Chinese cities also perform well, with Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, Shanghai and Hangzhou ranking third, fourth, seventh and eighth, respectively. The outstanding performance of Chinese cities is a result of China's resolution to take self-reliance and strength in science and technology as the strategic support for national development, focus on innovation and build an innovation ecosystem. It is also attributed to the fact that Chinese enterprises have kept strengthening on the front of innovation and increasingly invested in research and development to transform the development model from being big to being powerful.

San Francisco-San Jose, New York MA and Beijing lead the world with 310, 140 and 107 unicorn companies, respectively. Notably, known as the 'Silicon Valley of India', Bengaluru has seen rapid development in its tech enterprises. It has many more unicorn companies (36, ranking ninth) than leading innovative companies (two, ranking 78th). The opposite is true for Tokyo MA and Kyoto-Osaka-Kobe, where there are far more leading innovative companies than unicorn companies. Tokyo MA has 151 leading innovative companies and eight unicorn companies, while Kyoto-Osaka-Kobe has 49 leading innovative companies but no unicorns.

FIGURE 17

Number of leading innovative companies and unicorn companies for the top 20 GIHs in innovative enterprises



4.Innovation economy

4.4
Emerging industries

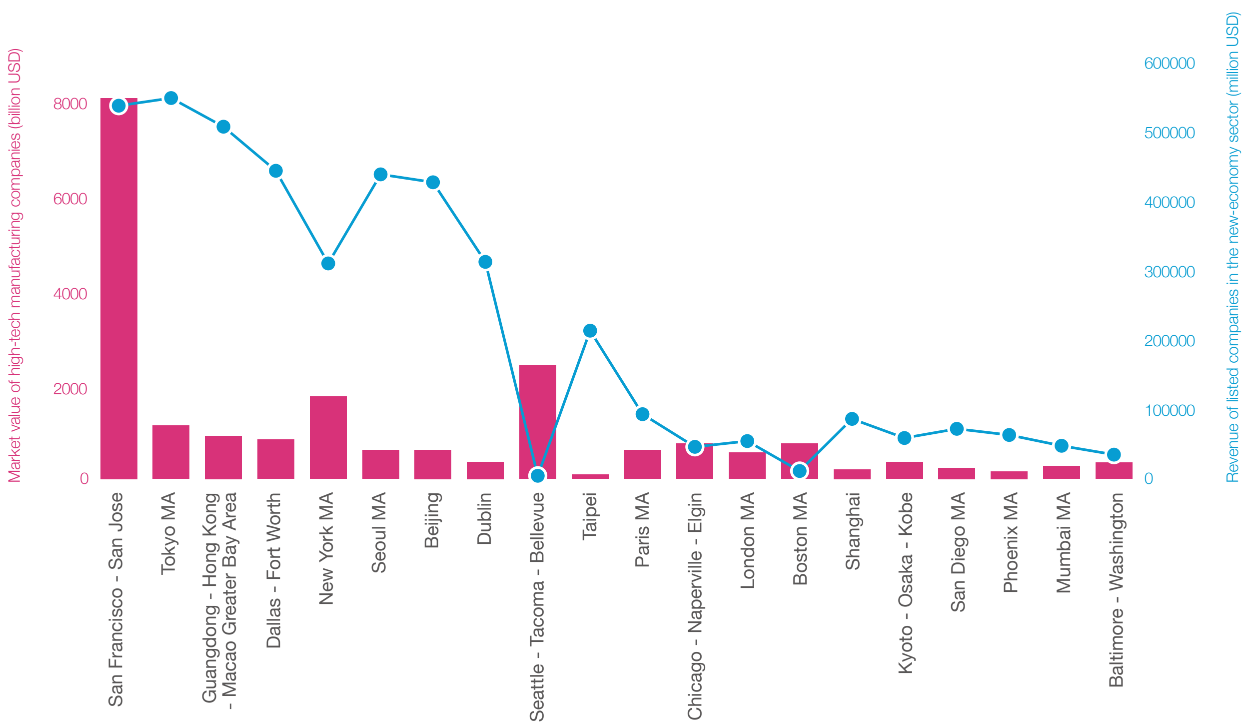
Emerging industries refer to high-tech manufacturing and new economy industries that help sustain the competitive edge of the economy, such as biomedicine, high-end equipment manufacturing and next-generation information technology. This report uses the market value of high-tech manufacturing companies and the revenue of listed companies in new economy industries to measure the activity of emerging industries. The top five cities/metropolitan areas for emerging industries are San Francisco-San Jose, Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, Dallas-Fort Worth, and New York MA.

The top three cities/metropolitan areas in terms of market value of high-tech manufacturing companies are all in the United States: San Francisco-San Jose, Seattle-Tacoma-Bellevue and New York MA. The market value of electronic information enterprises in US cities/metropolitan areas account for 72.5% of that of all the assessed cities/metropolitan areas and is notably high in San Francisco-San Jose and Seattle-Tacoma-Bellevue. New York MA is well positioned in the pharmaceutical industry because many of the world's top pharmaceutical companies, such as Pfizer, Johnson & Johnson and Merck, have their headquarters there, showing a cluster effect. New York MA has also been active in developing innovative pharmaceutical start-ups in biotechnology, medical equipment and other fields.

When looking at the revenue of listed companies in new economy industries, the Asian cities of Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area and Seoul MA hold the first, third and fifth positions respectively, with US cities/metropolitan areas San Francisco-San Jose second and Dallas-Fort Worth fourth. In recent years, many companies in the new economy industries have moved their headquarters to Texas, which offers preferential taxes and a relatively low cost of living. Fortune 500 health care company McKesson moved its headquarters to Irving near Dallas in 2019; Financial services company Charles Schwab moved its headquarters to Westlake near Fort Worth. The result is that Dallas-Fort Worth has seen significant increases in revenue of listed companies in the new economy industries. Asian cities take up five spots in the top ten. There are a vast number of potential users in Asia due to its large population. Companies in the new economy sector are expanding rapidly and Asian cities stand to benefit from the scale effect of the digital economy and are catching up quickly.

FIGURE 18

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



4.5
Economic growth

This report uses the GDP growth rate in 2021, adjusted by purchasing power parity (PPP), to measure a city's overall economic growth and living standards. Labour productivity in 2021 is used to measure social productivity. The top five cities/metropolitan areas in economic growth are Singapore, San Francisco-San Jose, Dublin, Perth and Seattle-Tacoma-Bellevue.

With respect to GDP growth, 90% of the assessed cities achieved positive GDP growth in 2021, compared to only 29% in 2020, showing that leading cities are gradually recovering from the COVID-19 pandemic and epidemic control policies at national/local levels had a distinct impact on their economic recovery. In terms of labour productivity, the top 20 cities/metropolitan areas have been stable in the past two years, with Singapore, San Francisco-San Jose, Seattle-Tacoma-Bellevue, Dublin and Boston MA remaining in the top five.

FIGURE 19

The GDP growth rate and labour productivity for the top 20 GIHs in economic growth

4.Innovation economy

FOCUS

PATENTS FOR ARTIFICIAL INTELLIGENCE

Transformative AI technologies represented by mobile Internet, big data and supercomputing are emerging which promote the progress of the digital economy and serve as an important engine for new economic growth. In 2023, large language models (LLM), such as ChatGPT, surprised the world by opening up new possibilities for AI applications. AI is driving scientific and technological revolution, industrial transformation and social progress. They are playing an increasingly important role in the innovation and development of GIHs.

This report uses public data of AI patents and three indicators to further compare the innovation capacity of GIHs in AI: the number of valid patents; the number of high-quality patents; and the distribution of the International Patent Classification (IPC), to measure the quantity, quality and technical advantages of technological innovation. The measurement methods are detailed in Appendix IX.

Quantity of patents

In terms of the total number of valid patents, Chinese cities lead the world, with Beijing ranking first in the total number of AI patents.

As patents are valid for 20 years, the valid patents used in this report were published after 2003. Beijing is way ahead with 26,638; Guangdong-Hong Kong-Macao Greater Bay Area rank second with 20,207, Tokyo MA rank third with 16,587, and Seoul MA and San Francisco-San Jose rank fourth and fifth with 9,908 and 9,341, respectively. In general, Chinese cities lead the world in the total number of valid AI patents, accounting for 14 of the top 20 cities/metropolitan areas.

The valid patents for AI have followed a three-stage trend over time. The first stage was before 2011 when AI was still in its infancy and the development of AI technology was slow. The second stage was from 2012 to 2020 when the number of AI patents increased steadily at an average annual growth rate of 32.5% as each city/metropolitan area gradually built its technological competence in AI. The third stage has been after 2020, when AI patents have grown explosively at an average annual growth rate of 75.9%. In particular, the average annual growth rate of AI patents for Beijing and Guangdong-Hong Kong-Macao Greater Bay Area reached 77% and 92.4%, respectively. Chinese cities have become a leading force in the development of global AI technology. Notably, Tokyo MA ranked first in the number of valid AI patents before 2017, but it was overtaken by Beijing in 2018 and by Guangdong-Hong Kong-Macao Greater Bay Area in 2020.

AI patents have grown explosively after 2020. Beijing and Guangdong-Hong Kong-Macao Greater Bay Area have surpassed Tokyo MA in the number of patents, becoming the main force in the development of global AI technology.

FIGURE 20

Top 20 cities/metropolitan areas by the total number of valid patents in AI

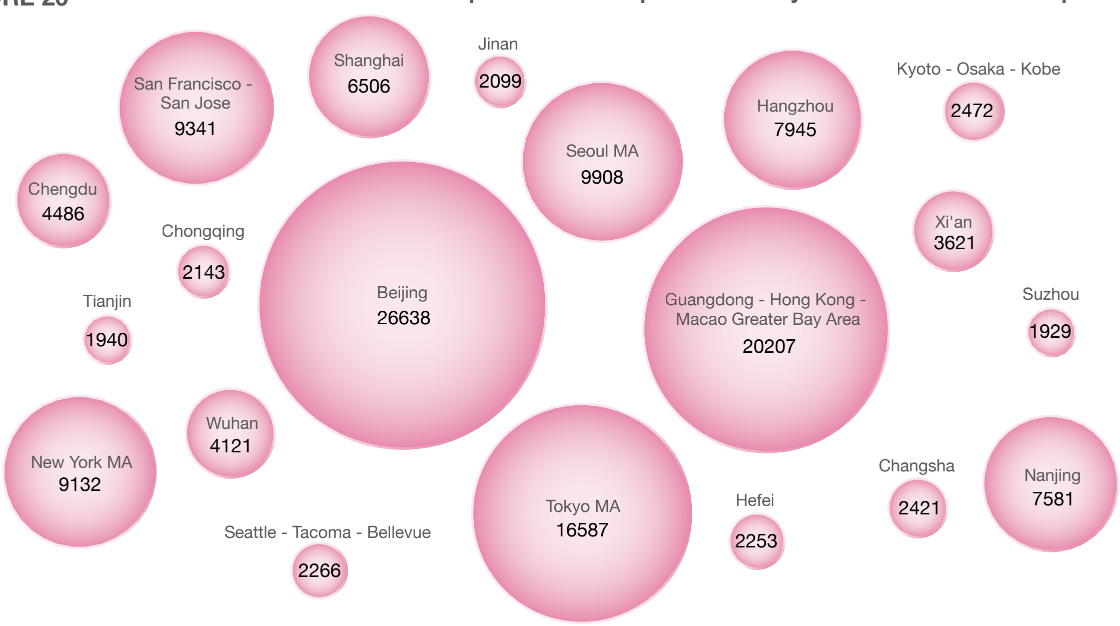
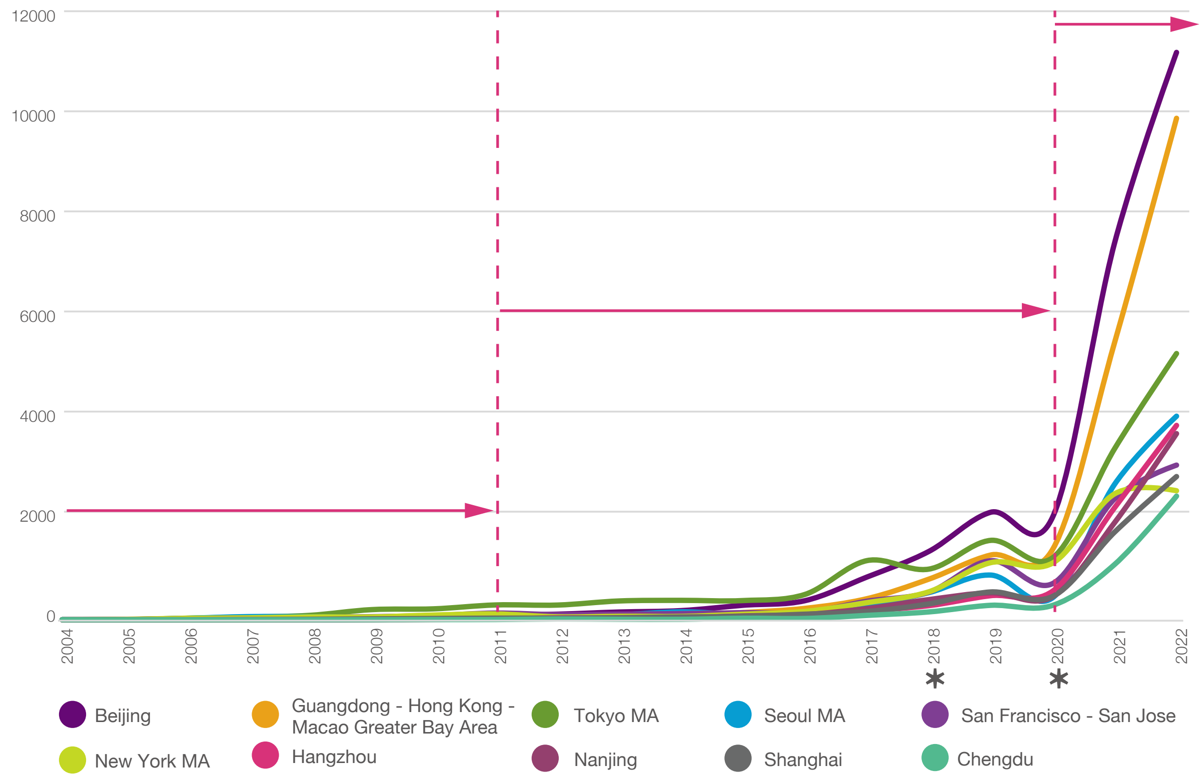


FIGURE 21

Trends of patents of the top 10 cities/metropolitan areas by the total number of valid patents in AI between 2004-2022



Note: * indicates that Tokyo is overtaken by Beijing and by Guangdong-Hong Kong-Macao Greater Bay Area, respectively.

Quality of patents

Tokyo MA is the absolute leader in the number of high-quality patents. Europe and the United States boast a high proportion of high-quality patents and outstanding performance of large high-tech enterprises.

This report uses the total number of Patent Cooperation Treaty (PCT) patents and triadic patents – which are those listed in Europe, the United States and Japan – to characterize high-quality patents. The top 20 cities/metropolitan areas for the total number of high-quality patents are Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, San Francisco-San Jose, Seoul MA, Beijing, New York MA, Kyoto-Osaka-Kobe, Eindhoven, Munich, San Diego MA, Houston MA, Paris MA, Boston MA, London MA, Shanghai, Stockholm, Stuttgart, Seattle-Tacoma-Bellevue, Nagoya MA and Hangzhou. Tokyo MA leads with 10,688 high-quality patents, while Guangdong-Hong Kong-Macao Greater Bay Area and San Francisco-San Jose rank second and third with 9,137 and 5,037 high-quality patents, respectively. The trend indicates that over the past five years, cities/metropolitan areas such as Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, San Francisco-San Jose, Seoul MA, Beijing, New York MA and Kyoto-Osaka-Kobe have maintained strong growth. Tokyo MA had held the lead until 2020 and was overtaken by Guangdong-Hong Kong-Macao Greater Bay Area in the past two years. In addition, Seoul MA and Beijing have also shown a competitive edge. Overall, among the top 20 cities/metropolitan areas for high-quality patents, five cities are in the United States, four in China, and three in Japan, which is quite different from the landscape based on the total number of patents.

In terms of the number of PCT patents, Tokyo MA is the absolute leader with 4,222 patents, followed by Guangdong-Hong Kong-Macao Greater Bay Area and Beijing with 2,769 and 1,608 patents, respectively. The remaining cities/metropolitan areas in the top ten are San Francisco-San Jose, Kyoto-Osaka-Kobe, New York MA, Seoul MA, San Diego MA, Shanghai and Dallas-Fort Worth. Among the top 20 list, the United States occupies six spots, China takes four spots, and Japan and Germany each occupy two spots, forming a landscape dominated by the United States, Europe and Asia. Regarding the proportion of PCT patents to valid patents, Stockholm, Tokyo MA, Kyoto-Osaka-Kobe, San Diego MA, Dallas-Fort Worth account for a relatively high share, reflecting their high productivity and the importance they attach to overseas markets.

4.Innovation economy

FIGURE 22

Trends of patents of the top 10 cities/metropolitan areas by the total number of high-quality patents in AI between 1970-2022

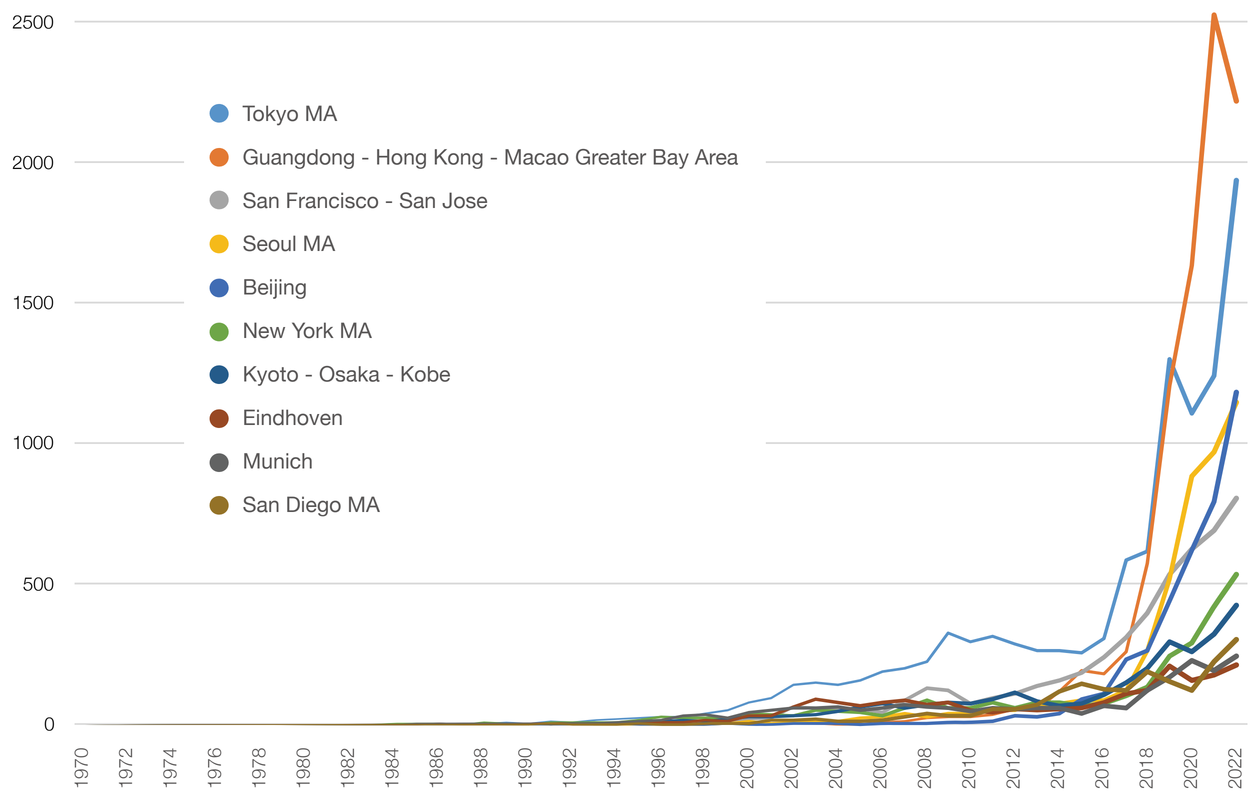
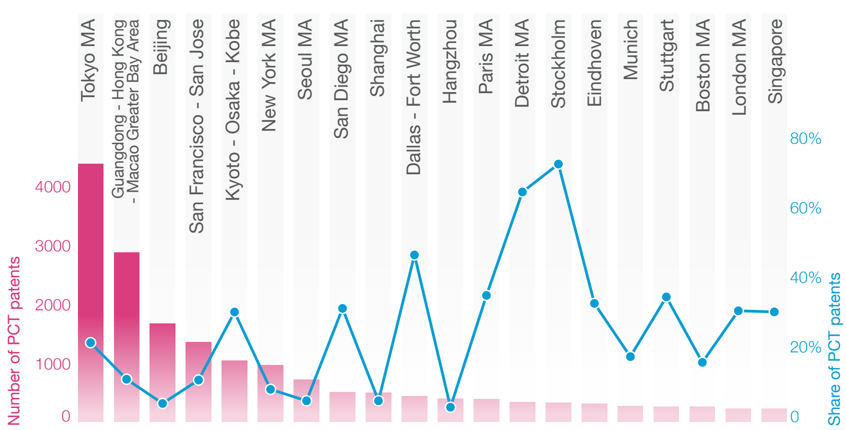


FIGURE 23

Top 20 cities/metropolitan areas by the number of PCT patents in AI



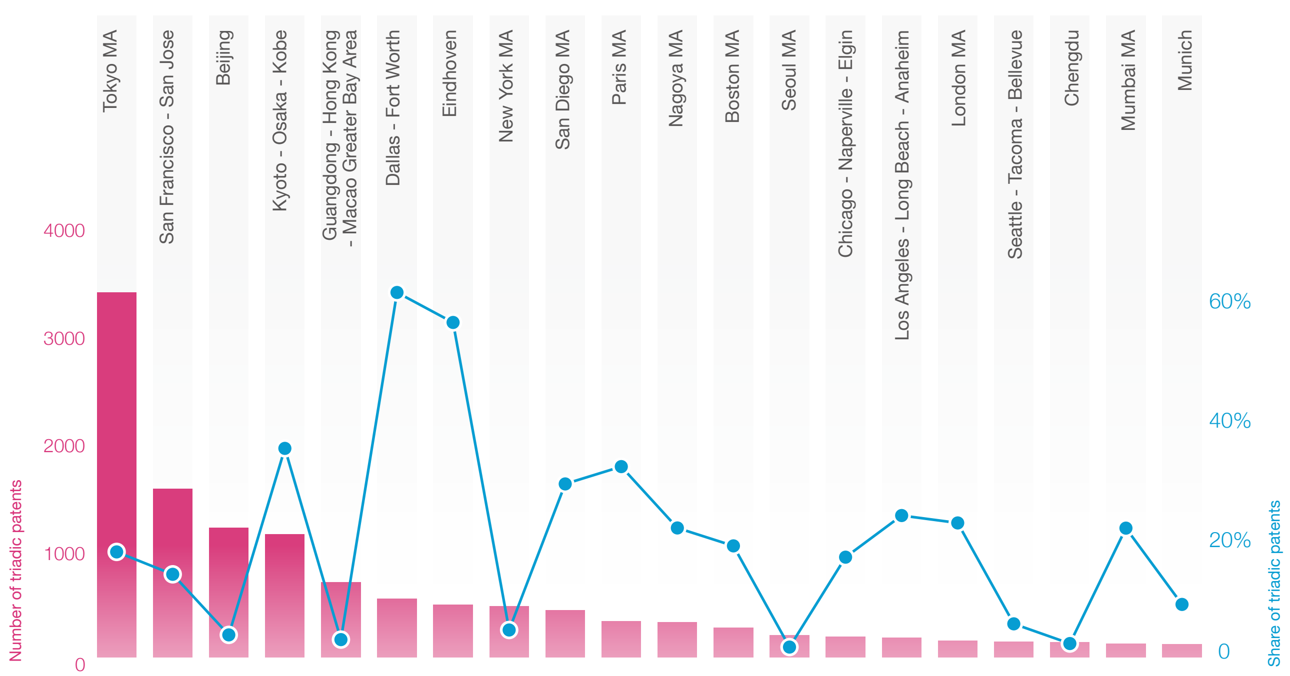
Tokyo MA still ranks first in the number of triadic patents for AI, reflecting its absolute leadership in the field. San Francisco-San Jose ranks second and Beijing third, followed by Kyoto-Osaka-Kobe, Guangdong-Hong Kong-Macao Greater Bay Area, Dallas-Fort Worth, Eindhoven, New York MA, San Diego MA and Paris MA. The United States occupies eight spots in the top 20 cities/metropolitan areas for triadic patents, while Japan and China each account for three spots, revealing these countries' strong technical strength in AI. By the proportion of triadic patents to valid patents, Dallas-Fort Worth, Eindhoven, Kyoto-Osaka-Kobe and Paris MA have a relatively high share.

There are 14 cities/metropolitan areas that have entered the top 20 in both PCT patents and triadic patents: Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, San Francisco-San Jose, Kyoto-Osaka-Kobe, New York MA, Seoul MA, San Diego MA, Dallas-Fort Worth, Paris MA, Eindhoven, Munich, Boston MA and London MA. Most of these cities/metropolitan areas are leaders in the AI industry with large high-tech enterprises. Thanks to high-tech companies such as Sony with 1,746 valid patents, NEC with 1,089, Japan's mobile communications operators with 839, and Fujitsu Group with 579, Tokyo MA has maintained its global leadership in AI for a long time. Guangdong-Hong Kong-Macao Greater Bay Area is a leader in the AI industry and with its strong industrial agglomeration it brings together high-tech enterprises such as Huawei with 2,267 valid patents, Ping An Group with 2,145, Tencent with 985, ZTE with 369 and OPPO with 368. In contrast, the holders of high-quality patents in Beijing are relatively scattered. The city mainly relies on enterprises and universities to drive its AI development: Baidu with 380 valid patents, BOE with 228, Xiaomi with 157, JD.com with 136 and other high-tech enterprises, Huawei with 121, Siemens with 71 and other cross-regional multinational enterprises, as well as Tsinghua University with 168, Peking University with 61 and other internationally renowned universities. San Francisco-San Jose has gained an edge with Google which has 2,496 valid patents, Intel with 942 and the University of California with 387. Kyoto-Osaka-Kobe is home to large companies such as Panasonic Corporation which has 869 valid patents and Omron Group with 569. Seoul MA boasts two major information technology companies: Samsung Group which has 2,131 valid patents and LG Group with 890. The technology giants IBM, which has 1,369 valid patents, Qualcomm, which has 1,250, Philips, which has 2,017 and Siemens, which has 1,506, are fundamental pillars of AI development in New York MA, San Diego MA, Eindhoven and Munich, respectively.

Tokyo MA is far ahead in high-quality patents. Tokyo MA, San Francisco-San Jose, Shenzhen, New York MA, and Seoul MA have high concentrations of high-quality patents, with large high-tech enterprises leading the way. In comparison, the entities of high-quality patents in Beijing are relatively scattered, indicating that the city is in the early stage of this market.

FIGURE 24

Top 20 cities/metropolitan areas by the number of triadic patents in AI



4.Innovation economy

Hot fields

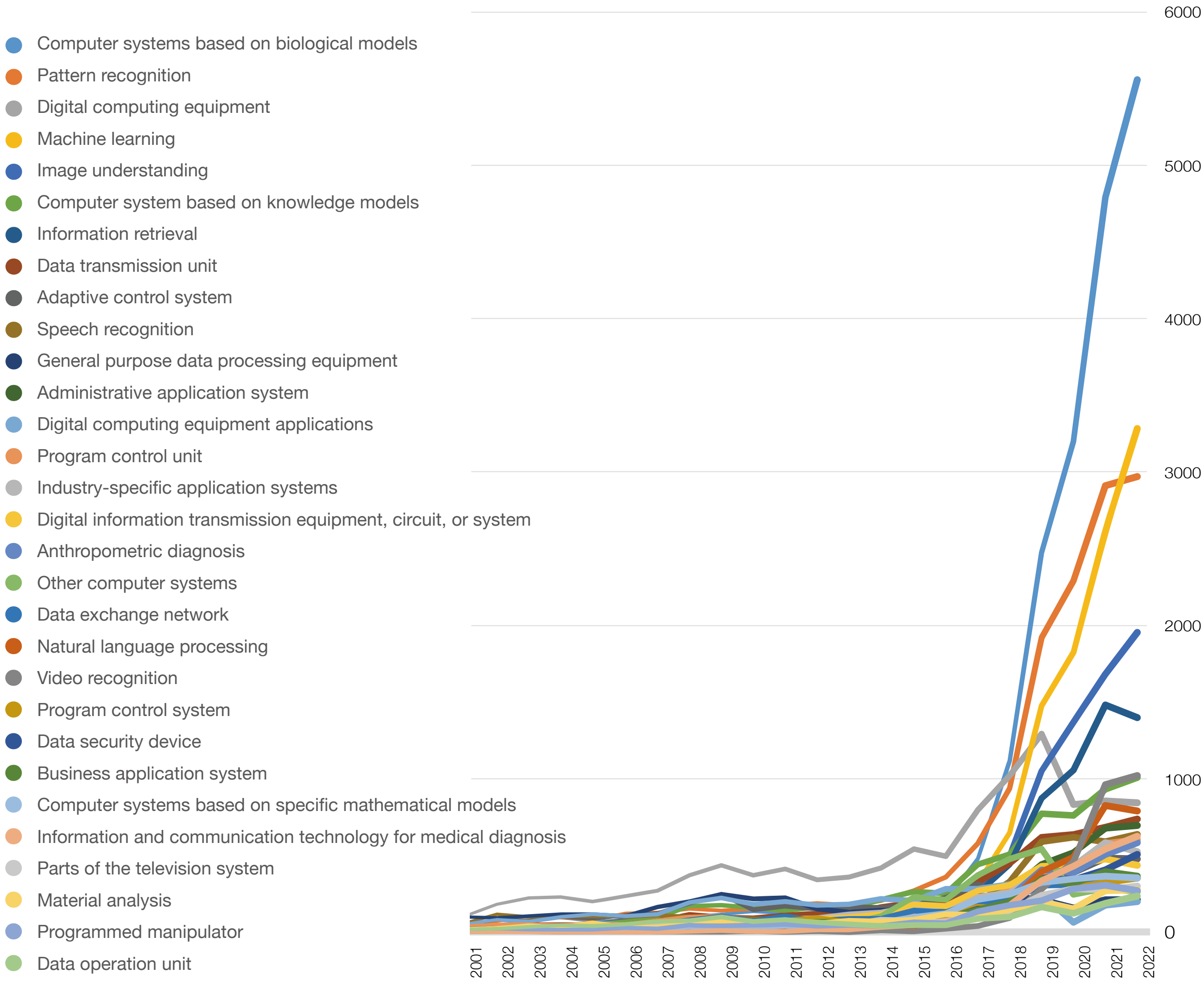
Tokyo MA and San Francisco-San Jose are leading in all aspects of AI. Chinese cities/metropolitan areas focus more on areas such as computer vision, neural networks and genetic algorithms.

This report selects the cities/metropolitan areas that are in the top 20 both in PCT patents and triadic patents and analyses the distribution of the hottest AI technologies in these cities. Hot fields are defined as the top 30 fields for high-quality patents by IPC (see Appendix IX). At present, the hot fields of AI are mainly neural network algorithms, graphics/image recognition, machine learning, automatic driving (adaptive control systems), and speech recognition. Among them, computer systems based on biological models (neural networks and genetic algorithms) has the highest number of high-quality patents of 29,514, accounting for 24.85% of the total. The 30th field is data computing devices, which records 3,611 high-quality patents, accounting for 3.04% of the total.

The hot fields have evolved over time. Digital computing devices were the key hot field in AI before 2016, as well as a key battlefield for cities/metropolitan areas. After 2016, with the rapid advancement of AI, a large number of new technologies and applications have emerged. Neural networks and genetic algorithms, pattern recognition, machine learning, image understanding and information retrieval have experienced explosive growth, injecting new impetus into AI development, driving the innovation of a new generation of AI and ushering in a new global competition landscape.

FIGURE 25

Patent trends in hot fields of AI

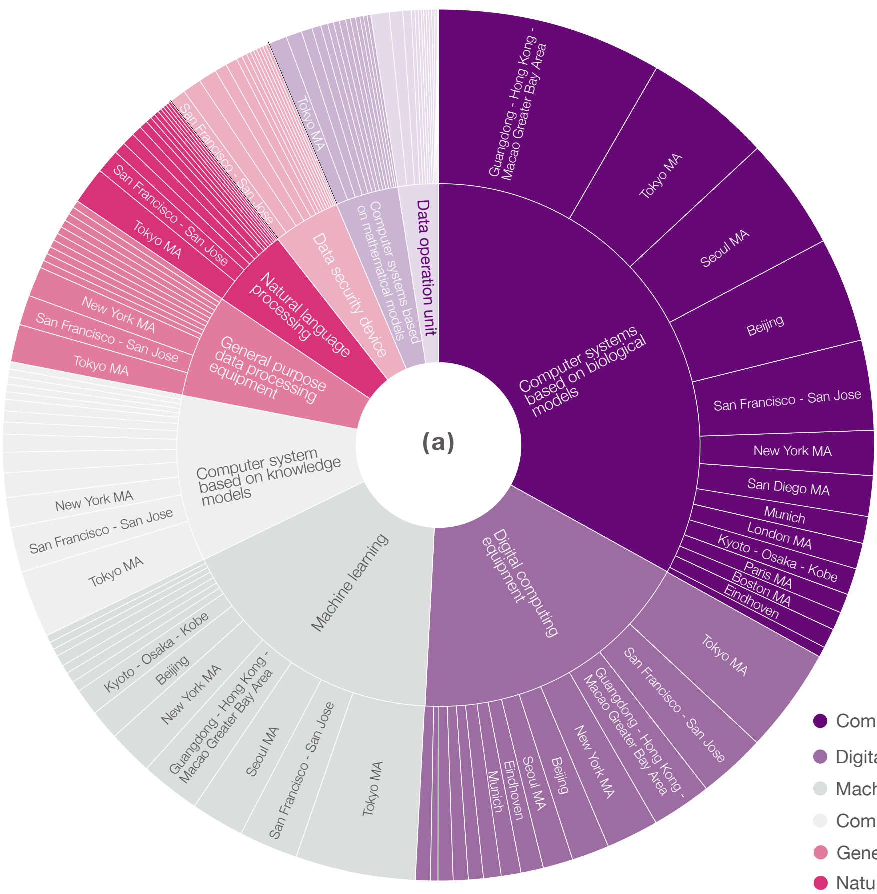


Regarding AI algorithms and computing power (see Figure 26a), with the rapid development of neural network and big data technologies, major cities/metropolitan areas attach great importance to the research and development of neural networks and genetic algorithms, digital computing devices and machine learning. Tokyo MA and San Francisco-San Jose have significant advantages in neural networks and genetic algorithms, digital computing devices and machine learning. These cities also have comparative advantages in various AI algorithms and digital computing devices. Guangdong-Hong Kong-Macao Greater Bay Area, Seoul MA and Beijing focus on the research and development of neural networks and genetic algorithms, machine learning and natural language processing. Guangdong-Hong Kong-Macao Greater Bay Area ranks first in high-quality patents of neural networks and genetic algorithms.

Intelligent control technology (as in Figure 26b) is dominated by Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, San Francisco-San Jose, Kyoto-Osaka-Kobe and New York MA. Tokyo MA and Kyoto-Osaka-Kobe attach great importance to the research and development of data transmission devices, adaptive control systems and program control systems. As a leader in AI, Tokyo MA not only has comprehensive plans in all aspects of intelligent control technology but also takes the lead in other hot fields. Guangdong-Hong Kong-Macao Greater Bay Area, San Francisco-San Jose and New York MA excel in similar fields, especially in data transmission and data exchange technologies.

FIGURE 26 (a) AI algorithm and computing power

AI hot fields across major cities/metropolitan areas



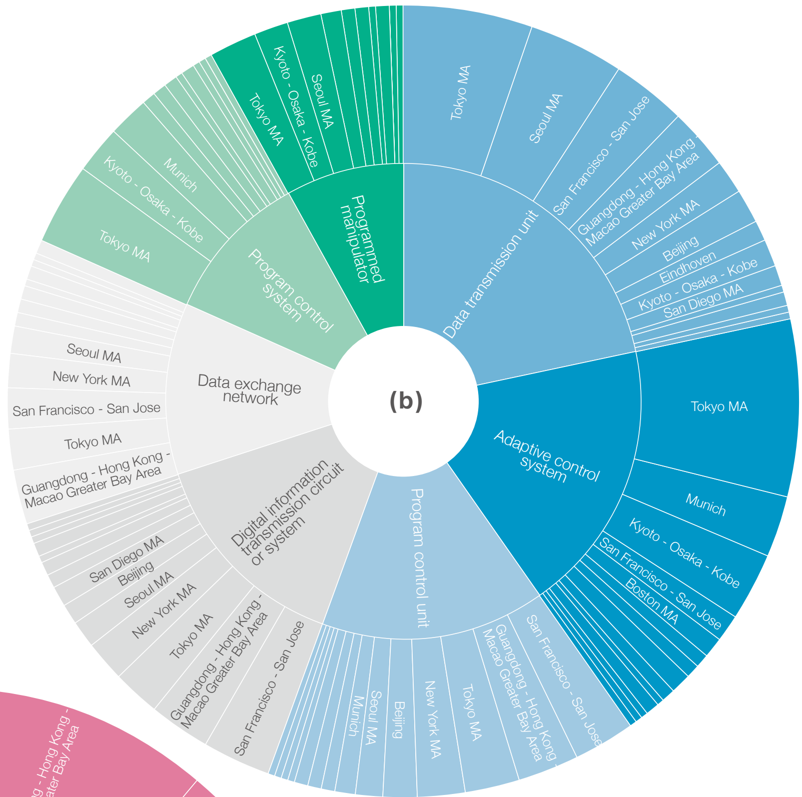
- Computer systems based on biological models
- Digital computing equipment
- Machine learning
- Computer system based on knowledge models
- General purpose data processing equipment
- Natural language processing
- Data security device
- Computer systems based on mathematical models
- Data operation unit

4.Innovation economy

FIGURE 26 (b) Intelligent control technique

AI hot fields across major cities/metropolitan areas

- Data transmission unit
- Adaptive control system
- Program control unit
- Digital information transmission circuit or system
- Data exchange network
- Program control system
- Programmed manipulator



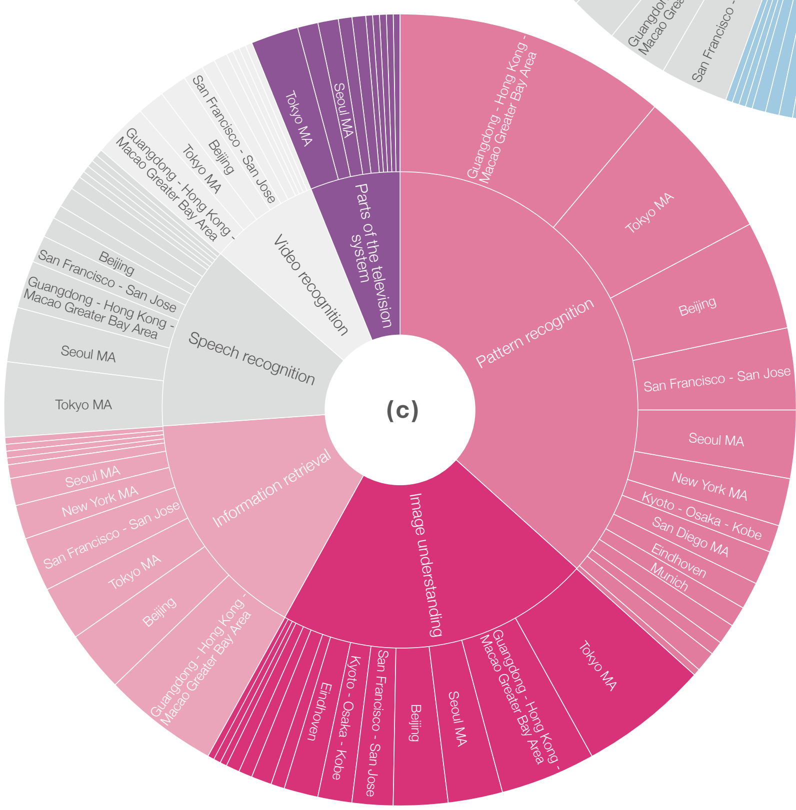


FIGURE 26 (c) Computer vision technique

- Pattern recognition
- Image understanding
- Information retrieval
- Speech recognition
- Video recognition
- Parts of the television system

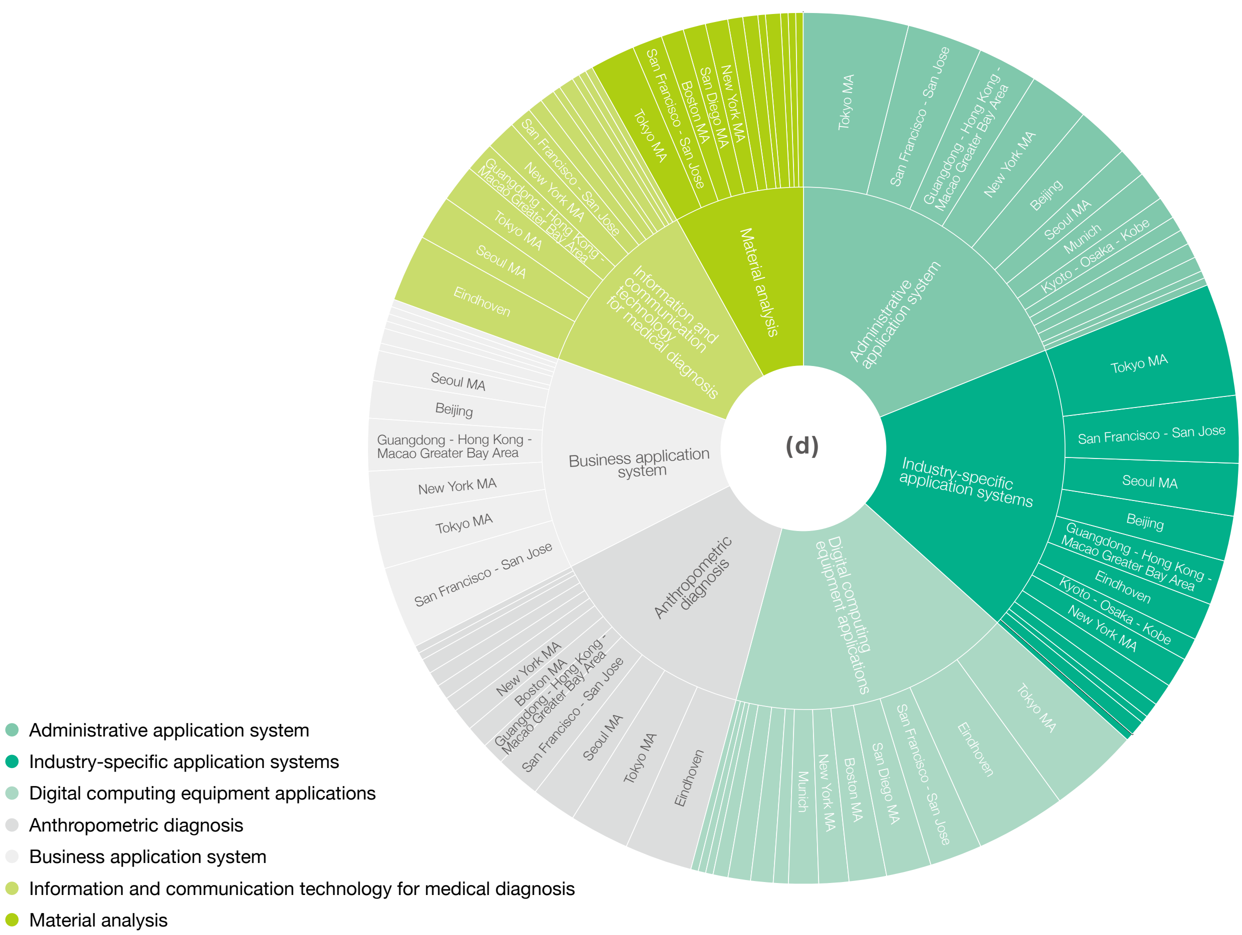
Asia is the main front for computer vision (Figure 26c). Asian cities/metropolitan areas such as Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, Tokyo MA, and Seoul MA are the major R&D spots for this technology. Guangdong-Hong Kong-Macao Greater Bay Area ranks first in the number of high-quality patents in graphic recognition, information retrieval and video recognition technology. Tokyo MA is leading in image understanding, speech recognition and television system technology and it also maintains a competitive edge in graphic recognition and information retrieval. Beijing and Seoul MA have advantages in hot fields such as graphic recognition, image understanding, information retrieval and speech recognition.

AI technology (Figure 26d) is primarily applied in the fields of medical diagnosis, anthropometry and application systems. Tokyo MA and San Francisco-San Jose have shown leading advantages in all aspects. Eindhoven performs well in digital computing equipment applications, medical diagnosis and anthropometry. Guangdong-Hong Kong-Macao Greater Bay Area and Beijing have comparative advantages in industrial applications.

Overall, GIHs show distinct strength in AI. Tokyo MA and San Francisco-San Jose are strong in all areas of AI and dominate in many, such as machine learning, knowledge processing technology, basic algorithms, speech recognition, digital information transmission, natural language processing and digital computing equipment. Chinese cities are key driving forces for AI applications, including image recognition, speech recognition, application in various industries, especially computer vision, and algorithms for biological models. Notably, Chinese cities/metropolitan areas play a pivotal role in the new wave of AI technology and are critical drivers for hot fields, such as neural networks and genetic algorithms, pattern recognition, machine learning and image understanding.

FIGURE 26 (d) AI application technology

AI hot fields across major cities/metropolitan areas



5. Innovation ecosystem

The top GIHs generally have a good innovation ecosystem. Infrastructure services and a strong culture of innovation support cities/metropolitan areas in Europe and the United States to gain a leading edge globally, while Asian cities/metropolitan areas continue to catch up by developing emerging industries and policies.

5.1

A comprehensive analysis of innovation ecosystem

The GIHI2023 ranking for innovation ecosystem is shown in Table 10.

TABLE 10

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	San Francisco - San Jose	100.00	97.95	100.00	87.14	89.80
2	London MA	98.80	98.78	84.95	100.00	99.79
3	New York MA	91.49	92.51	87.79	89.94	82.57
4	Paris MA	82.39	92.17	70.63	89.43	79.63
5	Seoul MA	82.10	98.53	72.79	81.34	75.94
6	Guangdong - Hong Kong - Macao Greater Bay Area	81.81	100.00	74.74	85.81	67.08
7	Singapore	80.89	93.57	69.39	84.41	79.06
8	Boston MA	80.08	81.06	74.69	76.58	83.99
9	Dubai	79.62	81.00	62.59	95.06	88.21
10	Phoenix MA	79.51	96.65	63.04	81.09	84.65
11	Beijing	79.24	95.88	72.17	76.71	72.69
12	Toronto MA	79.11	75.86	66.69	84.07	92.33
13	Shanghai	79.03	89.78	77.60	78.17	67.06
14	Amsterdam MA	79.03	71.48	63.20	98.94	90.14
15	Baltimore - Washington	77.81	80.69	69.13	81.70	81.58
16	Dallas - Fort Worth	77.80	75.27	65.51	89.74	85.91
17	Munich	77.26	73.85	71.01	76.82	86.01
18	Austin	77.00	67.51	66.97	82.15	92.99
19	Chicago - Naperville - Elgin	76.98	71.09	70.02	88.64	79.99
20	Los Angeles - Long Beach - Anaheim	76.69	74.60	68.59	86.84	79.75
21	Madrid	76.39	71.26	68.59	86.75	81.58
22	Helsinki	76.28	63.28	62.08	84.80	100.00
23	Seattle - Tacoma - Bellevue	76.24	72.19	65.78	82.45	88.13
24	Tokyo MA	75.98	86.32	63.77	83.11	78.22
25	Miami MA	75.01	63.92	68.78	85.74	83.33
26	Denver MA	74.80	63.07	67.51	82.22	88.08
27	Zurich	74.32	65.00	63.94	81.75	91.00
28	San Diego MA	74.27	70.61	65.70	74.71	88.59
29	Frankfurt	74.17	62.75	68.74	87.17	80.37
30	Stockholm	73.73	67.28	63.42	84.40	85.89
31	Chapel Hill - Durham - Raleigh	73.35	67.63	64.07	77.32	88.56
32	Oslo	72.94	63.61	67.03	79.43	84.05

5.Innovation ecosystem

Rank	City/metropolitan area	Innovation ecosystem	Openness and collaboration	Support for start-ups	Public services	Innovation culture
33	Berlin MA	72.92	66.08	68.05	70.40	87.13
34	Vancouver MA	72.77	67.44	62.98	75.84	89.61
35	Hamburg	72.64	62.10	64.33	70.43	95.52
36	Sydney	72.58	68.97	66.97	81.31	77.01
37	Copenhagen	72.38	67.35	62.06	91.15	78.22
38	Rome	72.34	67.73	68.06	72.53	82.08
39	Dublin	72.01	69.28	65.12	78.65	79.81
40	Brisbane	71.93	66.08	63.36	82.59	82.08
41	Houston MA	71.82	72.97	64.54	79.62	76.26
42	Dusseldorf	71.64	60.31	70.13	76.25	79.63
43	Abu Dhabi	71.57	70.85	60.21	75.95	87.06
44	Barcelona MA	71.40	67.71	66.20	82.51	74.30
45	Manchester	71.39	62.50	64.42	76.33	86.20
46	Montreal MA	71.35	66.49	65.98	74.03	81.94
47	Atlanta MA	71.09	68.20	64.38	79.84	77.82
48	Tel Aviv	70.90	63.30	74.17	68.57	73.78
49	Lisbon	70.29	66.60	68.92	70.33	76.14
50	Philadelphia MA	70.26	68.07	64.52	78.67	75.69
51	Melbourne	70.23	68.18	64.61	76.35	77.11
52	Kuala Lumpur	70.06	63.05	61.09	69.66	91.65
53	Pittsburgh	69.87	67.16	63.10	75.78	79.59
54	Minneapolis - Saint Paul	69.76	62.51	64.00	78.58	79.52
55	Sao Paulo	69.76	64.46	69.66	72.51	73.21
56	Milan	69.74	67.03	66.95	76.47	72.45
57	Lyon - Grenoble	69.05	65.87	62.80	71.73	81.39
58	Portland	68.72	61.45	62.60	76.66	80.52
59	Rotterdam	68.67	63.65	61.35	76.81	80.43
60	Bengaluru	68.27	66.57	69.92	64.81	71.70
61	Perth	68.13	65.50	62.90	74.18	76.48
62	Cincinnati	68.08	62.23	62.17	74.53	79.95
63	Las Vegas	68.08	60.00	62.69	79.29	77.35
64	Cologne	68.01	60.33	67.88	67.07	77.61
65	Taipei	67.96	67.63	64.09	72.09	73.74
66	Kyoto - Osaka - Kobe	67.89	69.46	60.60	77.21	73.78

Rank	City/metropolitan area	Innovation ecosystem	Openness and collaboration	Support for start-ups	Public services	Innovation culture
67	Mexico City	67.75	62.04	73.12	65.20	68.13
68	Nagoya MA	67.62	64.24	60.31	74.01	80.14
69	Hangzhou	67.57	75.85	63.71	69.65	68.02
70	Vienna	67.36	62.39	62.11	76.91	75.61
71	St. Louis	67.24	63.52	62.52	73.25	76.36
72	Göteborg	67.11	61.14	60.84	77.19	77.65
73	Nanjing	67.09	78.57	62.17	69.08	67.01
74	Central National Capital Region Delhi MA	66.89	71.87	67.07	64.53	67.34
75	Moscow	66.79	61.60	61.26	66.75	83.39
76	Warsaw	66.73	64.30	62.90	67.50	77.69
77	Detroit MA	66.22	62.35	62.88	74.53	72.21
78	Busan	65.87	60.93	60.44	78.80	72.94
79	Stuttgart	65.70	63.36	63.38	65.40	75.68
80	Daejeon	65.66	62.08	60.92	76.45	72.27
81	Wuhan	65.47	75.09	61.81	68.39	65.39
82	Brussels	65.41	63.38	62.28	69.34	73.45
83	Tianjin	64.59	70.83	60.87	70.30	65.97
84	Suzhou	64.52	68.79	62.39	67.71	66.88
85	Chengdu	64.29	73.33	61.89	67.81	63.05
86	Buenos Aires	64.14	60.64	61.70	64.40	76.05
87	Hefei	64.03	72.34	61.84	66.78	63.86
88	Mumbai MA	63.91	69.03	64.92	62.32	64.54
89	Prague	63.70	64.98	61.60	60.05	74.36
90	Xi'an	63.63	71.47	60.63	65.46	66.17
91	Changsha	63.44	70.25	61.36	66.13	64.81
92	Qingdao	63.37	70.33	61.13	66.75	64.39
93	Zhengzhou	63.27	68.00	61.12	67.77	65.23
94	Istanbul	63.10	62.59	65.11	68.19	62.31
95	Bangkok	62.80	61.40	62.04	66.02	68.96
96	Harbin	62.72	69.88	60.23	67.57	63.39
97	Jinan	62.40	67.36	61.07	67.65	62.94
98	Chongqing	62.39	69.24	61.10	67.85	61.11
99	Budapest	62.29	60.99	61.55	62.60	70.94
100	Ankara	62.20	60.11	64.70	64.10	65.03

5.Innovation ecosystem

San Francisco-San Jose takes the lead in innovation ecosystem, followed by London MA, New York MA, Paris MA and Seoul MA. In general, the top 20 cities/metropolitan areas all score highly, suggesting that most of the leading GIHs have solid ecosystems that support innovation.

Geographically, cities/metropolitan areas in Europe and the United States account for 78% of the top 50. In Asia, Seoul MA, Guangdong-Hong Kong-Macao Greater Bay Area, Singapore, Dubai, Beijing, Shanghai, Tokyo MA, Abu Dhabi and Tel Aviv are among the top 50. Overall, Asian cities rank lower than European and American cities, indicating a big gap in innovation ecosystems.

Over the past three years, there has been little change to the top 20 cities/metropolitan areas in this category, suggesting that it takes time to build and improve the ecosystem. Despite small fluctuations in the overall ranking, Phoenix MA and Dubai have made significant progress, moving up by 33 and 24 places respectively compared with the previous year. The COVID-19 pandemic hit cities around the world and post-pandemic uncertainty lingers, but some cities/metropolitan areas are recovering. Thanks to the release of travel restrictions, the number of international flights in aviation hubs such as Dubai, London MA and Paris MA have significantly increased. Although it has not returned to the pre-pandemic level, the increase in international flights has driven innovation. Moreover, Phoenix MA has exhibited strong growth in capital attraction. By virtue of outstanding performance in openness and collaboration, as well as growing support for start-ups, Seoul MA rose by 9 places in the overall ranking, showing the greatest improvement among Asian cities.

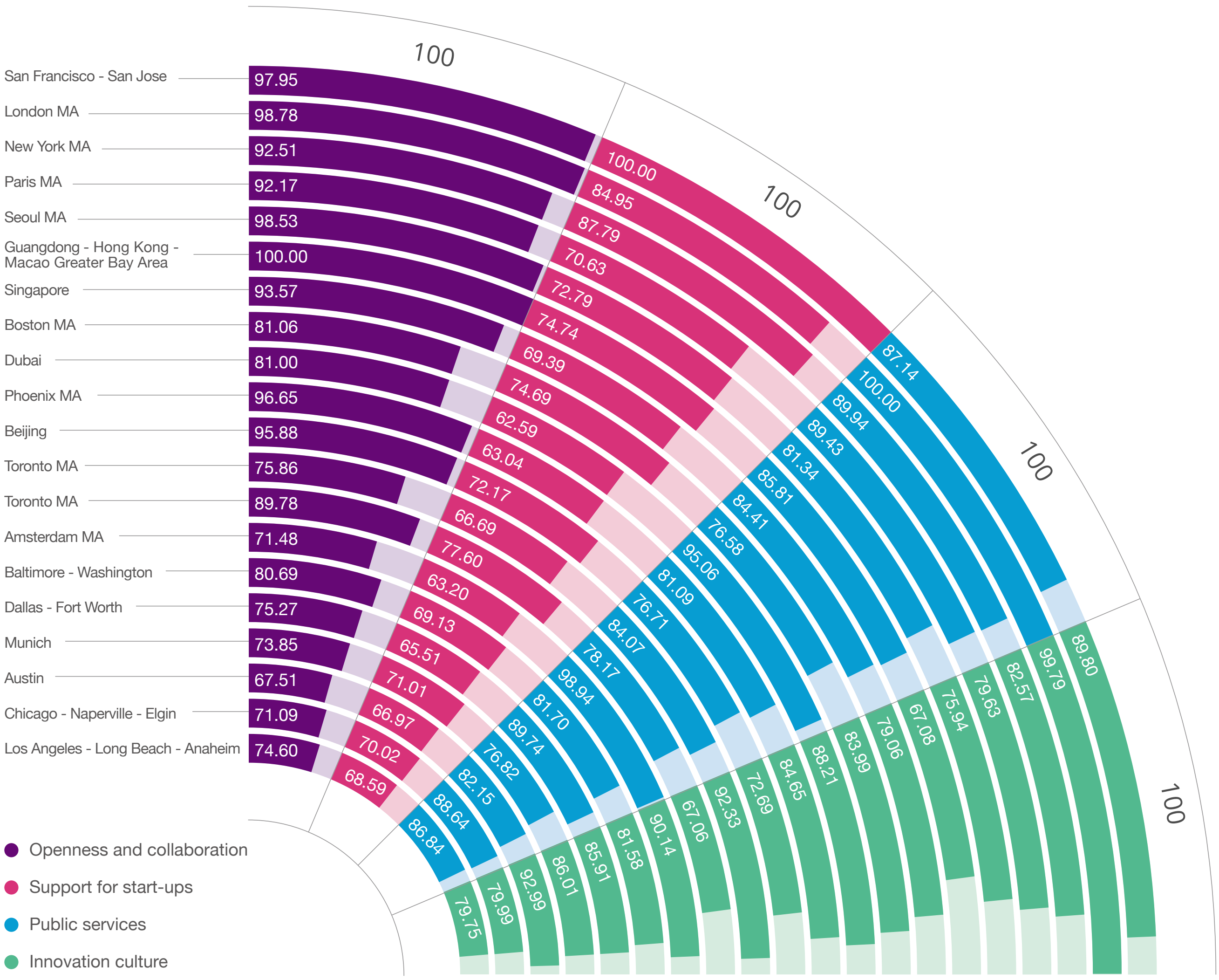
TABLE 11 **A comparison of the top 20 GIHs in innovation ecosystem between 2021-2023**

City/metropolitan area	Rank 2023	Rank 2022	Rank 2021
San Francisco - San Jose	1	1	2
London MA	2	2	1
New York MA	3	3	3
Paris MA	4	9	5
Seoul MA	5	14	21
Guangdong - Hong Kong - Macao Greater Bay Area	6	4	7
Singapore	7	10	9
Boston MA	8	8	8
Dubai	9	33	31
Phoenix MA	10	43	20
Beijing	11	5	4
Toronto MA	12	6	16
Shanghai	13	12	10
Amsterdam MA	14	11	12
Baltimore - Washington	15	18	14
Dallas - Fort Worth	16	22	19
Munich	17	13	6
Austin	18	23	32
Chicago - Naperville - Elgin	19	27	18
Los Angeles - Long Beach - Anaheim	20	16	13

Figure 27 shows the performance across each indicator of the GIHI top 20 cities/metropolitan areas for innovation ecosystem. By comparison, San Francisco-San Jose maintains the first position in support for start-ups. London MA stands out in public services and innovation culture. Asian cities/metropolitan areas, such as Guangdong-Hong Kong-Macao Greater Bay Area, Seoul MA, Beijing, Singapore and Shanghai, excel in openness and collaboration. Seoul MA and Singapore have caught up and entered the top 20 in the support for start-ups. European and American cities boast advantages in public services and innovation culture, providing long-term support for innovation. Cities such as London MA and Amsterdam MA support innovation by offering high-quality public services.

FIGURE 27

Development patterns of the top 20 GIHs in innovation ecosystem



5.Innovation ecosystem

5.2
Openness and collaboration

Openness and cooperation promote and stimulate innovation through the sharing of resources and knowledge. This report evaluates a city's level of openness and collaboration using four level-3 indicators — paper co-authorship network centrality, patent collaboration network centrality, foreign direct investment (FDI) and outward foreign direct investment (OFDI). The GIHI2023 looks at paper co-authorship in all disciplines to measure the extent of cooperation among GIHs. Also, the patents in AI, integrated circuits and renewable energy technology are used to gain insights into openness and cooperation.

Guangdong-Hong Kong-Macao Greater Bay Area, London MA, Seoul MA, San Francisco-San Jose and Phoenix MA are the top five cities/metropolitan areas for 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. Figure 28 shows paper co-authorship network centrality of GIHs. The node size indicates the importance and impact of a city/metropolitan area to the global co-authorship network, while the thickness of the node connection measures the closeness of cooperation among researchers. Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, New York MA and Boston MA are key leaders in the innovation collaboration networks and play a critical role in knowledge production and cooperation.

The paper co-authorship network is characterized by the co-evolution of four innovation sub-networks featuring close cooperation. The network centred on New York MA, Boston MA, Baltimore-Washington and San Francisco-San Jose occupies a more important niche. The innovation sub-network centred on Chinese cities has a global influence that cannot be ignored, as the network centrality of Beijing ranks first, Guangdong-Hong Kong-Macao Greater Bay Area second and Shanghai fifth, taking the lead in the global innovation network. The sub-network centred on London MA and Paris MA indicates that there is broader cooperation among European cities. Cities in Japan and South Korea with Tokyo MA and Seoul MA as the core, and Australian cities with Sydney and Melbourne as the core, have become multicentre clusters. Digital technology supports remote collaborations, enabling more cross-border and inter-city collaboration and exchange of knowledge. Open science and data-sharing initiatives are also driving global knowledge collaboration.

FIGURE 28

The GIHI paper co-authorship network, 2022

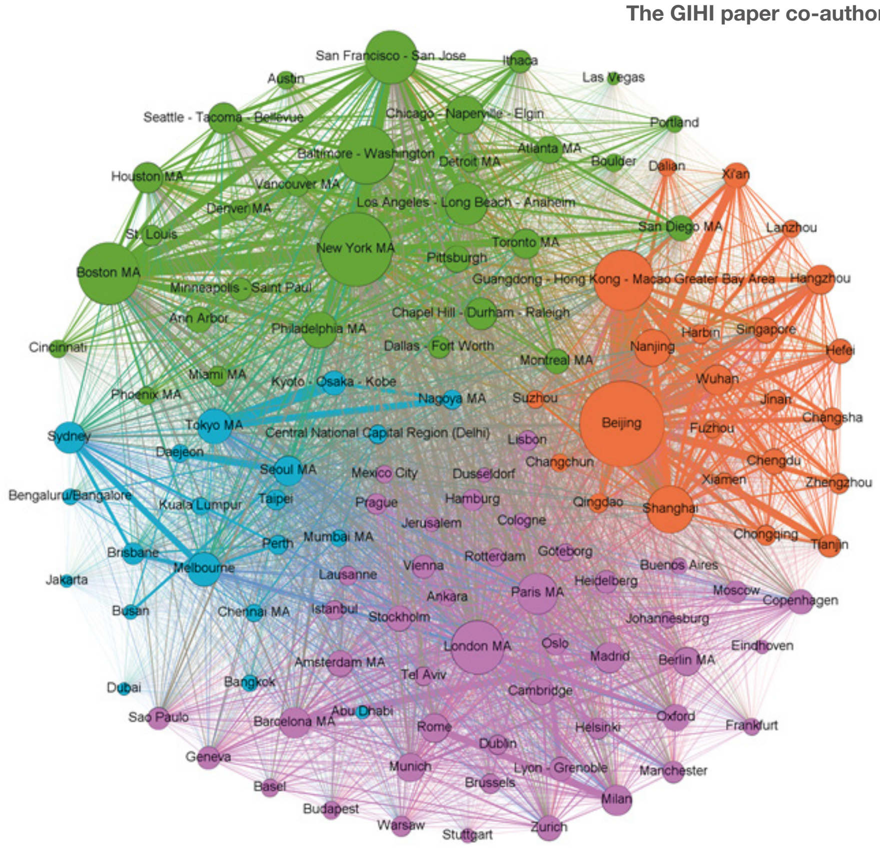
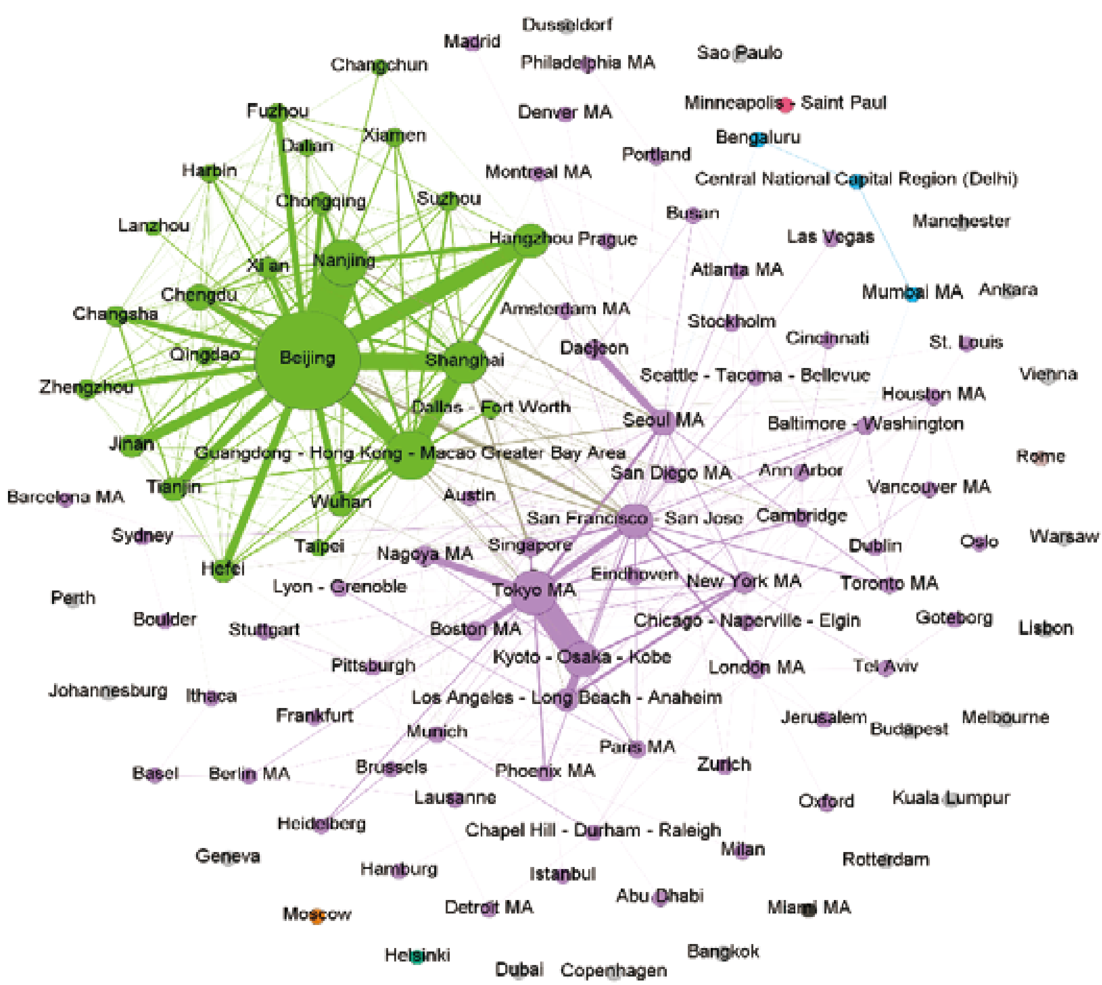


Figure 29 depicts the patent collaboration network centrality of GIHs, which measures the importance and impact of a city in the network. Node-to-node connections indicate partnerships between cities around the world. The top five cities/metropolitan areas for patent collaboration network centrality are San Francisco-San Jose, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, Seoul MA, and Tokyo MA. Among the top 11 cities/metropolitan areas (11 rather than ten as two cities tied), there are nine Asian cities, of which seven are Chinese. San Francisco-San Jose, ranking first at the centre of the network, is an important global innovation engine, and cities around the world constitute a relatively balanced and diversified global patent cooperation network. Chinese cities stand out in the network due to their close cooperation, with Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, Shanghai and Nanjing leading the way for other Chinese cities to achieve technological innovation. Close cooperation is also present within the sub-networks.

Figure 30 shows the total amounts of FDI and OFDI in 2022 for the top 20 cities/metropolitan areas for openness and collaboration. The top five for the total amount of FDI are Phoenix MA, Singapore, Toronto MA, Guangdong-Hong Kong-Macao Greater Bay Area and London MA. The top five for the total amount of OFDI are London MA, Seoul MA, Dubai, Paris MA and Tokyo MA.

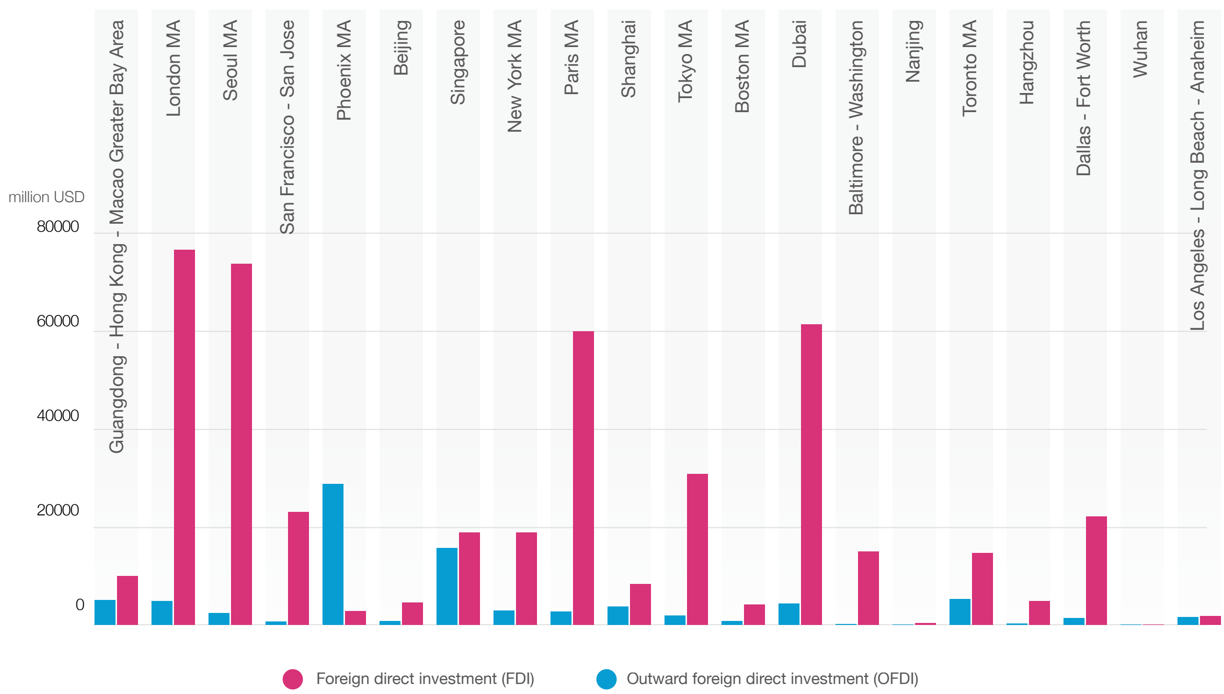
FIGURE 29 **The GIHI patent collaboration network, 2022**



5.Innovation ecosystem

FIGURE 30

Total amounts of foreign direct investment (FDI) and outward foreign direct investment (OFDI) for the top 20 GIHs in openness and collaboration



The FDI of Phoenix MA increased 28 times from the previous year, mainly because it is a major centre for the semiconductor industry. Given the national semiconductor strategy of the United States, Phoenix MA, which has a complete industrial chain of semiconductor and chip manufacturing, has attracted Taiwan Semiconductor Manufacturing Company (TSMC) and Intel to invest heavily in super factories. The proactive industrial policy from local government also reflects its strategic focus on expanding manufacturing and high-end technology industries. Cities relying on information industries and the digital economy, such as San Francisco-San Jose and Guangdong-Hong Kong-Macao Greater Bay Area, continue to flourish. Moreover, the FDI of Asian cities, including Bengaluru, Abu Dhabi and Mumbai MA has increased several times, as they have rapidly boosted their attractiveness for foreign investment for emerging industries.

In addition, the total amount of OFDI greenfield investment in most cities/metropolitan areas is much higher than that of FDI greenfield investment, indicating market vitality and strong capital spillover effects of leading GIHs. Compared with the previous year, among top cities/metropolitans for OFDI, London MA, Seoul MA, Dubai, Paris MA, Tokyo MA and Dallas-Fort Worth have recorded significant growth. Dubai's OFDI increased from US$ 5.03 billion in 2021 to US$ 61.5 billion in 2022. By industry, most of the top cities/metropolitan areas in OFDI prefer investment in software and Internet, business services and renewable energy.

5.3
Support for start-ups

A favourable business environment is key to stimulating innovation, entrepreneurship and creativity. The GIHI evaluates the capital driving force for local innovation and entrepreneurship by measuring the amount of venture capital (VC) and private equity (PE) investment. It also examines the legal business environment using the number of registered lawyers (per million people).

The top five cities/metropolitan areas for support for start-ups are San Francisco-San Jose, New York MA, London MA, Shanghai and Guangdong-Hong Kong-Macao Greater Bay Area. The top 20 cities/metropolitan areas are more evenly distributed with seven in Asia, six in the United States and five in Europe. Asian cities have risen significantly in the ranking, revealing these cities' commitment to encouraging innovation and entrepreneurship, enhancing the financial system and stimulating innovation.

Figure 31 shows the total VC and PE investment for the top 20 cities/metropolitan areas in support for start-ups. San Francisco Bay Area boasts top scientific and technological talent, research and development institutions, as well as an open and inclusive environment. Thanks to an ecosystem that fosters innovation, it continues to attract global attention and maintain its leading position. By total investment, Shanghai ranks third, Guangdong-Hong Kong-Macao Greater Bay Area fifth and Beijing eighth, demonstrating strong innovation vitality and prospects.

As shown in trends, investment slowed again in 2022 and had decreased overall. Specifically, VC experienced slight fluctuations and PE in top cities was exhibiting troughs. PE in European and American cities such as San Francisco-San Jose, New York MA, London MA and Boston MA decreased sharply. However, despite the challenging and volatile global economy, the total VC and PE investment of Asian cities such as Singapore, Seoul MA, Dubai and Hefei still showed promising growth. As a global financial centre, Singapore is a hot destination for VC and PE in southeast Asia. Its total VC and PE investment grew by 2.6 times thanks to its relatively looser COVID-19 controls.

FIGURE 31

Total venture capital (VC) and private equity (PE) investment for the top 20 GIHs in support for start-ups

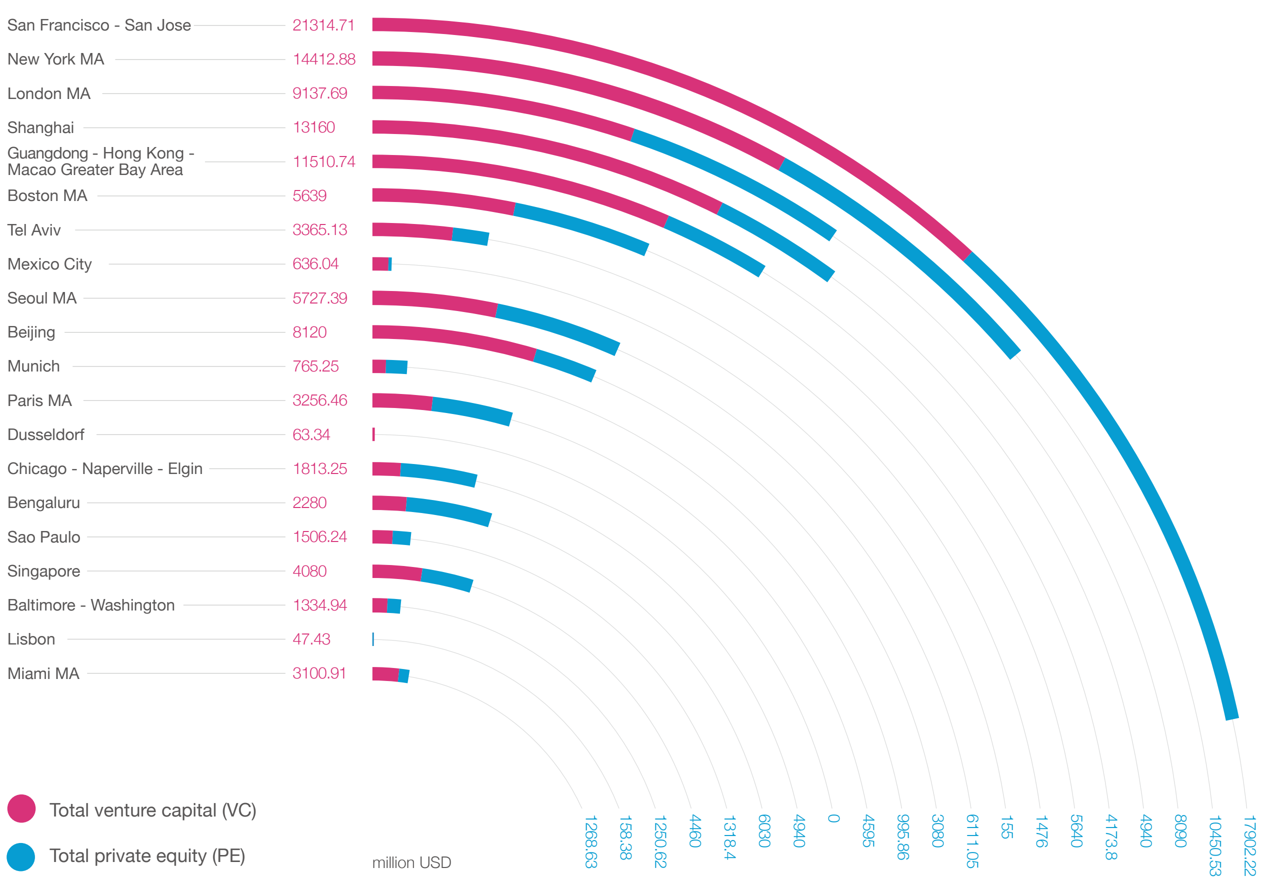
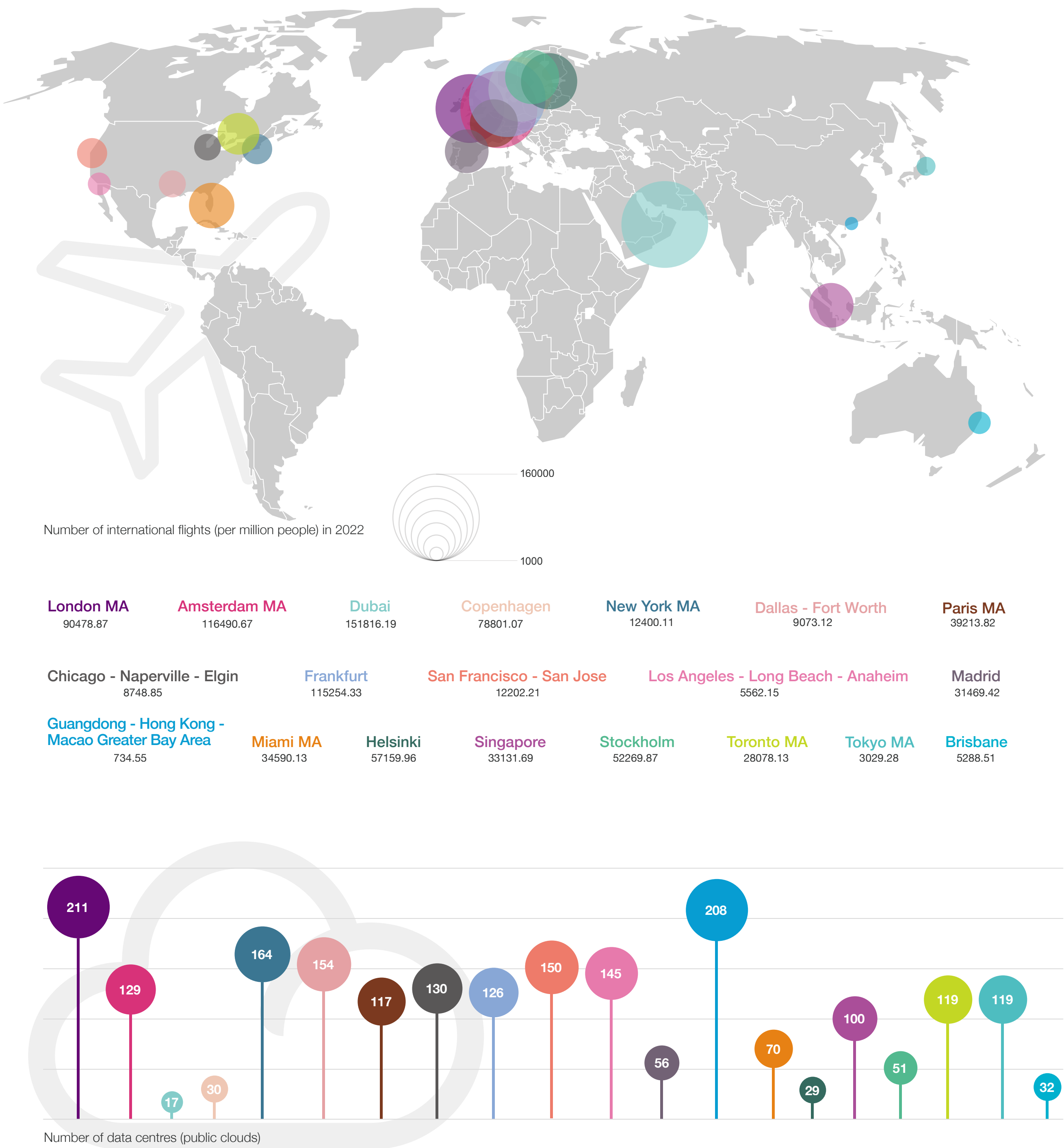


FIGURE 32

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



5.4
Public services

Urban public services are the infrastructure and public goods provided by cities to support research, innovation and start-ups as an effort to ensure sustainable development. The GIHI2023 uses the number of data centres (public clouds), broadband connection speed, the number of international flights (per million people) and the E-governance level to measure the maturity of data infrastructure and the strength of interconnectivity.

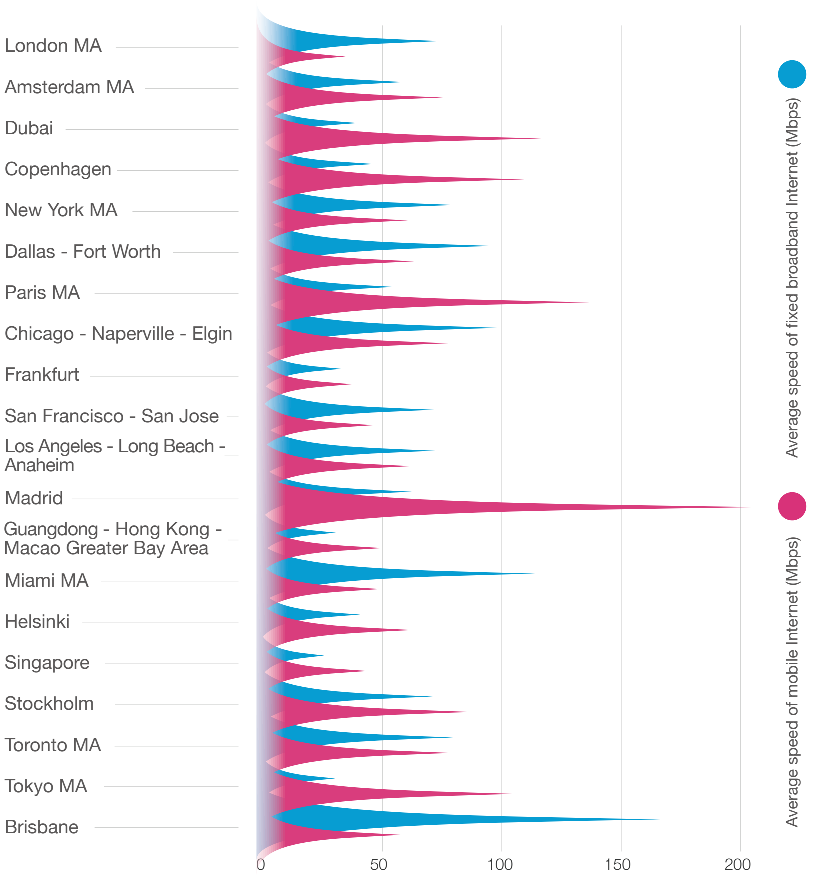
The top five cities/metropolitan areas for public services are London MA, Amsterdam MA, Dubai, Copenhagen and New York MA. Among the top 20 cities/metropolitan areas for public services, eight are in Europe, seven are in North America, one is in Oceania and the rest are Dubai, Guangdong-Hong Kong-Macao Greater Bay Area, Singapore and Tokyo MA in Asia.

London MA continues to take the lead as an important data hub with 211 data centres. The Guangdong-Hong Kong-Macao Greater Bay Area, New York MA, Dallas-Fort Worth and San Francisco-San Jose make up the remaining top five cities with the largest number of data centres. The United States dominates the global data centre market with absolute advantages. The vigorous development of data centres lays a solid foundation for the digital economy and digital innovation.

This report uses the average fixed broadband speed and the average mobile network speed to measure the broadband connection speed. In terms of the average fixed broadband speed, cities/metropolitan areas in the United States boast higher broadband connection speed, with Austin at the top. In terms of the average mobile network speed, European and Asian cities outperform others, with Madrid, Barcelona MA and Paris MA taking the top three spots. Madrid offers a mobile network speed of 208.6 Mbps, three times the average speed of 108 cities/metropolitan areas. Chinese cities/metropolitan areas also perform well in this respect thanks to the government's substantial efforts in building new digital infrastructure and the rapid development of 5G.

FIGURE 33

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



5.5
Innovation culture

Innovation culture is the source of urban vitality and a key driver for competitiveness. The GIHI2023 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 Helsinki, London MA, Hamburg, Austin and Toronto MA. Out of the top 20 cities/metropolitan areas 85% are in Europe and North America. In general, European cities outperform their counterparts in North America as on average their citizens spend a longer time in schooling and have a well-established cultural infrastructure. The top cities for the number of public museums and libraries (per million people) are mainly European cities with a rich innovation heritage.

Asian cities are committed to catching up in terms of attracting talent. Abu Dhabi and Dubai are top performers in the professional talent inflow (per million people), providing superior benefits and opportunities for talent. Dubai's ongoing visa services are one of the catalysts for attracting talent and its meticulously-planned initiatives have made it a destination of choice for global talent.

6. Summary

GIHI2023 is based on three dimensions: research innovation, innovation economy, and innovation ecosystem. The selection of measurements takes into account a variety of factors, including 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 crucial drivers in breaking new ground.

In GIHI2023, we have found that the international innovation landscape continues to move towards multipolarity, with European and American cities still taking the lead, and Asian cities catching up rapidly. The Bay Areas hold prominent advantages, with San Francisco Bay Area, New York Bay Area, Guangdong-Hong Kong-Macao Greater Bay Area, and Tokyo Bay Area all in the top 10 and displaying distinct development patterns. Mini-hubs are small in population, but strong in innovation.

In research innovation, Asian cities/metropolitan areas score much higher. In innovation economy, despite the impact of non-economic factors such as geopolitical conflicts and natural disasters, the 80-20 rule is even more evident in GIHs, driving resilient growth in the global economy. In innovation ecosystem, top GIHs generally have a good innovation ecosystem. Cities across Europe and the United States lead the world with their established infrastructure, services and innovation culture, but Asian cities are gaining momentum by supporting emerging industries with incentives.

The global discipline hubs are primarily located in North America, East Asia, and Western Europe. When considering the discipline-sourcing capability and discipline excellence of assessed cities and the distributions of Superstar cities, Champion cities, and Emerging science cities, cities in North America and Western Europe have comparative advantages, whereas cities in China and Australia are seeing rapid growth and stand out in some disciplines in the discipline-sourcing capability. Specifically, cities in North America and Western Europe have relatively stronger discipline-sourcing capability in medicine, humanities, arts and social sciences, while cities in East Asia have made major breakthroughs in science, technology, and engineering.

Artificial intelligence has seen explosive growth since 2020. Technical advantages in AI vary widely across GIHs. Tokyo MA and San Francisco-San Jose, in possession of important basic technology, develop in all areas of AI and dominate in many. For example, Tokyo MA and San Francisco-San Jose possess critical basic technologies in AI and are making progress on all fronts. Chinese cities are important drivers for the application of artificial intelligence technology, including the application of image recognition and speech recognition, as well as the application of artificial intelligence in various industry systems.

Notably, the global innovation network is dynamic and evolving, and the index system needs to be further improved. We sincerely invite evaluators, practitioners and policy-makers across the world to read the report and make suggestions or comments.

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Appendix

Appendix I: Adjustments to the GIHI Indicators

The GIHI indicators have been adjusted since GIHI 2022 to strengthen their authority and ensure the availability and compatibility of data. Cities with a population lower than 1 million have been evaluated and ranked separately as mini-hubs in GIHI2023 and ratios have been replaced by value and scale.

GIHI2022	Adjustment	GIHI2023	Descriptions
02. Percentage of highly cited scientists	Indicator removed		This indicator was removed as it has a strong positive correlation with indicator 07. number of highly cited papers.
08. Percentage of highly cited papers	Statistical method	07. Number of highly cited papers	The relative value indicator was adjusted to the absolute value indicator, which reflects both quantity and quality of papers and can be used to illustrate the ability to create knowledge in a city or metropolitan area.
09. Proportion of papers cited in patents, policy reports and clinical trials	Statistical method	08. Total citations from patents, policy reports and clinical trials	The relative value indicator has been adjusted to the absolute value indicator to reflect the impact of papers on technological innovation, policy reports and clinical trials.
30. Number of creative talent (per million people)	Indicator replacement	29. Residents' average years of schooling	A significant amount of data was unavailable for the previous indicator and data on education is more readily available.

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 2018 and 2022 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 13 June 2023.

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) 2022 to characterize a city's leading universities.
Data sources: Shanghai Ranking's Academic Ranking of World Universities (ARWU) 2022 (https://www.shanghairanking.cn/rankings/arwu/2022)

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 2022. 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.
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.
Data sources: Global Top 500 Supercomputers, data as of November 2022 (https://www.top500.org/statistics/sublist/)

07. Number of highly cited papers
Definition: The number of the top 1% of highly cited papers of each discipline between 2000 and 2021. 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 (https://www.digital-science.com/product/dimensions/)

08. Total citations from patents, policy reports and clinical trials
Definition: Total citations of scientific papers published in the city between 2018 and 2022 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 (https://www.digital-science.com/product/dimensions/)

B. Innovation economy

09. Total number of valid patents (per million people)
Definition: This study considers five fields, including machine learning, computer vision, natural language processing, expert systems and robotics, as the main fields of artificial intelligence (AI), with the supplementary field of integrated circuits (ICs) and renewable energy technology. The strategies for patent search have been established through multiple rounds of discussions with experts in AI, IC, sustainable energy technology and patent search. We searched AI patent applications using the Derwent Innovation patent database platform. Considering the time AI patents were generated and the time lag between patent application and publication and the history of technology development, the patent

publication year of this report was 1956-2022 for AI, 1965-2022 for IC and 1970-2022 for renewable energy technology. By removing duplicate data, 374,594 patents for AI applications, 1,088,902 patents for IC, and 198,295 for renewable energy technology have been obtained.
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 is the usual category of valid patents). After data cleaning and processing, 309,326 patents in AI, 605,738 patents in IC and 120,085 patents in renewable energy technology have been obtained to analyse a GIH's innovation capacity.
Data sources: Derwent Innovation patent database

10. Number of Patent Cooperation Treaty patents
Definition: The report identifies the number of Patent Cooperation Treaty (PCT) patents in IC (1965-2021), AI (1956-2021) and renewable energy technology (1970-2021). By filing one international patent application under the PCT, applicants can simultaneously seek protection for an invention in a large number of countries. Residents of all PCT contracting states are entitled to file an international application. Applicants can file an application, in most cases, with their national patent office, or directly with the World Intellectual Property Organization (WIPO). PCT patents are usually recognized as technologically valuable.
PCT patents refer to those that have passed the preliminary examination and are in the public phase. During the public phase, a public patent becomes invalid if the applicant "withdraws or abandons the patent, fails to request a substantive examination without a valid reason, or fails to pass the substantive examination". After data cleaning and processing, 37,388 patents in AI, 39,330 patents in IC, and 19,846 patents in renewable energy technology have been obtained to analyse a GIH's innovation capacity.
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 2021 published by the EU Industrial R&D Investment Scoreboard 2022, Derwent Top 100 Global Innovators 2022 and Fortune Global 500 2022 (only science and technology enterprises are included) to rank enterprises in evaluated cities as an indicator of the enterprises' ability to drive innovation and the spillover effect to surrounding regions.
Data sources: The EU Industrial R&D Investment Scoreboard, 2022; Top 100 Global Innovators 2022 by Clarivate; Fortune Global 500, 2022

12. Number of unicorn companies
Definition: Unicorn is the term used to refer to start-ups that are valued at $1 billion or more, which 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 2022 by CB Insights and the 2022 Hurun Global Unicorn List. By removing duplicated companies, 1,553 unicorn companies in the assessed cities have been included in this report.
Data sources: the Complete List of Unicorn Companies published by CB Insight (https://www.cbinsights.com/research-unicorn-companies), data as of 19 April 2023; 2022 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 2023 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 and health care equipment and services enterprises, electronic information enterprises include companies engaged in IT software and services, semiconductors, technology hardware and equipment and telecommunications, high-end manufacturing companies include those engaged in aerospace and defense, materials and transportations.
Data sources: Forbes China (https://www.forbes.com/lists/global2000/?sh=1e326f185ac0)

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 2022 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 2021 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 2020 are used for Vienna, Berlin MA, Cologne, Dusseldorf, Frankfurt, Hamburg, Heidelberg, Munich, Stuttgart, Dublin, Milan, Rome, Amsterdam MA, Eindhoven, Rotterdam, Warsaw, Barcelona MA, Madrid, Göteborg, Stockholm, Mumbai MA, Kyoto-Osaka-Kobe, Nagoya MA, Tokyo MA, and Seoul MA; the GDP growth rates for 2019 are used for Montréal MA, Toronto MA, Vancouver MA, Oslo and Johannesburg; the GDP growth rates for 2018 are used for Basel, Geneva, Lausanne and Zurich.
Data sources: GDP data are from the Organisation for Economic Co-operation and Development (OECD) and statistics offices of countries and cities, such as the National Bureau of Statistics of China, United States Bureau of Economic Analysis and Eurostat; 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 2021 (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 of 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 2022 intercity paper publication collaboration matrix of the 119 evaluated cities. The importance of a node in the eigenvector centrality depends on the number of neighboring nodes (the degree of the node) and the importance of the neighboring 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 constructed the technology collaboration network of an assessed city on the basis of joint filing on AI, IC and renewable energy technology to examine the patent cooperation network centrality of cities and to reflect the range of cooperation of each GIH. It is calculated as shown below:

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

Data sources: Derwent Innovation patent database

19. Foreign direct investment (FDI)

Definition: This study measures a city's attractiveness to foreign investment by its foreign direct investment (FDI) in greenfield projects in 2022. 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)

Appendix

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 2022, 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 2022, 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 2022. 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 2021. 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 Brussels, Prague, Helsinki, Budapest, Gothenburg, Stockholm, Jakarta, Jerusalem, Tel Aviv, Kuala Lumpur, Bangkok, Buenos Aires and Sao Paulo, the country-level data are used instead; for Toronto MA, Vancouver MA, Heidelberg, Bengaluru, Central National Capital Region (Delhi), Chennai, Mumbai MA, Kyoto-Osaka-Kobe, Nagoya MA, Tokyo MA, Brisbane, Melbourne, Perth, Sydney and Johannesburg, 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 5 June, 2023

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: Broadband connection speed was measured at Testmy (https:// testmy.net/list) on 7 May 2023; mobile terminal connection speed was measured at Speedtest (https://www.speedtest.net) on 17 May 2023

26. Number of international flights (per million people)
Definition: The number of all direct flights departing from and arriving at the city in 2022.
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 (OSQ) 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 July 2022 and July 2023 is used to measure the attraction of the city/metropolitan areas to talents. For Dublin, Moscow, Busan, Daejeon, Seoul MA, Dubai, and Abu Dhabi, as the data is unavailable at the city level, the indicator is estimated using the proportion of citizens in the country and the talent inflow into that country. As LinkedIn shut down its China platform in October 2021, the data for Chinese cities (except for Hong Kong and Taipei) in 2022 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 24 July 2023

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 (UNDP) are used to measure a city's education quality and human resources.
Data sources: Subnational HDI, UNDP

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 2022 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.

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

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. $\overline{x_i}$ 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 2022, the 2022 Global Cities Index by Kearney, the WIPO Global Innovation Index 2022 and those in the Innovation Cities™ Index 2022 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 119 cities/metropolitan areas to be assessed. Among them, there were 11 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 119 cities/metropolitan areas are from 37 countries in six continents, covering 373 major administrative cities. Among them, there are 43 Asian cities, 38 European cities, 31 North American cities, four Oceanian cities, two South American cities and 1 African city.

Appendix

Appendix V: Scope of administrative divisions of GIHs

No.	City/metropolitan area	Administrative division	Country
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

Appendix

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
		H̱olon	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	Brisbane	Brisbane	Australia
114	Melbourne	Melbourne	Australia
115	Perth	Perth	Australia
116	Sydney	Sydney	Australia
117	Buenos Aires	Buenos Aires	Argentina
118	São Paulo	São Paulo	Brazil
		São Bernardo do Campo	Brazil
		Santo André	Brazil
		Diadema	Brazil
		Barueri	Brazil
		São Caetano do Sul	Brazil
119	Johannesburg	Johannesburg	South Africa
		Soweto	South Africa
		Randburg	South Africa

Note: The 119 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: Measurement of element agglomeration and spillover effect

Taking into account the characteristics of each indicator, this report uses 12 level-3 indicators of element agglomeration, such as the number of active researchers (per million people), the number of winners of top scientific awards, the number of world-leading universities, the number of top 200 world-class research institutions, total number of valid patents (per million people), the number of PCT patents, the number of leading innovative companies, the number of unicorn companies, foreign direct investment, venture capital investment, private equity and professional talent inflow (per million people) to measure a city's aggregation of innovation elements. The report also uses eight level-3 indicators, such as the number of large scientific facilities, the number of highly cited papers, total citations from patents, policy reports and clinical trials, the paper co-authorship network centrality, the patent collaboration network centrality, OFDI, the number of data centres (public clouds) and the number of international flights (per million people), to characterize a city's spillover effect.

First, we use the Z-score to standardize the raw data of all level-3 indicators, with the formula shown as below:

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

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. $\overline{x_i}$ 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.

We calculated the mean of the 12 indicators of the element agglomeration and 8 indicators of the spillover effect as the Z-score for estimating the element agglomeration and spillover effect of cities. This report compares cities using min-max normalization on the basis of the Z-score to map the evaluated cities' scores to the [0,1] range.

$$Y_j^n = \frac{X_j - X_{min}}{X_{max} - X_{min}}$$

Y_j^n is the min-max normalized value for element agglomeration and spillover effect of the Z-score for the city j, X_j is the Z-score of the element agglomeration and spillover effect for city j, X_{min} is the minimum Z-score for the element agglomeration and spillover effect for all cities. X_{max} is the maximum Z-score of the element agglomeration and spillover effect for all cities. Based on this, this report sets the base score of the element agglomeration and spillover effect in [0,100], the scores of element agglomeration and spillover effect for city j are as follows Y_{Aj} and Y_{Bj}.

$$Y_{Aj} = Y_{Aj}^n * 100$$
$$Y_{Bj} = Y_{Bj}^n * 100$$

Appendix VIII: Measurement of discipline hubs

The data for the sublist of discipline hubs are all derived from Dimensions, a research intelligence big data platform from Digital Science. The list adopts the same classification system as Dimensions, namely Fields of Research (ANZSRC 2020).

Number of highly cited papers refers to the number of the top 1% cited papers of a discipline globally in the same publication year in the source statistics. Percentage of highly cited papers refers to the proportion of the number of highly cited papers in a discipline to the total number of papers published in the same discipline. These papers are attributed to a city/metropolitan area according to the affiliated institution and address of the authors. A highly cited paper of a city/ metropolitan area means that an institution or address of the city/ metropolitan area appears at least once in the authorship of the paper. Different sub-cities in the same metropolitan area are not counted twice.

The list analyses a decade of data as the time window for this year's analysis is from 2012 to 2021, mainly because it takes time for citations to accumulate and the cited half-life of papers in different disciplines should be fully covered.

Number of highly cited papers is standardized through min-max normalization, producing a standardized score with a range of 60~100. That is, the first-ranked city scores 100 points, and the last-ranked city scores 60 points. For details about the formula, please refer to Appendix III.

Appendix

Appendix IX: Measurement of artificial intelligence innovation

This report determined the keywords and strategies for the AI patent search after multiple rounds of discussions with AI experts and patent search experts with reference to the classification standards of AI technology in relevant literature and research reports at home and abroad. A total of 408,937 AI patents were retrieved, 118,764 of which were PCT patents and triadic patents after searching for disclosed patents in the field of AI from 1970-2022 on Derwent Innovation, a patent database platform, considering the development history of AI and the time lag of patent disclosure. The number of effective invention patents, the number of PCT patents and United States-Europe-Japan triadic patents and the IPC distribution of high-quality patents were used to measure a city's total amount of innovation, quality of innovation, and technological advantages in hot fields respectively.

The number of effective invention patents measures the total amount of innovation of a city/ metropolitan area. Effective invention patents are divided into two categories: one refers to authorized patents that have been approved by the Intellectual Property Office and have not exceeded the statutory protection period, they are normally maintained and have not been sued for invalidity and are still in a valid state; the other refers to those that have not yet been granted but are made public after undergoing the patent disclosure procedures (application – acceptance – preliminary examination – publication – substantive examination – authorization). At the patent disclosure stage, if the applicant fails to request substantive examination within the time limit without justifiable reasons or doesn't pass substantive examination, the patent is found to be invalid.

The number of PCT patents and United States-Europe-Japan triadic patents measures the innovation quality of a city/ metropolitan area. PCT patents and US-Europe-Japan triadic patents are collectively referred to as high-quality patents. PCT is an international treaty in the field of patents, through which an inventor filing an international application can simultaneously apply for patent protection for a technical invention in many contracting states. The examination mechanism for PCT patents is relatively strict, so the quality of patents from this channel is relatively high. The United States-Europe-Japan triadic patents refer to a set of patents applied at the same time in the United States Patent and Trademark Office, the European Patent Office and the Japanese Patent Office for the protection of the same invention and authorized in at least one of the patent offices. Such patents are generally considered to be of high scientific and technological content and economic value, reflecting the innovation level and scientific and technological strength of a country or region in terms of technological inventions.

The hot technology fields are primarily identified by selecting the top 30 international patent classification (IPC) patents based on the distribution of high-quality patents.

No.	IPC	Definition	Number of high-quality patents	Percentage
1	G06N-0003	Computer systems based on biological models	29514	24.85%
2	G06K-0009	Pattern recognition	22282	18.76%
3	G06F-0017	Digital computing equipment	21482	18.09%
4	G06N-0020	Machine learning	17913	15.08%
5	G06T-0007	Image understanding	13133	11.06%
6	G06N-0005	Computing arrangements using knowledge-based models	11756	9.90%
7	G06F-0016	Information retrieval	9926	8.36%
8	G06F-0003	Data transmission unit	9504	8.00%
9	G05B-0013	Adaptive control system	8847	7.45%
10	G06Q-0010	Administrative application system	8422	7.09%
11	G06F-0015	Data processing equipment in general	8216	6.92%
12	G06F-0019	Digital computing equipment applications	7648	6.44%
13	G10L-0015	Speech recognition	7607	6.41%
14	G06Q-0050	Systems or methods specially adapted for specific business sectors	7269	6.12%
15	G06F-0009	Program control unit	7122	6.00%
16	H04L-0029	Digital information transmission equipment, circuit, or system	6367	5.36%
17	A61B-0005	Measuring for diagnostic purposes; identification of persons	6239	5.25%
18	G06Q-0030	Business application system	5410	4.56%
19	H04L-0012	Data switching networks	5225	4.40%
20	G05B-0019	Program control system	5110	4.30%
21	G06F-0040	Handling natural language data	4883	4.11%
22	G06N-0099	Other computer systems	4790	4.03%
23	G16H-0050	Information and communication technology adapted for medical diagnosis	4592	3.87%
24	G01N-0033	Investigating or analysing materials	4578	3.85%
25	G06F-0021	Data security device	4439	3.74%
26	G06V-0010	Video recognition or understanding	4365	3.68%
27	G06N-0007	Computer systems based on specific mathematical models	4126	3.47%
28	B25J-0009	Programmed-controlled manipulator	3708	3.12%
29	H04N-0005	Parts of the television system	3637	3.06%
30	G06F-0007	Data operation unit	3611	3.04%

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) focuses on policy research and academic exchanges in the areas of industrial development, environmental governance, and institutional change. The mission of CIDEG 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, business, non-governmental organizations, and government departments.

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