Global Innovation Hubs Index 2022

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Executive summary

Global innovation and development in 2022 are 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, the 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 and Nature Research, has been tracking and analysing year-on-year changes and the latest trends in global innovation since 2020. The GIHI2022 continues to apply scientific, objective, independent and impartial principles in evaluating 100 GIHs by three indicators known as research innovation, innovation economy, and innovation ecosystem, providing a reference for policy-makers, entrepreneurs, and practitioners.

The GIHI2022 report has improved its indicators and data in the following ways:

First, the number of evaluated cities has increased from 50 to 100, which also include mini-hubs with populations of less than one million. With a combined population of just 10.43% of the global total, these cities/metropolitan areas (MA) boast some of the world's best innovation resources, including 125 world-leading universities, 133 of the top 200 world-class research institutions, and 1,870 leading innovative enterprises.

Second, the indicators are calculated using multi-source data instead of relying on single data source. As data availability is hampered by factors such as the COVID-19 pandemic and international unrest, we have diversified our data sources to ensure that the index system is robust and consistent. For example, data both from LinkedIn and Zhaopin.com are used to measure the 'number of professional talent inflows' for cities, and the 'fixed broadband internet speed' and the 'mobile internet speed' are used to measure the broadband connection speed of a city.

Third, some indicators of innovation economy and innovation ecosystem have been adjusted. For example, the 'renewable energy technology patents' has been added to the previous patent indicators of 'artificial intelligence patents' and 'integrated circuit manufacturing patents' to reflect the low-carbon transition and the sustainable development adopted around the world, and the 'number of creative talent (per million people)' has been used as an indicator of innovation ecosystem to measure a city's ability to attract innovation talent.

The assessment results for GIHI2022 are as follows:

The GIHI2022 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, Geneva, Paris MA, Shanghai, Seattle-Tacoma-Bellevue, Seoul MA, Singapore, Munich, Baltimore-Washington, Los Angeles-Long Beach-Anaheim, Amsterdam MA, San Diego MA, Cambridge, and Zurich.

The GIHI2022 top 20 cities/metropolitan areas in research innovation are New York MA, San Francisco-San Jose, Boston MA, Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, Geneva, Cambridge, London MA, Oxford, Baltimore-Washington, Los Angeles-Long Beach-Anaheim, Ann Arbor, Zurich, Chapel Hill-Durham-Raleigh, San Diego MA, Paris MA, Chicago-Naperville-Elgin, Boulder, Seattle-Tacoma-Bellevue, and Stockholm.

The GIHI2022 top 20 cities/metropolitan areas in innovation economy are San Francisco-San Jose, Tokyo MA, Beijing, New York MA, Kyoto-Osaka-Kobe, Seoul MA, Guangdong-Hong Kong-Macao Greater Bay Area, Dublin, Taipei, Munich, Boston MA, Seattle-Tacoma-Bellevue, Shanghai, San Diego MA, Dallas-Fort Worth, Austin, Singapore, Paris MA, Zurich, and London MA.

The GIHI2022 top 20 cities/metropolitan areas in innovation ecosystem are San Francisco-San Jose, London MA, New York MA, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, Toronto MA, Geneva, Boston MA, Paris MA, Singapore, Amsterdam MA, Shanghai, Munich, Seoul MA, Madrid, Los Angeles-Long Beach-Anaheim, Seattle-Tacoma-Bellevue, Baltimore-Washington, Stockholm, and Tokyo MA.

Overall, the GIHI2022 has drawn the following conclusions:

First, the international innovation landscape is moving towards multipolarity and a low-carbon future, with Asian cities gaining competitive edge in innovation economy, and the Bay Areas and mini-hubs demonstrating unique innovation characteristics.

As a new centre of innovation, Asia stands out in renewable energy technology. Asian cities sweep up six spots among the top 20 in overall ranking, and have strong performance in green low-carbon development: seven out of the leading 10 cities/metropolitan areas for the total number of valid patents for renewable energy technology are in Asia. Cities/metropolitan areas including Beijing, Tokyo MA, Seoul MA, Hangzhou, Guangdong-Hong Kong-Macao Greater Bay Area, and Kyoto-Osaka-Kobe are important nodes in the network of renewable energy technology, leading the world in a global shift towards green development.

Executive Summary

An increasing number of Chinese cities have boosted their innovation capability and become GIHs, providing new power for global development. There are a total of 19 Chinese cities/metropolitan areas on the list. They are active in innovation economy and rapidly growing in research innovation and innovation ecosystem, resulting in improved capability across the board.

The Bay Areas hold prominent advantages in innovation resource integration. Four out of the GIHI2022 top 10 cities/metropolitan areas overall are in Bay Areas. In addition to the three Bay Areas of San Francisco, New York, and Tokyo, Guangdong-Hong Kong-Macao Greater Bay Area, which has overtaken Tokyo Bay Area for the first time, ranks sixth on the list and has become a new innovation hub in Asia.

The mini-hubs have made an excellent debut in the global innovation landscape with strong research performance. They are all located in the world's top science hubs in Europe or the United States. Having access to unmatched scientific talent resources, all seven mini-hubs are among the top 20 cities overall and the top 5 for the number of active researchers (per million people).

Second, GIHs have strong agglomeration and spillover effects. Cities vary in their abilities in agglomerating innovation elements and exerting spillover effect. San Francisco-San Jose, New York MA, Beijing, Boston MA have a heavier concentration of innovation elements, while London MA, Geneva, Paris MA, Seattle-Tacoma-Bellevue, Seoul MA, Baltimore-Washington, and Amsterdam MA have a stronger impact on the innovation capability of surrounding areas.

Third, in uncertain times, global research is becoming more concentrated, and the competitive heterogeneity in research innovation among different regions have increased. The GIHI2022 ranking in research innovation has changed significantly. High-quality talent and resources are rapidly flowing to research hubs such as New York MA, Beijing, and San Francisco-San Jose. The difference in their research innovation capability is becoming more distinct. The United States, which is known for its science and technology human resources and knowledge creation, has 11 cities both in the top 20 cities in science and technology human resources, and in the top 20 cities in knowledge creation. Asian cities are picking up speed in building major scientific and technological infrastructure, and have established a comprehensive system of institutions that covers the whole knowledge chain and industry chain. European cities record balanced performance in all indicators in research innovation.

Fourth, in innovation economy, GIHs have demonstrated economic resilience despite the COVID-19 pandemic and unprecedented changes in the international situation, serving as an important engine for driving global growth. Despite a decline in capital and talent flows, the 80-20 rule is even more evident in GIHs. Digital information technology, biotechnology, and renewable energy technology are the major technology domains, while high-tech manufacturing and emerging industries are the main industrial sectors for driving growth. The rapid growth of leading innovation enterprises and emerging industries stands in stark contrast to the global economic downturn.

Fifth, in innovation ecosystem, cities across Europe and the United States are in the lead with their unique innovation culture, and Asian cities are gaining by fostering an innovation ecosystem for emerging industries. European cities outperform others in innovation ecosystem, reflecting its long-established innovation environment and culture. European cities have relatively strong performance in public services and innovation culture. Cities in the United States stand out in openness and collaboration and support for innovation, showcasing their strengths in global attraction and spillover effect. Although Asian cities, a late starter in innovation ecosystem, score relatively lower in this indicator, they stand out in renewable energy technology, innovation industry concentration, and digital information technology. A multi-dimensional innovation ecosystem network with Asian cities as its core is taking shape and expanding rapidly, which has an immediate impact on the global innovation ecosystem and facilitates its diversification.

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Contents

Contents

Introduction

As places where people exchange creative ideas, global innovation hubs (GIHs) are aggregating innovation elements and driving mobility across the world. By exerting spillover effect on surrounding areas and establishing the global innovation value chain, GIHs have become a major driver of future revolution.

The world continues to see COVID-19 outbreaks and intensified geopolitical conflicts in 2022, which has painted a more complex picture of global innovation and reshaped the distribution and competition landscape of innovation resources. Meanwhile, digital technology is fuelling the growth of global economy, accelerating the exchange and transfer of innovation elements, such as technology, capital, and data, around the world. The low-carbon transition has also made new progress, creating a global innovation landscape that features high-quality, and sustainable development. As important enablers of innovation, the way cities occupy the forefront of scientific research, become first-movers by leveraging their unique innovation paradigms, and foster a supportive innovation ecosystem to advance science and technology, are now central to urban innovation and development. To this end, building cities into GIHs has become a priority on countries' agendas for science and technology development.

The Global Innovation Hubs Index (GIHI) traces performance and rankings of leading GIHs in areas such as scientific research, technological innovation, and support for start-ups based on objective data. It helps explore the key drivers behind innovative transformation, reveal key elements and approaches for cities to deliver global innovation value, and provide references for policy-makers about the development of GIHs.

We uphold the principles of being scientific, objective, independent and impartial when developing the GIHI2022 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, **the evaluation scope has been expanded and a new type of innovation cities has been added to cover more cities in our assessment.** To explore the role of global hubs of different types in the innovation landscape, we have included mini-hubs — cities with a population of less than one million. A total of seven mini-hubs, such as Geneva and Cambridge, are newly included in the report. Meanwhile, the number of evaluated cities has increased from 50 in 2021 to 100 in 2022, resulting in a significant increase in the scope of administrative divisions, percentage of global population, as well as the number of world-leading research institutions, scientists, and leading innovation enterprises in the assessment.

Second, **the index system has been optimized to reflect trends in scientific development and improve the accuracy of measurement.** In order to ensure the stability and authority of the index system while considering availability and compatibility of the index data, some adjustments have been made to the index system of the GIHI2022. First, we have adjusted the absolute value and relative value of some indicators. For example, the 'professional talent inflow' has been replaced with the 'professional talent inflow (per million people)'. Second, we have optimized some indicators for innovation ecosystem to better capture the core elements of innovation. For example, the 'residents' average years of schooling' indicator has been replaced with the 'number of creative talent (per million people)' to measure creative human resources.

Third, **our data sources have been expanded and multi-source data have been included. The low-carbon energy technology was also taken into consideration.** Multi-source data were used to enable horizontal comparison between cities and to ensure the consistency of data sources. For example, data from LinkedIn and Zhaopin.com are both used to measure 'professional talent inflow' for cities, the 'fixed broadband internet speed' and the 'mobile internet speed' are used to measure the broadband connection speed of a city, and several rankings of innovation enterprises are used to measure 'leading innovative companies'. Three level-3 indicators, the 'number of valid patents (per million people)', the 'patent collaboration network centrality', and the 'number of patent cooperation treaty (PCT) patents', have expanded their sample scope from 'artificial intelligence' and 'integrated circuit manufacturing' to 'renewable energy technology', in order to reflect the low-carbon transition and sustainable development around the world. See Appendix I for detailed adjustments to the indicators.

We hope that the GIHI2022 could provide better reference and insights for the development of GIHs.

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 (Sassen, 2001:4). 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 ecosystem 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.

First, **a GIH is a science centre that emerges as a result of expanding research activities both in depth and geographic breadth (Csomós, & Tóth, 2016).** The concentration of research activities promotes knowledge sharing and exchange of ideas, reduces risks and costs of innovation, increase the efficiency of resource allocation through sharing of scientific infrastructure. With large-scale aggregation of research activities and innovation resources, global science hubs exert spillover effects on surrounding areas and even lead the world in scientific and technological development. Therefore, the effect of research innovation is measured by science and technology human resources, research institutions, scientific infrastructure, and knowledge creation.

Second, **a GIH features thriving innovation activities and a vibrant innovation economy.** Bringing together global leading innovative companies and economic activities, it guides, leads and influences the flow and the development efficiency of global innovation elements (Sassen,1991; Parnreiter 2010). They are also home to headquarters and R&D centres of multinational corporations, which direct and drive the global allocation of industrial chains and production resources. The concentration of industries such as advanced manufacturing and production services generates technological demands for innovation and creates market space. This continues to promote thriving emerging industries and start-ups, and enhance the growth efficiency of the innovation economy. Therefore, the dimension of innovation economy includes technological innovation capacity, innovative enterprises, emerging industries, and economic growth to measure.

Third, **a GIH benefits from a supportive innovation ecosystem.** A well-governed, dynamic, and evolving innovation ecosystem within and among cities requires collaboration and mutual support of diverse innovation subjects. This open and mobile system facilitates the flow of a slew of important innovation elements such as talent, technology, capital and data. It generates innovation and commercialization capacities (Derudder & Taylor, 2017). A healthy innovation ecosystem also offers support for start-ups, and stimulates innovation with high-quality public services. Therefore, the reach of an innovation ecosystem includes openness and collaboration, support for start-ups, public service, and innovation culture.

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1.2 Principles and process for constructing the index system

The GIHI2022 continues to apply scientific, objective, independent and impartial principles and has added diversified data sources to ensure the consistency of the index. The construction of the index system follows the principles below:

First, balance the theoretical basis and feasibility. Based on the concept of a GIH and its assessment framework, simple, clear and feasible indicators are selected to construct an index system that is theoretically grounded, internationally comparable and transparent in methodology.

Second, consider the index's current performance and future potential. The index system should capture historic strengths and existing innovation capacities of GIHs, as well as their dynamic development, and the future trends in emerging technologies and frontier fields. For example, the topic of renewable energy technology has been added to reflect the transition to a low-carbon, sustainable society.

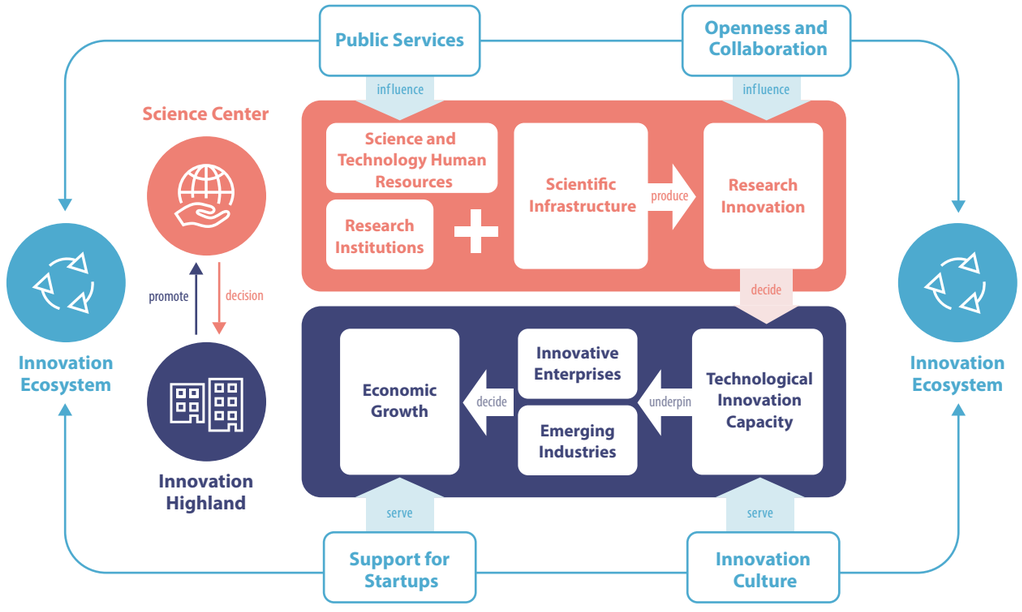
Third, be independent, stable, and forward-looking. The index system should be based on independent, objective, and stable data sources. The indicators selected should be able to capture the dynamic development of GIHs, and allow for regular evaluations and adjustments to existing indicators.

Fourth, be inherently logical and consistent. Among different innovation subjects, huge disparities still exist in their conversion efficiency between innovation input and output. In order to objectively evaluate their innovation capacity and performance, indicators related to innovation input, such as R&D expenditure, financial investment, and industrial policies, are not included in the assessment framework.

The index system is constructed following a three-stage process: qualitative design, quantitative screening, and feedback and testing. Qualitative design focuses on optimizing, adjusting and supplementing level-3 indicators, and making appropriate adjustments to data sources and statistical methods. This is conducted in accordance with the GIHI assessment framework, which consists of research innovation, innovation economy, and innovation ecosystem. In quantitative screening, data are collected, and their variability across time and cities are demonstrated, in order to eliminate indicators with low variability (scores do not vary much across cities), and those with high or low time sensitivity (scores vary too much or too little over time). In the feedback-and-testing stage, the results are compared with the opinions of experts and the general public. Data or results that are counterintuitive or difficult to interpret are re-examined and modified accordingly.

FIGURE 1

A conceptual model for GIHI assessment



1.3 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. Percentage of highly cited scientists
				03. Number of winners of top scientific awards
		A2. Research institutions	30%	04. Number of world-leading universities
				05. Number of top 200 world-class research institutions
		A3. Scientific infrastructure	10%	06. Number of large scientific facilities
				07. Number of top 500 supercomputers
		A4. Knowledge creation	30%	08. Percentage of highly cited papers
				09. Proportion of papers cited in patents, policy reports and clinical trials
B Innovation economy	30%	B1. Technological innovation capacity	25%	10. Total number of valid patents (per million people)
				11. Number of patent cooperation treaty (PCT) patents
		B2. Innovative enterprises	25%	12. Number of leading innovative companies
				13. Number of unicorn companies
		B3. Emerging industries	25%	14. Market value of high-tech manufacturing companies
				15. Revenue of listed companies in new economy industries
		B4. Economic growth	25%	16. GDP growth rate
				17. Labour productivity
C Innovation ecosystem	40%	C1. Openness and collaboration	25%	18. Paper co-authorship network centrality
				19. Patent collaboration network centrality
				20. Foreign direct investment (FDI)
				21. Outward foreign direct investment (OFDI)
		C2. Support for start-ups	25%	22. Venture capital investment (VC)
				23. Private equity (PE)
				24. Number of registered lawyers (per million people)
		C3. Public services	25%	25. Number of data centres (public clouds)
				26. Broadband connection speed
				27. Number of international flights (per million people)
				28. E-governance level
		C4. Innovation culture	25%	29. Professional talent inflow (per million people)
				30. Number of creative talent (per million people)
				31. 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 which 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 the data standardization).

1 The index system

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1.4
Subjects of evaluation

In order to stay in line with the development pattern of urban spatial systems, while being consistent with metrics used for the Nature Index, this report defines subjects of evaluation as a metropolitan area (MA), which is a region comprising a densely populated urban core area and less densely populated peripheral areas that are connected to the core economically and socially.

To ensure objectivity, comprehensiveness and validity of the coverage of evaluated cities, this report has optimized the selection process of cities/metropolitan areas and expanded the types and number of evaluated cities. It takes into account five international city rankings, including the Nature Index 2021 Science Cities, the 2021 Global Cities Index by Kearney, the Global Power City Index by the Mori Memorial Foundation, the WIPO Global Innovation Index 2021, and the Innovation Cities™ Index 2021 by 2thinknow. Cities/metropolitan areas with prominent innovation capabilities would make the shortlist, from which 100 cities/metropolitan areas that feature in at least two of the five lists will be selected as the final cities/metropolitan areas. These subjects are then assessed based on cross-comparison of the comprehensive rankings in the lists. The GIHI2022 now includes seven mini-hubs — innovative cities with a population of less than one million — such as Cambridge and Geneva. See Appendix IV for the GIH selection process.

These 100 cities/metropolitan areas are from 35 countries in 6 continents, covering 295 major administrative divisions. Among them, there are 37 Asian cities, 29 European cities, 27 North American cities, 4 Oceanian cities, 2 South American cities and 1 African city. These cities/metropolitan areas, home to the most advanced innovation resources and innovation output in the world, stand out in research innovation, innovation economy, and innovation ecosystem. Accounting for only 10.43% of the world's total population, they boast 125 world-leading universities, 133 of the top 200 world-class research institutions, 1,242 unicorn companies valued at more than one billion US dollars, and 1,870 leading innovative enterprises. They have attracted 278 winners of Nobel Prizes, Turing Awards, Fields Medals, and other top scientific awards. See Appendix V for the scope of administrative divisions of GIHs.

2 Overall GIHI ranking

2.1
Ranking results

The GIHI2022 ranking is shown in Table 2.

TABLE 2

Overall ranking of the 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	97.93	2	**100.00**	1	**100.00**	1
New York MA	**87.13**	2	100.00	1	**74.77**	4	**94.52**	3
Beijing	**80.39**	3	88.40	4	**75.34**	3	**82.60**	5
London MA	**79.49**	4	85.17	8	**65.77**	20	**97.41**	2
Boston MA	**78.85**	5	94.24	3	**68.88**	11	**81.88**	8
Guangdong-Hong Kong-Macao Greater Bay Area	**78.53**	6	86.17	5	**72.45**	7	**83.06**	4
Tokyo MA	**78.39**	7	74.31	39	**84.15**	2	**75.94**	20
Geneva	**74.89**	8	85.84	6	**65.49**	23	**82.12**	7
Paris MA	**73.67**	9	80.80	16	**66.27**	18	**81.73**	9
Shanghai	**73.05**	10	78.12	25	**68.31**	13	**79.09**	12
Seattle-Tacoma-Bellevue	**73.04**	11	80.17	19	**68.71**	12	**76.49**	17
Seoul MA	**72.93**	12	71.52	55	**72.74**	6	**78.19**	14
Singapore	**72.84**	13	78.44	24	**66.35**	17	**81.11**	10
Munich	**72.54**	14	76.28	31	**68.92**	10	**78.22**	13
Baltimore-Washington	**72.48**	15	84.57	10	**64.87**	32	**76.37**	18
Los Angeles-Long Beach-Anaheim	**72.40**	16	83.85	11	**64.99**	29	**76.61**	16
Amsterdam MA	**72.28**	17	78.96	23	**65.33**	25	**80.34**	11
San Diego MA	**72.03**	18	80.83	15	**67.90**	14	**73.78**	30
Cambridge	**71.83**	19	85.83	7	**64.22**	36	**74.02**	28
Zurich	**71.51**	20	81.54	13	**65.89**	19	**74.51**	25
Toronto MA	**71.51**	21	75.04	34	**64.91**	31	**82.22**	6
Stockholm	**71.34**	22	79.93	20	**65.40**	24	**76.22**	19
Ann Arbor	**71.12**	23	83.13	12	**64.09**	41	**74.45**	26
Chicago-Naperville-Elgin	**70.77**	24	80.53	17	**65.08**	28	**74.29**	27
Boulder	**70.50**	25	80.41	18	**64.18**	38	**74.90**	24
Austin	**70.19**	26	74.86	35	**66.89**	16	**75.00**	23
Chapel Hill-Durham-Raleigh	**70.09**	27	81.17	14	**64.22**	35	**72.73**	36
Dublin	**69.90**	28	71.03	61	**69.93**	8	**73.04**	32
Dallas-Fort Worth	**69.70**	29	72.63	49	**67.14**	15	**75.15**	22
Oxford	**69.53**	30	84.67	9	**62.17**	85	**70.72**	45

2 Overall GIHI ranking

City/metropolitan area	Overall		Research innovation		Innovation economy		Innovation ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Kyoto-Osaka-Kobe	**69.28**	31	**70.87**	62	**73.43**	5	**65.78**	74
Copenhagen	**68.91**	32	**77.99**	26	**63.95**	46	**72.33**	37
Vancouver MA	**68.59**	33	**74.74**	36	**64.56**	33	**73.45**	31
Sydney	**68.53**	34	**75.94**	32	**63.46**	61	**73.79**	29
Houston MA	**68.33**	35	**79.14**	21	**63.50**	60	**70.02**	51
Atlanta MA	**68.15**	36	**77.62**	27	**63.68**	52	**70.60**	46
Frankfurt	**67.99**	37	**71.45**	56	**64.21**	37	**75.15**	21
Melbourne	**67.98**	38	**77.40**	28	**63.53**	59	**70.50**	47
Lausanne	**67.81**	39	**78.97**	22	**64.93**	30	**66.27**	71
Montréal MA	**67.49**	40	**73.40**	43	**64.16**	40	**71.72**	40
Phoenix MA	**67.46**	41	**72.83**	48	**65.10**	27	**70.72**	43
Denver MA	**67.28**	42	**71.68**	53	**64.04**	42	**72.85**	35
Berlin MA	**67.05**	43	**72.90**	46	**64.17**	39	**70.72**	44
Oslo	**67.04**	44	**74.39**	38	**63.64**	53	**70.10**	50
Philadelphia MA	**66.84**	45	**74.49**	37	**63.74**	49	**69.18**	55
Barcelona MA	**66.81**	46	**72.46**	50	**63.55**	58	**71.33**	42
Helsinki	**66.80**	47	**72.31**	51	**63.09**	70	**72.14**	38
Milan	**66.77**	48	**73.07**	45	**64.02**	43	**69.90**	52
Pittsburgh	**66.75**	49	**76.77**	30	**62.77**	77	**68.22**	61
Taipei	**66.69**	50	**66.49**	79	**69.26**	9	**67.85**	64
Heidelberg	**66.39**	51	**77.07**	29	**63.80**	48	**65.15**	75
Madrid	**66.19**	52	**67.48**	74	**61.48**	92	**77.21**	15
Nanjing	**66.14**	53	**71.29**	59	**64.52**	34	**68.73**	58
Minneapolis - Saint Paul	**66.13**	54	**73.17**	44	**63.35**	65	**68.74**	57
Vienna	**66.08**	55	**71.88**	52	**63.62**	55	**69.36**	53
Brussels	**65.89**	56	**73.66**	41	**63.37**	63	**67.44**	67
Hamburg	**65.87**	57	**71.66**	54	**62.80**	76	**70.14**	49
Brisbane	**65.79**	58	**73.88**	40	**62.34**	82	**68.50**	59
Rome	**65.70**	59	**71.35**	58	**63.37**	64	**69.04**	56
St. Louis	**65.65**	60	**75.42**	33	**62.72**	79	**65.96**	73
Miami MA	**65.50**	61	**67.75**	72	**62.68**	80	**72.87**	34
Perth	**65.47**	62	**71.43**	57	**63.89**	47	**67.39**	68
Hangzhou	**65.47**	63	**68.10**	70	**65.69**	21	**67.80**	65
Tel Aviv	**64.93**	64	**70.77**	63	**62.84**	74	**67.88**	63
Manchester	**64.76**	65	**73.61**	42	**60.84**	98	**67.67**	66

City/metropolitan area	Overall		Research innovation		Innovation economy		Innovation ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Daejeon	**64.70**	66	**69.13**	66	**65.54**	22	**64.53**	78
Portland	**64.60**	67	**71.18**	60	**63.01**	71	**66.13**	72
Dubai	**64.60**	68	**65.92**	82	**61.80**	88	**73.00**	33
Moscow	**64.59**	69	**63.90**	90	**63.71**	51	**71.95**	39
Warsaw	**64.35**	70	**64.55**	87	**65.15**	26	**68.33**	60
Lyon-Grenoble	**64.20**	71	**69.65**	64	**61.80**	89	**68.11**	62
Wuhan	**64.18**	72	**72.90**	47	**62.18**	84	**64.36**	81
Abu Dhabi	**64.08**	73	**66.87**	75	**61.06**	95	**71.51**	41
Nagoya MA	**64.05**	74	**66.76**	76	**63.99**	44	**67.02**	69
Suzhou	**63.37**	75	**68.34**	68	**63.98**	45	**63.29**	86
Hefei	**63.30**	76	**69.40**	65	**63.55**	57	**62.73**	88
Chengdu	**63.21**	77	**68.52**	67	**62.82**	75	**64.39**	80
Changsha	**63.05**	78	**68.26**	69	**63.17**	67	**63.56**	84
Xi'an	**62.84**	79	**68.08**	71	**63.38**	62	**62.75**	87
Tianjin	**62.84**	80	**67.63**	73	**62.11**	86	**65.11**	76
Kuala Lumpur	**62.79**	81	**65.75**	84	**62.36**	81	**66.34**	70
Mexico City	**62.56**	82	**62.72**	97	**61.15**	93	**70.35**	48
Jinan	**62.31**	83	**66.11**	80	**63.57**	56	**62.57**	90
Sao Paulo	**62.18**	84	**64.39**	88	**60.00**	100	**69.28**	54
Busan	**61.78**	85	**62.63**	98	**63.00**	72	**65.04**	77
Budapest	**61.77**	86	**65.86**	83	**61.84**	87	**63.71**	83
Istanbul	**61.64**	87	**63.62**	91	**62.88**	73	**63.81**	82
Bengaluru	**61.64**	88	**63.18**	94	**62.76**	78	**64.40**	79
Chongqing	**61.53**	89	**65.14**	86	**63.10**	69	**61.67**	96
Dalian	**61.50**	90	**66.61**	78	**61.77**	90	**62.21**	93
Qingdao	**61.47**	91	**63.60**	92	**63.34**	66	**62.58**	89
Ankara	**61.19**	92	**62.91**	95	**63.63**	54	**61.85**	95
Mumbai MA	**61.10**	93	**61.86**	99	**63.73**	50	**62.41**	92
Changchun	**60.91**	94	**65.72**	85	**62.31**	83	**60.27**	99
Harbin	**60.79**	95	**65.93**	81	**61.14**	94	**61.50**	98
Johannesburg	**60.71**	96	**66.64**	77	**61.49**	91	**60.00**	100
Central National Capital Region Delhi MA	**60.42**	97	**62.79**	96	**60.97**	97	**63.54**	85
Bangkok	**60.32**	98	**63.36**	93	**61.05**	96	**62.53**	91
Buenos Aires	**60.15**	99	**63.96**	89	**60.61**	99	**62.08**	94
Jakarta	**60.00**	100	**60.00**	100	**63.11**	68	**61.52**	97

2.2 Overall analysis

The results show that San Francisco-San Jose has been the top ranked GIH for three consecutive years, scoring much higher than other cities/metropolitan areas; New York MA ranks second again with a score of 87.13; Beijing surpasses London MA in third place, with London MA and Boston MA at fourth and fifth. Other cities/metropolitan areas in the top 20 are Guangdong-Hong Kong-Macao Greater Bay Area, Tokyo MA, Geneva, Paris MA, Shanghai, Seattle-Tacoma-Bellevue, Seoul MA, Singapore, Munich, Baltimore-Washington, Los Angeles-Long Beach-Anaheim, Amsterdam MA, San Diego MA, Cambridge, and Zurich.

Compared with 2021, Geneva and Shanghai have entered the top 10 for the first time; Seoul MA, Cambridge, and Zurich have entered the top 20 for the first time, of which Seoul MA is up by nine spots. By comparing the assessment results of GIHI over the past three years, it is found that the overall rankings of Beijing, Shanghai and Singapore have continued to improve significantly, indicating that policy support at the national and regional levels has made a remarkable difference. The overall rankings of London MA, Guangdong-Hong Kong-Macao Greater Bay Area, Paris MA, and Munich have also edged up.

TABLE 3

A comparison of the top 20 cities/metropolitan areas in overall ranking between 2020 and 2022

City/metropolitan area	Rank 2022	Rank 2021	Rank 2020
San Francisco-San Jose	1	1	1
New York MA	2	2	2
Beijing	3	4	5
London MA	4	3	6
Boston MA	5	5	3
Guangdong-Hong Kong-Macao Greater Bay Area	6	7	N/A
Tokyo MA	7	6	4
Geneva	8	N/A	N/A
Paris MA	9	8	11
Shanghai	10	14	17
Seattle-Tacoma-Bellevue	11	9	7
Seoul MA	12	21	16
Singapore	13	13	14
Munich	14	11	19
Baltimore-Washington	15	10	9
Los Angeles-Long Beach-Anaheim	16	12	8
Amsterdam MA	17	16	12
San Diego MA	18	15	N/A
Cambridge	19	N/A	N/A
Zurich	20	N/A	N/A

For the first time, GIHI2022 has evaluated mini-hubs with a population of less than one million. Seven mini-hubs from the United States, the United Kingdom, Switzerland and Germany make the list of the 100 GIHs. Their overall rankings are relatively high, with Geneva, Cambridge, and Ann Arbor ranking 8th, 19th and 23rd respectively, demonstrating their excellent innovation capabilities. Analysis has shown that the mini-hubs are among the top GIHs in research innovation. All of them rank in the top 30 and five rank in the top 20. They have continued to drive innovation for urban development with their strong research power. Six mini-hubs, except Oxford, also perform well in innovation economy with balanced development in science and technology. Individually, Geneva has a strong performance in research innovation, innovation economy, and innovation ecosystem, ranking 6th, 23rd and 7th respectively; Cambridge and Oxford have come to the fore with their renowned research strengths.

TABLE 4

The GIHI 2022 ranking of mini-hubs

City/metropolitan area	Overall		Research innovation		Innovation economy		Innovation ecosystem	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Geneva	74.89	8	85.84	6	65.49	23	82.12	7
Cambridge	71.83	19	85.83	7	64.22	36	74.02	28
Ann Arbor	71.12	23	83.13	12	64.09	41	74.45	26
Boulder	70.50	25	80.41	18	64.18	38	74.90	24
Oxford	69.53	30	84.67	9	62.17	85	70.72	45
Lausanne	67.81	39	78.97	22	64.93	30	66.27	71
Heidelberg	66.39	51	77.07	29	63.80	48	65.15	75

Europe and the United States continue to lead in global innovation, with Asian cities rising to a new level and diversifying the international innovation landscape. Among the top 50 cities/metropolitan areas, 19 are in the United States, 18 in Europe and 8 in Asia. Among Asian cities/metropolitan areas, Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, Tokyo MA, Shanghai, Seoul MA, Singapore, Kyoto-Osaka-Kobe, and Taipei rank among the top 50, and 6 of them even make it to the top 20, suggesting Asia has become one of the most dynamic regions in the world for innovation.

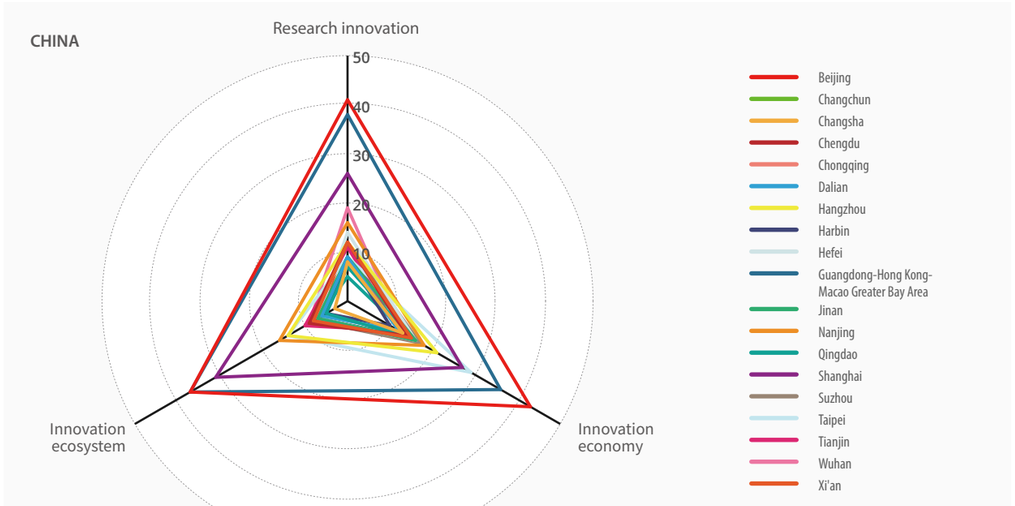
Bay Areas take four spots among the top ten cities/metropolitan areas in the overall ranking with their concentrated innovation resources. San Francisco Bay is far ahead in innovation economy and remains a global leader in technology and industrial innovation. New York Bay dominates technology innovation thanks to its solid research strengths. Guangdong-Hong Kong-Macao Greater Bay Area, with its advantages in research innovation and innovation ecosystem, surpasses Tokyo Bay for the first time and ranks sixth in overall ranking, making it the new hub of the value chain in Asia. Tokyo Bay ranks seventh.

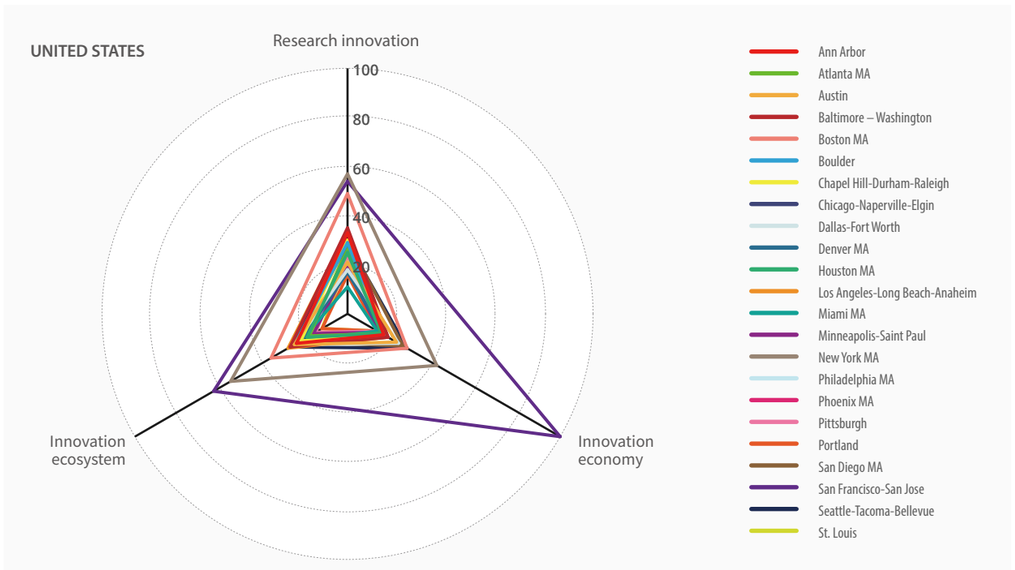
Chinese cities are on the rise, sweeping up 19 spots, with Changsha, Tianjin, Xi'an, Chongqing, Jinan, Qingdao, Changchun, Dalian, and Harbin entering the list for the first time. The overall innovation capabilities of Chinese cities continue to improve. Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, and Shanghai have made it to the top 10. The distribution of Chinese cities on the list, however, is relatively scattered, with Beijing, Shanghai, and Guangdong-Hong Kong-Macao Greater Bay Area taking the lead and facilitating the development of surrounding cities.

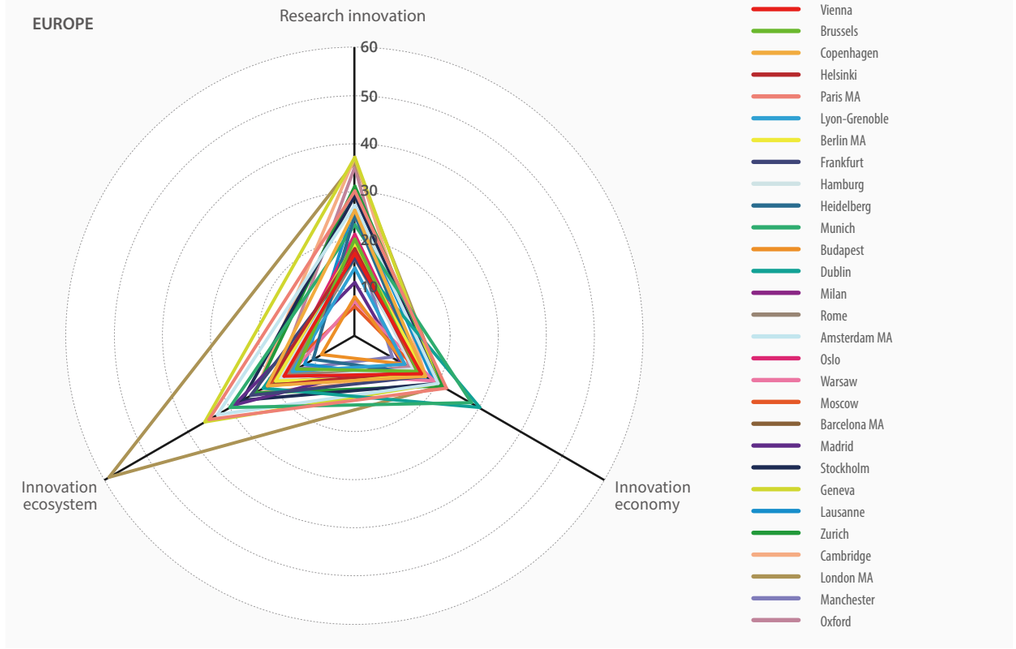
In terms of development patterns, GIHs show distinctive regional characteristics of development. Generally, European cities/metropolitan areas lead the world in innovation ecosystem by providing a favourable environment for their regional innovation and development. In addition to San Francisco-San Jose, which boasts the world's most influential innovation economy, other cities/metropolitan areas in the United States stand out in both research innovation and innovation ecosystem, driving a positive interaction between the two indicators. Chinese cities/metropolitan areas have relatively balanced development in all three level-1 indicators, although their innovation economy is more remarkable compared with other regions. An active regional innovation economy is key to help boost local innovation capacity. The development patterns of GIHs in the United States, Europe and China are shown in Figure 2.

FIGURE 2

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



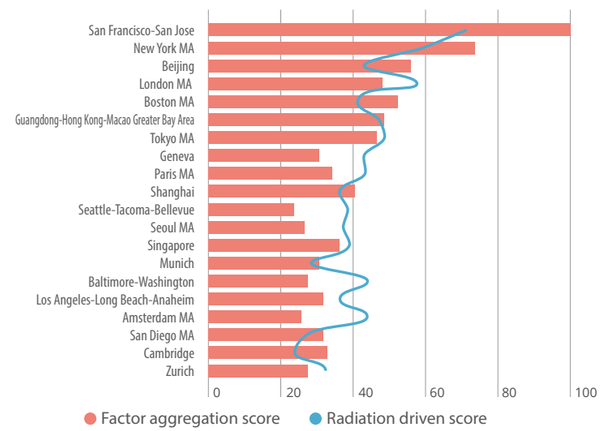




The GIHI2022 measures element agglomeration and spillover effect of GIHs (see Appendix VI for assessment methodology). It shows a strong relation between their abilities in agglomerating elements and their spillover effect, with innovation elements being drawn to the top cities. Among the top 20 cities/metropolitan areas, San Francisco-San Jose, New York MA, Beijing, and Boston MA have significant clustering strengths, gathering a large amount of high-end innovation resources around the world to stay dominant in the global innovation network. Guangdong-Hong Kong-Macao Greater Bay Area, London MA, and Tokyo MA have comparable performance in the second tier. The gap between spillover effect exerted by different GIHs is relatively small, with San Francisco-San Jose, New York MA, and London MA having a stronger effect than Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, Baltimore-Washington, Amsterdam MA, Paris MA, Geneva, and Beijing. Cities including London MA, Geneva, Paris MA, Seattle-Tacoma-Bellevue, Seoul, Baltimore-Washington, and Amsterdam MA have much stronger spillover capacity than element agglomeration capacity. The performance in element agglomeration and spillover effect for the GIHI top 20 cities/metropolitan areas is shown in Figure 3.

FIGURE 3

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



3 Research innovation

Scientific research is the cornerstone of innovation. The GIHI measures research innovation via four level-2 indicators — science and technology human resources, research institutions, scientific infrastructure, and knowledge creation — and nine level-3 indicators.

3.1

A comprehensive analysis of research innovation

The GIHI2022 ranking in research innovation is shown in Table 5.

TABLE 5

Ranking and scores of 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**	91.39	100.00	67.51	86.11
2	San Francisco-San Jose	**97.93**	100.00	77.45	80.51	96.45
3	Boston MA	**94.24**	97.60	78.24	62.20	96.55
4	Beijing	**88.40**	73.54	88.23	100.00	69.01
5	Guangdong-Hong Kong-Macao Greater Bay Area	**86.17**	68.48	94.90	70.90	73.29
6	Geneva	**85.84**	88.11	65.10	61.36	100.00
7	Cambridge	**85.83**	95.01	65.10	62.82	92.66
8	London MA	**85.17**	78.30	78.24	62.71	88.46
9	Oxford	**84.67**	89.13	65.10	61.36	95.67
10	Baltimore-Washington	**84.57**	82.70	72.35	67.51	88.23
11	Los Angeles-Long Beach-Anaheim	**83.85**	77.66	78.24	60.00	86.67
12	Ann Arbor	**83.13**	94.31	65.10	60.00	87.00
13	Zurich	**81.54**	80.66	70.20	61.36	87.63
14	Chapel Hill-Durham-Raleigh	**81.17**	76.88	72.35	60.00	87.86
15	San Diego MA	**80.83**	77.25	67.25	63.45	91.81
16	Paris MA	**80.80**	74.46	76.08	72.15	77.59
17	Chicago-Naperville-Elgin	**80.53**	75.02	72.35	66.16	84.57
18	Boulder	**80.41**	82.16	65.10	60.73	90.32
19	Seattle-Tacoma-Bellevue	**80.17**	74.48	65.10	61.47	96.56
20	Stockholm	**79.93**	73.22	70.20	68.25	86.46
21	Houston MA	**79.14**	70.89	75.29	60.73	83.22
22	Lausanne	**78.97**	77.18	68.04	60.00	87.22
23	Amsterdam MA	**78.96**	73.83	65.88	66.27	90.09
24	Singapore	**78.44**	73.80	70.20	64.80	83.39
25	Shanghai	**78.12**	67.89	81.76	70.34	69.17
26	Copenhagen	**77.99**	74.06	68.04	60.00	87.34
27	Atlanta MA	**77.62**	68.85	70.20	60.73	87.84
28	Melbourne	**77.40**	73.27	70.20	60.00	83.41
29	Heidelberg	**77.07**	78.43	65.10	60.00	84.62
30	Pittsburgh	**76.77**	72.40	68.04	60.00	85.42

3 Research innovation

Rank	City/metropolitan area	Research innovation	Science and technology human resources	Research institutions	Scientific infrastructure	Knowledge creation
31	Munich	**76.28**	72.84	70.20	61.47	79.84
32	Sydney	**75.94**	72.14	68.04	61.36	82.57
33	St. Louis	**75.42**	70.41	65.10	60.00	87.47
34	Toronto MA	**75.04**	71.31	65.10	62.09	84.44
35	Austin	**74.86**	69.74	65.10	62.94	84.99
36	Vancouver MA	**74.74**	70.76	65.10	61.47	84.41
37	Philadelphia MA	**74.49**	70.42	65.10	60.00	84.81
38	Oslo	**74.39**	71.42	62.94	64.07	84.42
39	Tokyo MA	**74.31**	65.37	70.20	91.24	65.72
40	Brisbane	**73.88**	71.50	65.10	60.00	82.01
41	Brussels	**73.66**	69.39	62.94	60.00	86.38
42	Manchester	**73.61**	70.44	65.10	60.00	82.24
43	Montréal MA	**73.40**	68.56	68.04	61.47	78.59
44	Minneapolis - Saint Paul	**73.17**	67.31	65.10	60.73	83.56
45	Milan	**73.07**	70.99	62.94	66.78	79.62
46	Berlin MA	**72.90**	71.52	62.16	64.80	80.76
47	Wuhan	**72.90**	68.87	72.35	62.71	70.21
48	Phoenix MA	**72.83**	67.95	65.10	60.00	82.36
49	Dallas-Fort Worth	**72.63**	68.29	65.10	60.00	81.46
50	Barcelona MA	**72.46**	69.01	65.10	60.73	79.91
51	Helsinki	**72.31**	71.35	62.94	61.36	79.91
52	Vienna	**71.88**	70.41	62.94	60.73	79.88
53	Denver MA	**71.68**	67.89	60.00	60.00	86.17
54	Hamburg	**71.66**	73.50	60.00	61.47	80.01
55	Seoul MA	**71.52**	65.68	69.41	68.47	70.34
56	Frankfurt	**71.45**	67.30	62.94	60.00	81.98
57	Perth	**71.43**	70.17	62.94	60.00	79.20
58	Rome	**71.35**	70.47	65.10	62.20	74.55
59	Nanjing	**71.29**	68.19	72.35	61.47	66.89
60	Portland	**71.18**	66.80	60.00	60.00	85.78
61	Dublin	**71.03**	68.67	62.94	62.71	78.07
62	Kyoto-Osaka-Kobe	**70.87**	68.27	70.20	67.63	65.38
63	Tel Aviv	**70.77**	66.70	65.10	61.36	76.89
64	Lyon-Grenoble	**69.65**	68.21	62.94	61.36	75.25
65	Hefei	**69.40**	66.65	65.10	68.13	69.48

Rank	City/metropolitan area	Research innovation	Science and technology human resources	Research institutions	Scientific infrastructure	Knowledge creation
66	Daejeon	**69.13**	70.06	62.16	66.16	70.56
67	Chengdu	**68.52**	64.28	68.04	64.80	66.84
68	Suzhou	**68.34**	65.13	65.10	60.73	71.72
69	Changsha	**68.26**	66.01	67.25	60.73	67.66
70	Hangzhou	**68.10**	66.48	65.10	64.41	67.81
71	Xi'an	**68.08**	65.73	68.04	61.36	65.98
72	Miami MA	**67.75**	65.12	60.00	60.00	77.48
73	Tianjin	**67.63**	64.82	67.25	60.73	66.96
74	Madrid	**67.48**	67.29	60.00	61.36	73.94
75	Abu Dhabi	**66.87**	65.77	60.00	61.47	73.56
76	Nagoya MA	**66.76**	64.29	65.10	66.27	65.07
77	Johannesburg	**66.64**	64.18	60.00	61.36	74.45
78	Dalian	**66.61**	64.99	64.31	61.36	67.63
79	Taipei	**66.49**	68.29	62.16	60.00	67.85
80	Jinan	**66.11**	63.47	67.25	60.00	64.26
81	Harbin	**65.93**	64.48	65.10	61.36	65.05
82	Dubai	**65.92**	62.90	60.00	60.00	74.32
83	Budapest	**65.86**	65.35	60.00	60.00	71.80
84	Kuala Lumpur	**65.75**	70.14	60.00	60.00	66.94
85	Changchun	**65.72**	64.04	65.10	60.00	65.60
86	Chongqing	**65.14**	63.29	64.31	60.00	65.72
87	Warsaw	**64.55**	65.46	60.00	61.36	67.23
88	Sao Paulo	**64.39**	63.28	62.94	60.00	65.46
89	Buenos Aires	**63.96**	63.21	60.00	61.36	67.66
90	Moscow	**63.90**	63.90	62.94	65.14	60.78
91	Istanbul	**63.62**	61.76	60.00	64.07	66.64
92	Qingdao	**63.60**	64.50	60.00	60.00	66.10
93	Bangkok	**63.36**	61.57	60.00	60.00	68.19
94	Bengaluru	**63.18**	61.22	62.16	60.00	65.02
95	Ankara	**62.91**	62.54	60.00	60.00	65.98
96	Central National Capital Region Delhi MA	**62.79**	62.05	60.00	60.73	65.72
97	Mexico City	**62.72**	61.81	60.00	60.00	66.11
98	Busan	**62.63**	61.98	60.00	60.00	65.70
99	Mumbai MA	**61.86**	61.49	60.00	60.00	63.95
100	Jakarta	**60.00**	60.00	60.00	60.00	60.00

3 Research innovation

New York MA ranks top in research innovation, followed by San Francisco-San Jose and Boston MA. Beijing and Guangdong-Hong Kong-Macao Greater Bay Area rank fourth and fifth. European and American cities/metropolitan areas stand out in research innovation, with 18 of them entering the top 20. Chinese cities have risen significantly, with Beijing up by two spots and Guangdong-Hong Kong-Macao Greater Bay Area up by five spots from 2021.

Geographically, the gap between research innovation of European and American cities and those of Asian cities is narrowing. Asian cities are catching up and rising up the ranks rapidly. In recent years, a number of Asia cities have become GIHs of international importance with the strength of their scientific infrastructure and research institutions.

From the perspective of dynamic evolution, the top 20 cities in research innovation have changed significantly due to fierce competition. Specifically, 19 spots have changed, with one city up by as many as five spots. Beijing and Guangdong-Hong Kong-Macao Greater Bay Area are leading in research innovation, benefiting from their research institutions and scientific infrastructure.

TABLE 6

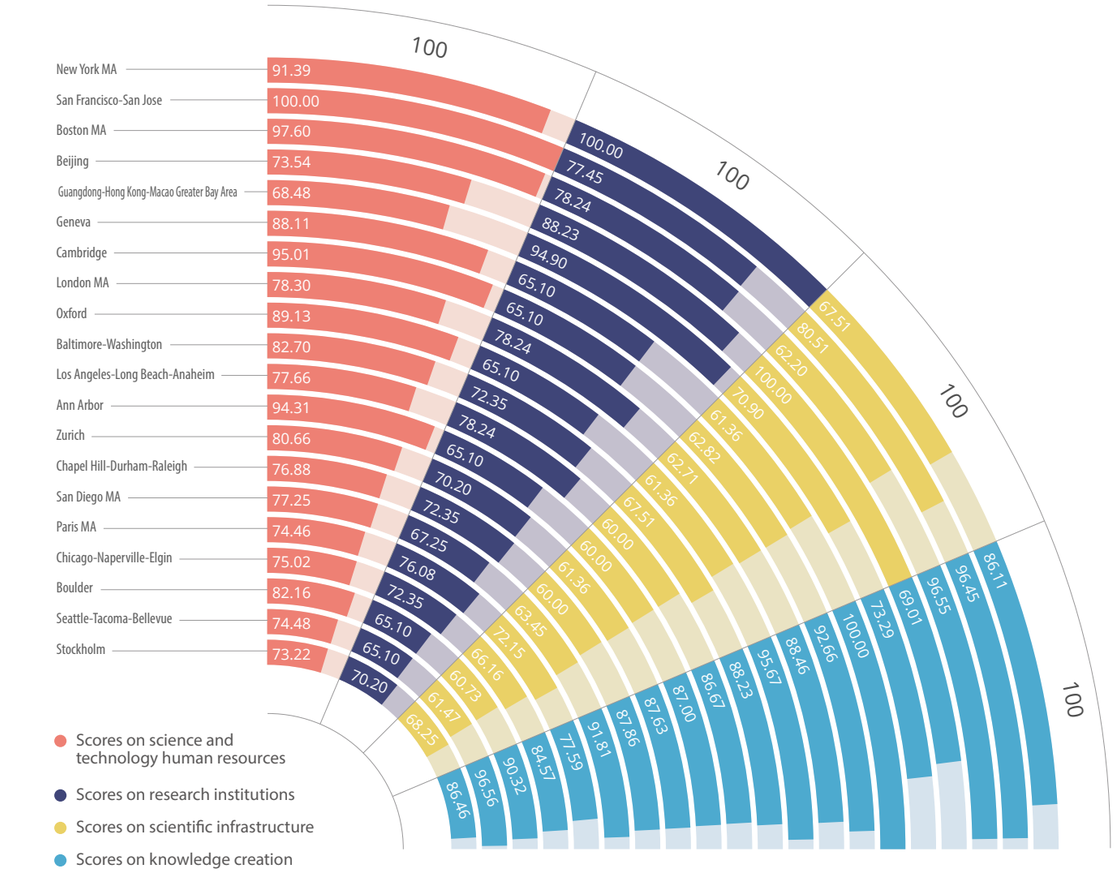
A comparison of the top 20 cities/metropolitan areas in research innovation between 2020 and 2022

City/metropolitan area	Rank 2022	Rank 2021	Rank 2020
New York MA	1	1	1
San Francisco-San Jose	2	3	3
Boston MA	3	2	2
Beijing	4	6	8
Guangdong-Hong Kong-Macao Greater Bay Area	5	10	N/A
Geneva	6	N/A	N/A
Cambridge	7	N/A	N/A
London MA	8	5	4
Oxford	9	N/A	N/A
Baltimore-Washington	10	4	5
Los Angeles-Long Beach-Anaheim	11	9	9
Ann Arbor	12	N/A	N/A
Zurich	13	N/A	N/A
Chapel Hill-Durham-Raleigh	14	7	7
San Diego MA	15	13	N/A
Paris MA	16	11	6
Chicago-Naperville-Elgin	17	12	15
Boulder	18	N/A	N/A
Seattle-Tacoma-Bellevue	19	14	14
Stockholm	20	15	13

The GIHI top 20 cities/metropolitan areas in research innovation have varied performance across each sub-indicator. With absolute advantages in science and technology human resources and research institutions, New York MA comes first on the list. San Francisco-San Jose, at second, has balanced performance in all four indicators: science and technology human resources, research institutions, scientific infrastructure, and knowledge creation. Beijing and Guangdong-Hong Kong-Macao Greater Bay Area have enhanced their research power by building scientific infrastructure and research institutions. Beijing, in particular, is the leading city in scientific infrastructure. Boston MA, Cambridge, and Oxford are strong in both science and technology human resources as well as knowledge creation. Geneva and Seattle-Tacoma-Bellevue excel in knowledge creation. Ann Arbor has strong science and technology human resources. Development of the GIHI top 20 cities/metropolitan areas in research innovation is shown in Figure 4.

FIGURE 4

Development patterns of the GIHI top 20 cities/metropolitan areas in research innovation



3.2
Science and technology human resources

Taking into account factors such as the distribution of scientific talent, their mobility, and the time period required for the transformation of scientific output, the GIHI2022 uses three indicators — the number of active researchers (per million people), the percentage of highly cited scientists, and the number of top scientific award winners — to measure a GIH's talent pool. Figure 5 shows the number of active researchers (per million people) and the percentage of highly cited scientists for the GIHI top 20 cities/metropolitan areas in science and technology human resources.

Cities in Europe and North America continue to enjoy a competitive edge in science and technology human resources, but Asian cities are catching up. The number of active researchers in Chinese cities is gradually increasing. The GIHI top 20 list in science and technology human resources is composed of 11 American cities/metropolitan areas and 9 European cities.

FIGURE 5

Number of active researchers (per million people) and percentage of highly cited scientists for the GIHI top 20 cities/metropolitan areas in science and technology human resources

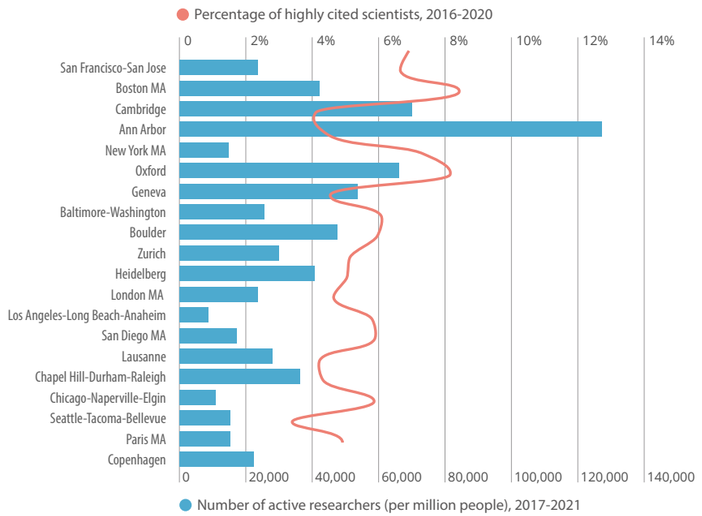
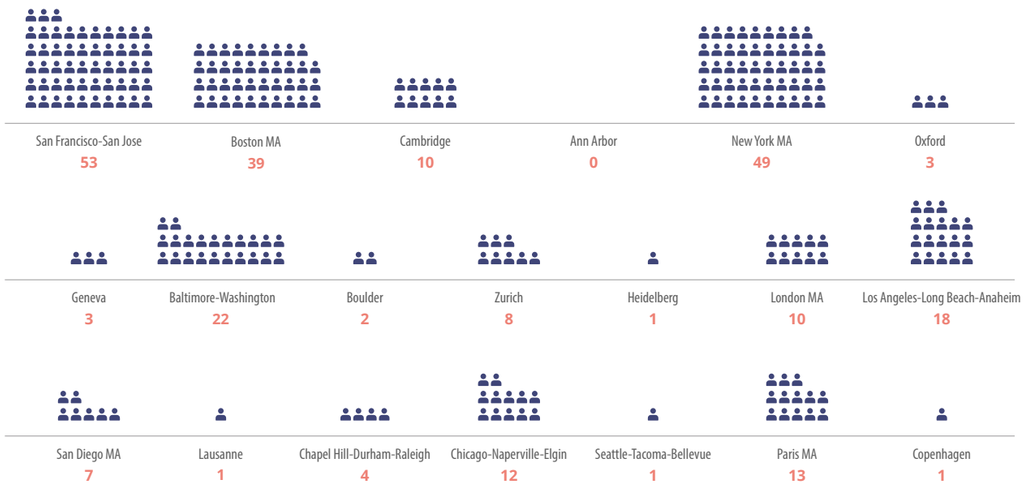


FIGURE 6

Number of winners of top scientific awards for the GIHI top 20 cities/metropolitan areas in science and technology human resources



The mini-hubs have certain advantages in science and technology human resources, and seven mini-hubs included in the assessment are all among the top 20. These cities have become the first choice for many top researchers and highly cited scientists to work as they not only house the world's best universities and research institutions, but also have established distribution mechanism of scientific rewards as well as comprehensive evaluation system, in addition to a favourable environment for scientific research and remarkable research outputs. For example, the University of Cambridge makes it a priority to protect the intellectual property rights of its faculties, and requires that the intellectual property rights from any research conducted with external funding (charitable foundations, enterprises, the European Union or the UK government) belong to the university. The lucrative rewards have attracted researchers from all over the world to collaborate with each other, and have nurtured a large number of outstanding scientists and technological talent.

The top five cities in the number of active researchers (per million people) are all mini-hubs, with Ann Arbor ranking first (127,313) followed by Cambridge (69,915) and Oxford (66,177) with a narrow margin. Geneva and Boulder are fourth and fifth, respectively. The number of active researchers in Asian cities has increased most significantly, with 26 Asian cities seeing an increase of more than 10% in 2021, of which Central National Capital Region Delhi MA, Suzhou, and Jakarta grew by up to 20%.

Cities in Europe and the United States perform noticeably well in the percentage of highly cited scientists. Cambridge tops the rank with 8.43%, followed by Geneva, Oxford, San Francisco-San Jose, Boston MA, Boulder, and Hamburg, all exceeding 6%.

By the number of winners of top scientific awards, 23 American cities/metropolitan areas assessed in the GIHI2022 have a total of 205 top award winners; four cities in the UK have 21 top award winners, and 19 cities in China have 16 top award winners. These leading talents have enhanced the regions' capabilities in basic research, and helped attract more brilliant teams.

3.3
Research institutions

The report measures the performance of universities and research institutions in a city by the number of institutions and world-leading universities in the Nature Index top 200 by publications.

The diversification of research institutions is a result of years of efforts, which requires strategic planning, continuous investment and relevant regulations, and has thus led to relatively stable rankings. In terms of research institutions, New York MA comes out on top with nine top 200 research institutions and seven leading universities. Chinese cities/metropolitan areas stand out with three spots among the top 5, among which, Guangdong-Hong Kong-Macao Greater Bay Area ranks second with eight top 200 research institutions and six leading universities; Beijing comes third with nine top 200 research institutions and three leading universities; and Shanghai ranks fourth with six top 200 research institutions and three leading universities. The Chinese cities of Nanjing and Wuhan, also home to many prestigious universities and research institutions, are among the top 20 for this indicator because of their strong scientific output.

FIGURE 7

Number of world-leading universities and top 200 world-class research institutions for the GIHI top 20 cities/metropolitan areas in research institutions

3.4 Scientific infrastructure

Scientific infrastructure provides the technological platform for researchers to carry out high-quality, innovative research. This report measures the development of scientific infrastructure in cities/metropolitan areas by the number of large scientific facilities and top 500 supercomputers.

Among the top 20 cities in scientific infrastructure, Beijing and Tokyo MA rank first and second with a significant edge, followed by San Francisco-San Jose, Paris MA, and Guangdong-Hong Kong-Macao Greater Bay Area.

China remains competitive in the number of large scientific facilities. There are 23 large scientific facilities in 23 American cities and 31 large scientific facilities in 19 Chinese cities. Tokyo MA is leading with 16 large scientific facilities, followed by Beijing with 10. Shanghai and Hefei tie for fourth with six large scientific facilities each. As scientific research becomes increasingly complex, inter-disciplinary and integrated, large scientific facilities, as a large-scale and complex research system, play a significant role in leading and transforming frontier technologies.

Asia performs exceptionally well with three cities/metropolitan areas among the top five in the number of top 500 supercomputers. Beijing is leading with 36 of the top 500 supercomputers, ahead of San Francisco-San Jose in second. Guangdong-Hong Kong-Macao Greater Bay Area and Tokyo MA are both in the third place. China had 173 top 500 supercomputers and the United States had 149 in 2021. However, the computing power of supercomputers in the United States on average is 986.47Pflop/s, much higher than that of China at 530.04Pflop/s. In recent years, Europe and the United States have deployed more supercomputers: the number of top 500 supercomputers owned by San Francisco-San Jose has increased from 10 in 2020 to 15 in 2021, and those owned by Amsterdam MA and Paris MA have increased by three units, respectively.

FIGURE 8 **Number of top 500 supercomputers for the GIHI top 20 cities/metropolitan areas** in scientific infrastructure

3.5 Knowledge creation

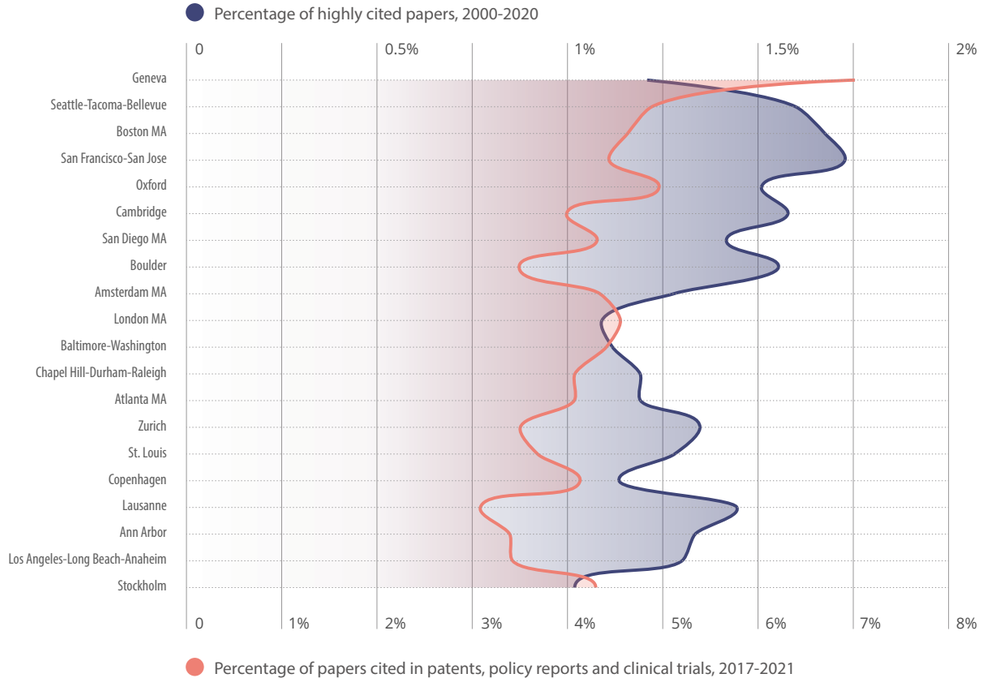
This report uses the percentage of highly cited papers published by researchers in a city to measure their overall quality and academic impact. It uses the proportion of papers cited in patents, policy reports and clinical trials to measure the application potential of the publications in industry and society.

Cities in Europe and the United States enjoy remarkable advantages in knowledge creation, with the latter performing exceptionally well on this indicator: eleven cities/metropolitan areas are among the top 20 in knowledge creation; six mini-hubs make the top 20. The top 5 cities/metropolitan areas in knowledge creation are Geneva, Seattle-Tacoma-Bellevue, Boston MA, San Francisco-San Jose, and Oxford.

Europe and the United States lead the world in the percentage of highly cited papers with three cities/metropolitan areas in the United States among the top 5. The average level for cities in the United States is 1.26%, among which San Francisco-San Jose, Boston MA, and Seattle-Tacoma-Bellevue accounting for the biggest share at 1.73%, 1.68% and 1.60%, respectively. The percentages of highly cited papers for Chinese cities are more dispersed, with Guangdong-Hong Kong-Macao Greater Bay Area and Suzhou at 0.83% and 0.76%, and the average level for Chinese cities is 0.55%.

European cities show advantages in the transformation of research output, measured by the percentage of papers cited in patents, policy reports and clinical trials. Geneva ranks first at 7.02%, followed by Oxford at 4.96% and Seattle-Tacoma Bellevue at 4.88%. The average level for cities in the UK, the United States, and China is 4.25%, 3.66%, and 1.20%, respectively. By comparison, European cities have a more comprehensive ecosystem that features close interactions and collaborations between industries, universities, and science communities, as well as a smooth flow of innovation elements. Universities, with their strong strengths in basic research, provide technical support for urban innovation. Governments facilitate resource integration and information sharing with industries and universities by providing incentives to support start-ups. For example, as of the end of 2021, the University of Oxford had a close partnership with more than a thousand high-tech companies based in Oxford, and had incubated nearly 200 spin-offs between 1998 and 2018.

FIGURE 9 **Percentages of highly cited papers and of papers cited in patents, policy reports and clinical trials** for the GIHI top 20 cities/metropolitan areas in knowledge creation



4 Innovation economy

The innovation economy reflects the scale and quality of a city/metropolitan area's innovation capacity. The GIHI examines the innovation economy using four level-2 indicators — technological innovation capacity, innovative enterprises, emerging industries, and economic growth — along with eight level-3 indicators.

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4.1

A comprehensive analysis of innovation economy

The GIHI2022 ranking in innovation economy is shown in Table 7.

TABLE 7

Ranking and scores of 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**	88.28	100.00	100.00	99.29
2	Tokyo MA	**84.15**	100.00	75.34	74.86	81.74
3	Beijing	**75.34**	68.29	79.27	73.05	77.79
4	New York MA	**74.77**	64.81	76.42	74.22	83.99
5	Kyoto-Osaka-Kobe	**73.43**	86.48	64.80	63.11	84.33
6	Seoul MA	**72.74**	73.31	65.08	73.19	82.05
7	Guangdong-Hong Kong-Macao Greater Bay Area	**72.45**	67.45	72.22	74.09	73.63
8	Dublin	**69.93**	62.15	62.12	68.61	100.00
9	Taipei	**69.26**	71.62	61.66	66.30	84.49
10	Munich	**68.92**	73.25	61.60	60.27	92.07
11	Boston MA	**68.88**	62.22	70.89	62.38	87.51
12	Seattle-Tacoma-Bellevue	**68.71**	62.86	62.16	67.24	93.65
13	Shanghai	**68.31**	62.48	71.73	63.63	78.95
14	San Diego MA	**67.90**	70.14	63.56	62.42	82.46
15	Dallas-Fort Worth	**67.14**	65.01	61.45	66.97	81.83
16	Austin	**66.89**	67.90	61.69	61.08	86.82
17	Singapore	**66.35**	65.23	61.63	61.49	87.40
18	Paris MA	**66.27**	63.41	66.24	64.06	74.98
19	Zurich	**65.89**	61.06	61.36	60.06	95.53
20	London MA	**65.77**	61.09	67.29	63.13	75.71
21	Hangzhou	**65.69**	62.21	65.53	61.47	80.39
22	Daejeon	**65.54**	68.59	60.08	60.08	82.44
23	Geneva	**65.49**	60.77	60.38	60.15	95.39
24	Stockholm	**65.40**	62.58	62.50	61.19	84.92
25	Amsterdam MA	**65.33**	60.88	61.53	61.07	89.86
26	Warsaw	**65.15**	60.02	60.15	60.33	94.71
27	Phoenix MA	**65.10**	63.69	60.92	61.98	82.67
28	Chicago-Naperville-Elgin	**65.08**	61.37	63.53	63.07	78.87
29	Los Angeles-Long Beach-Anaheim	**64.99**	61.87	64.88	61.04	78.78
30	Lausanne	**64.93**	61.82	60.46	60.04	89.96

Rank	City/metropolitan area	Innovation economy	Technological innovation capacity	Innovative enterprises	Emerging industries	Economic growth
31	Toronto MA	64.91	60.98	61.46	61.67	85.83
32	Baltimore-Washington	64.87	60.62	62.82	61.21	84.29
33	Vancouver MA	64.56	60.76	61.00	60.66	87.10
34	Nanjing	64.52	62.58	61.32	60.62	82.98
35	Chapel Hill-Durham-Raleigh	64.22	61.81	60.76	60.54	83.80
36	Cambridge	64.22	67.34	60.23	62.63	70.59
37	Frankfurt	64.21	60.19	60.90	60.00	87.45
38	Boulder	64.18	62.17	60.23	60.00	85.13
39	Berlin MA	64.17	61.07	61.80	60.08	83.56
40	Montréal MA	64.16	60.35	60.53	61.02	85.52
41	Ann Arbor	64.09	64.53	60.08	60.00	80.67
42	Denver MA	64.04	60.47	61.00	61.81	81.88
43	Milan	64.02	60.43	60.53	60.63	85.27
44	Nagoya MA	63.99	63.75	61.20	60.88	77.16
45	Suzhou	63.98	61.42	61.60	60.29	81.72
46	Copenhagen	63.95	60.11	61.66	60.30	83.70
47	Perth	63.89	60.08	60.00	60.06	87.44
48	Heidelberg	63.80	60.50	60.53	60.00	85.08
49	Philadelphia MA	63.74	60.21	62.12	60.70	80.36
50	Mumbai MA	63.73	60.13	62.09	62.44	76.89
51	Moscow	63.71	60.11	60.15	61.09	83.71
52	Atlanta MA	63.68	61.20	61.08	61.37	79.03
53	Oslo	63.64	60.76	60.84	60.35	82.17
54	Ankara	63.63	60.03	60.08	60.00	85.81
55	Vienna	63.62	60.19	60.31	60.14	84.67
56	Jinan	63.57	60.68	60.45	60.30	82.86
57	Hefei	63.55	60.96	60.83	60.12	81.73
58	Barcelona MA	63.55	60.28	60.38	60.32	83.50
59	Melbourne	63.53	60.04	60.92	61.27	80.69
60	Houston MA	63.50	62.80	60.99	60.15	77.76
61	Sydney	63.46	60.21	60.54	60.39	82.54
62	Xi'an	63.38	60.86	60.38	60.59	80.83
63	Brussels	63.37	60.19	60.68	60.51	81.51
64	Rome	63.37	60.38	60.60	60.13	82.10
65	Minneapolis-Saint Paul	63.35	60.57	60.90	60.29	80.64

Rank	City/metropolitan area	Innovation economy	Technological innovation capacity	Innovative enterprises	Emerging industries	Economic growth
66	Qingdao	63.34	60.61	60.77	60.05	81.28
67	Changsha	63.17	60.63	60.62	60.32	79.94
68	Jakarta	63.11	60.00	60.71	60.81	79.50
69	Chongqing	63.10	60.37	60.85	60.31	79.49
70	Helsinki	63.09	60.84	60.84	60.23	78.80
71	Portland	63.01	60.42	60.23	60.12	80.53
72	Busan	63.00	60.41	60.08	60.01	81.07
73	Istanbul	62.88	60.05	60.69	60.21	79.21
74	Tel Aviv	62.84	60.42	62.16	60.11	75.36
75	Chengdu	62.82	60.70	61.00	60.20	77.00
76	Hamburg	62.80	61.20	60.61	60.04	77.18
77	Pittsburgh	62.77	60.94	60.53	60.18	77.33
78	Bengaluru	62.76	60.17	62.76	61.26	71.66
79	St. Louis	62.72	60.38	60.23	60.17	78.71
80	Miami MA	62.68	60.26	60.86	60.12	77.38
81	Kuala Lumpur	62.36	60.23	60.00	60.57	76.31
82	Brisbane	62.34	60.03	60.08	60.03	77.47
83	Changchun	62.31	60.28	60.23	60.05	76.47
84	Wuhan	62.18	61.75	61.14	60.95	69.20
85	Oxford	62.17	61.12	60.38	60.04	73.78
86	Tianjin	62.11	60.56	60.92	60.47	72.37
87	Budapest	61.84	60.03	60.08	60.13	74.09
88	Dubai	61.80	60.03	60.31	60.08	73.40
89	Lyon-Grenoble	61.80	60.82	60.08	60.00	72.65
90	Dalian	61.77	60.46	60.15	60.00	72.94
91	Johannesburg	61.49	60.01	60.00	60.10	72.10
92	Madrid	61.48	60.34	60.83	61.97	65.74
93	Mexico City	61.15	60.00	60.48	61.40	66.22
94	Harbin	61.14	60.49	60.30	60.12	68.29
95	Abu Dhabi	61.06	60.09	60.00	60.69	67.95
96	Bangkok	61.05	60.02	60.16	60.75	67.59
97	Central National Capital Region Delhi MA	60.97	60.05	61.81	61.25	62.44
98	Manchester	60.84	60.27	60.08	60.01	67.46
99	Buenos Aires	60.61	60.00	60.15	60.10	66.12
100	Sao Paulo	60.00	60.01	61.18	60.12	60.00

4 Innovation economy

The top ranked city for innovation economy is San Francisco-San Jose, well ahead of Tokyo MA and Beijing in second and third places. Among the top 20 cities/metropolitan areas, Asia takes up the biggest share with eight spots (four in China), while there are seven in the United States and five in Europe.

The top three spots remain unchanged, with San Francisco-San Jose ranking first for three consecutive years. New York MA has made significant progress, up from 11th in 2020 to 4th in 2022, especially for sub-indicators such as technological innovation capacity and emerging industries. Kyoto-Osaka-Kobe has also risen since 2020. Dublin has moved up from 11th in 2021 to 8th and entered the top 10 list for innovation economy for the first time, performing particularly well in emerging industries. Munich has risen from 20th in 2021 to 10th, performing well in technological innovation capacity and economic growth.

The top 20 cities/metropolitan areas in innovation economy have diverse advantages in each sub-indicator. San Francisco-San Jose has relatively balanced performance across four indicators, leading both in innovative enterprises and emerging industries, and ranking second in technological innovation capacity and economic growth. Tokyo MA, San Francisco-San Jose, and Kyoto-Osaka-Kobe have much stronger technological innovation capacity than other cities. Cities/metropolitan areas including Tokyo MA, Beijing, New York MA, and Guangdong-Hong Kong-Macao Greater Bay Area outperform in the emerging industries and innovative enterprises. Dublin, Zurich, Seattle-Tacoma-Bellevue, and Munich stand out in economic growth.

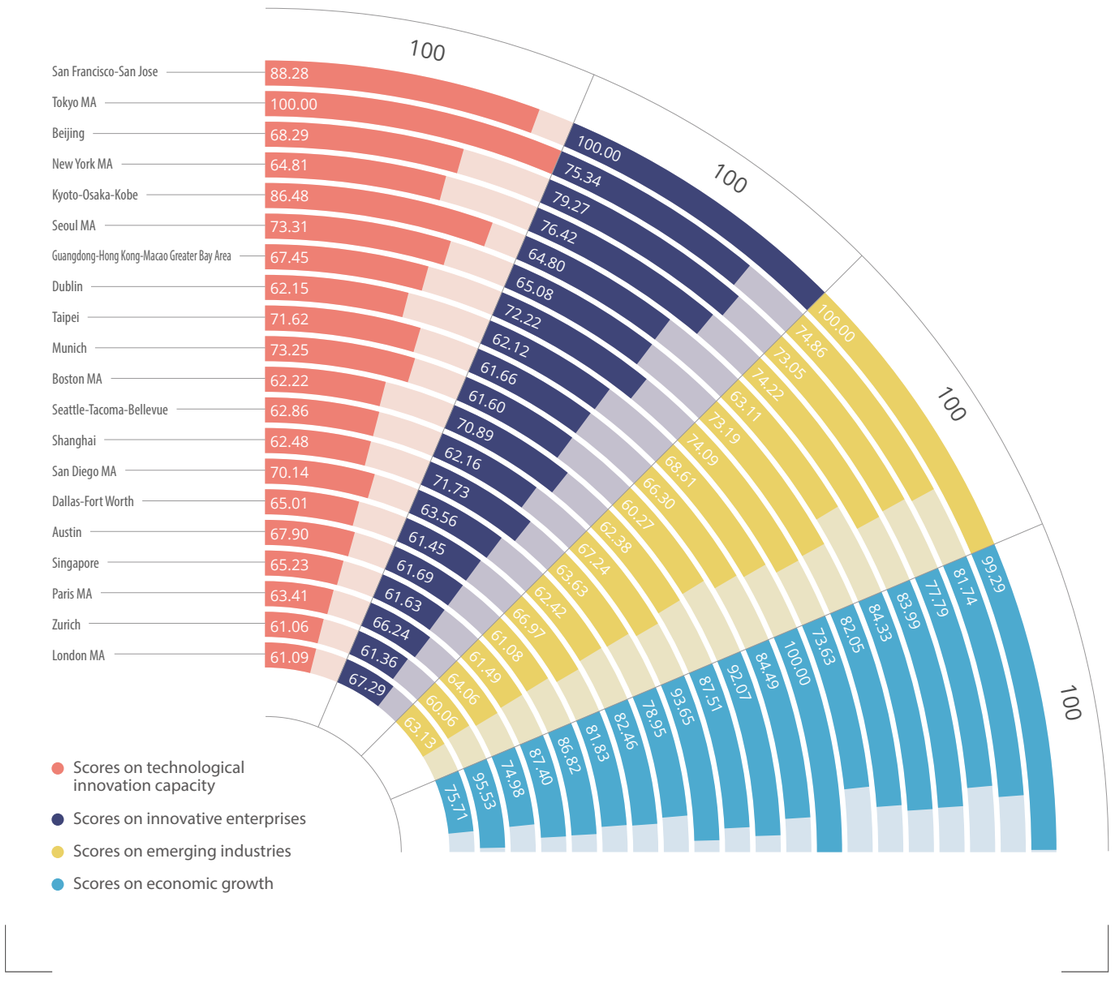
TABLE 8

A comparison of the top 20 cities/metropolitan areas in innovation economy between 2020 and 2022

City/metropolitan area	Rank 2022	Rank 2021	Rank 2020
San Francisco-San Jose	1	1	1
Tokyo MA	2	2	2
Beijing	3	3	3
New York MA	4	5	11
Kyoto-Osaka-Kobe	5	7	8
Seoul MA	6	6	7
Guangdong-Hong Kong-Macao Greater Bay Area	7	4	N/A
Dublin	8	11	N/A
Taipei	9	N/A	N/A
Munich	10	20	17
Boston MA	11	8	10
Seattle-Tacoma-Bellevue	12	9	9
Shanghai	13	13	5
San Diego MA	14	14	N/A
Dallas-Fort Worth	15	12	N/A
Austin	16	10	N/A
Singapore	17	16	16
Paris MA	18	15	12
Zurich	19	N/A	N/A
London MA	20	17	18

FIGURE 10

Development patterns of the GIHI top 20 cities/metropolitan areas in innovation economy



4.2
Technological innovation capacity

Patents are an important indicator of technological innovation capacity. 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. AI and IC patents represent the level of intelligent technology and information technology in the digital industry. The number of renewable energy technology patents, as a new indicator, represents the level of green technologies, which include solar, wind, biomass, geothermal, tidal, and nuclear fusion energies.

The top 5 cities/metropolitan areas in technological innovation capacity are Tokyo MA, San Francisco-San Jose, Kyoto-Osaka-Kobe, Seoul MA, and Munich. Among the top 20 cities/metropolitan areas in technological innovation capacity, eight are in the United States, three in Europe, and nine in Asia.

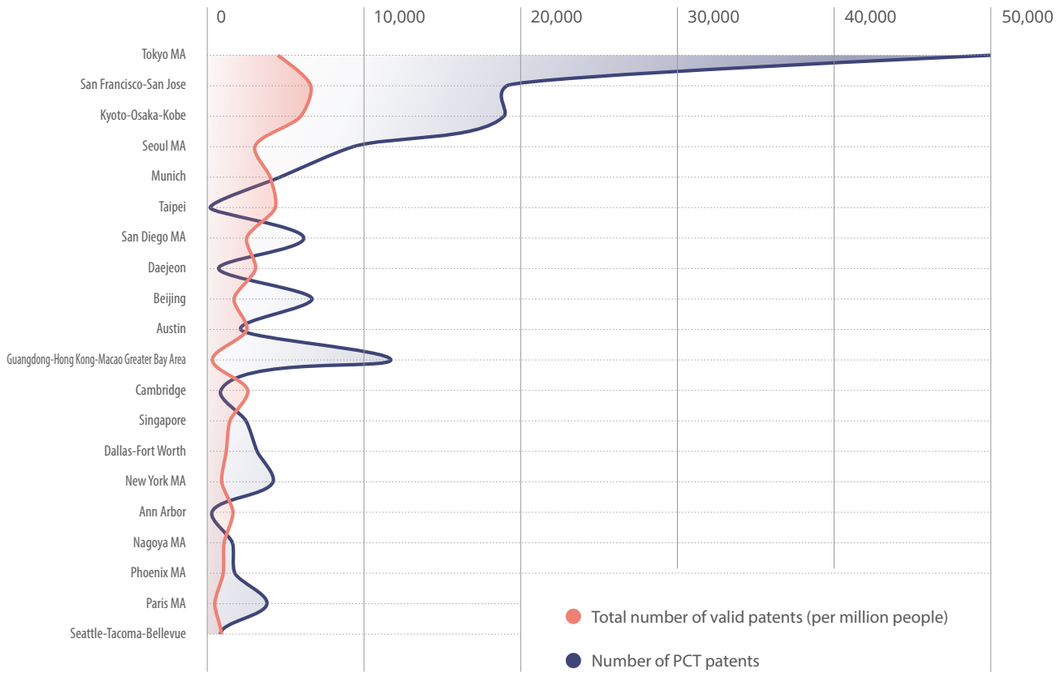
For the number of valid invention patents (per million people), five cities/metropolitan areas boast more than 4,000 patents, with San Francisco-San Jose topping the ranking with 6,607 patents, followed by Kyoto-Osaka-Kobe with 5,969, Tokyo MA with 4,494, Taipei with 4,341, and Munich with 4,009.

In terms of the number of PCT patents, Tokyo MA leads the world with 49,926 patents, San Francisco-San Jose ranks second with 19,120, and Kyoto-Osaka-Kobe comes third with 18,931. Guangdong-Hong Kong-Macao Greater Bay Area and Seoul MA rank fourth and fifth, but they lag behind San Francisco-San Jose and Tokyo MA notably.

Cities/metropolitan areas in East Asia have excelled in the number of patents for digital technology and renewable energy technology. In the fields of AI, IC and renewable energy, East Asian cities sweep up seven spots among the top 10 in the number of valid invention patents and five among the top 10 in the number of PCT patents.

FIGURE 11

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



4.3
Innovative enterprises

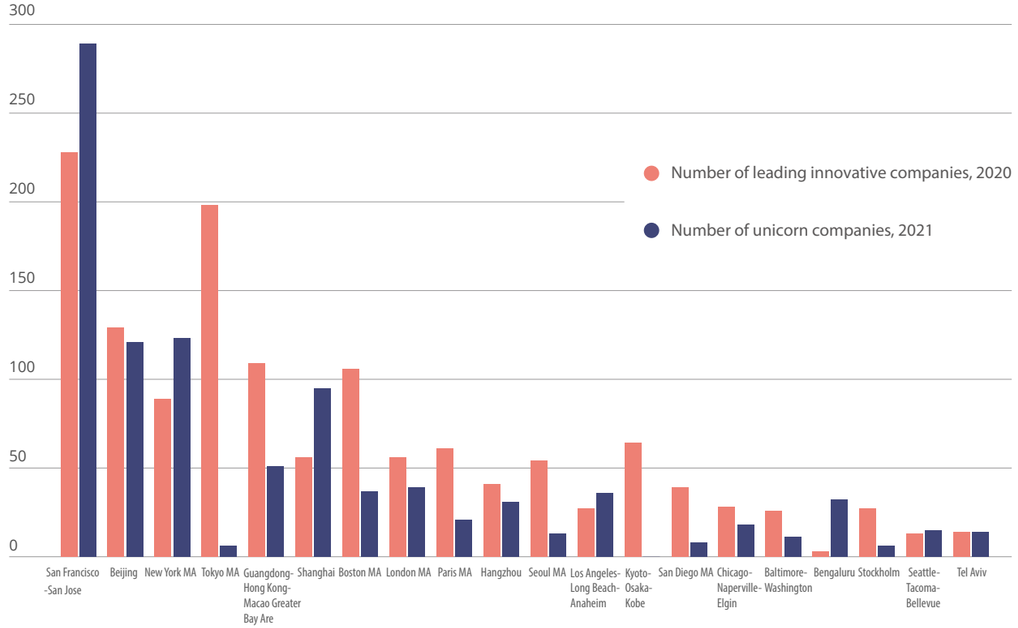
Enterprises are the major actors of technological innovation. This report uses the number of leading innovative companies and the number of unicorn companies to measure the scale and vitality of innovative companies. The top five cities/metropolitan areas in innovative enterprises are San Francisco-San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

Although San Francisco-San Jose is far ahead with 228 leading innovative companies, Chinese cities also perform well with Beijing ranking third, Guangdong-Hong Kong-Macao Greater Bay Area fourth, and Shanghai ninth, highlighting the vitality of Chinese enterprises as the major actors of innovation. These cities are also home to most of the 'lighthouse factories' in China, according to the list of 'lighthouse factories' published by the World Economic Forum (WEF), which comprises of leading enterprises that have been effective in integrating and applying cutting-edge technology in the Fourth Industrial Revolution.

By the number of unicorn companies, San Francisco-San Jose, New York MA, and Beijing lead the world with 289, 123 and 121, respectively. Tokyo MA ranks second in leading innovative companies with 198, but ranks 30th in this indicator with only six unicorns. Kyoto-Osaka-Kobe has similar performance, showing that Japan is an established innovative country dominated by 'the elephants ' — traditional giant corporations.

FIGURE 12

Number of leading innovative companies and unicorn companies
for the GIHI top 20 cities/metropolitan areas in innovative enterprises



4.4
Emerging industries

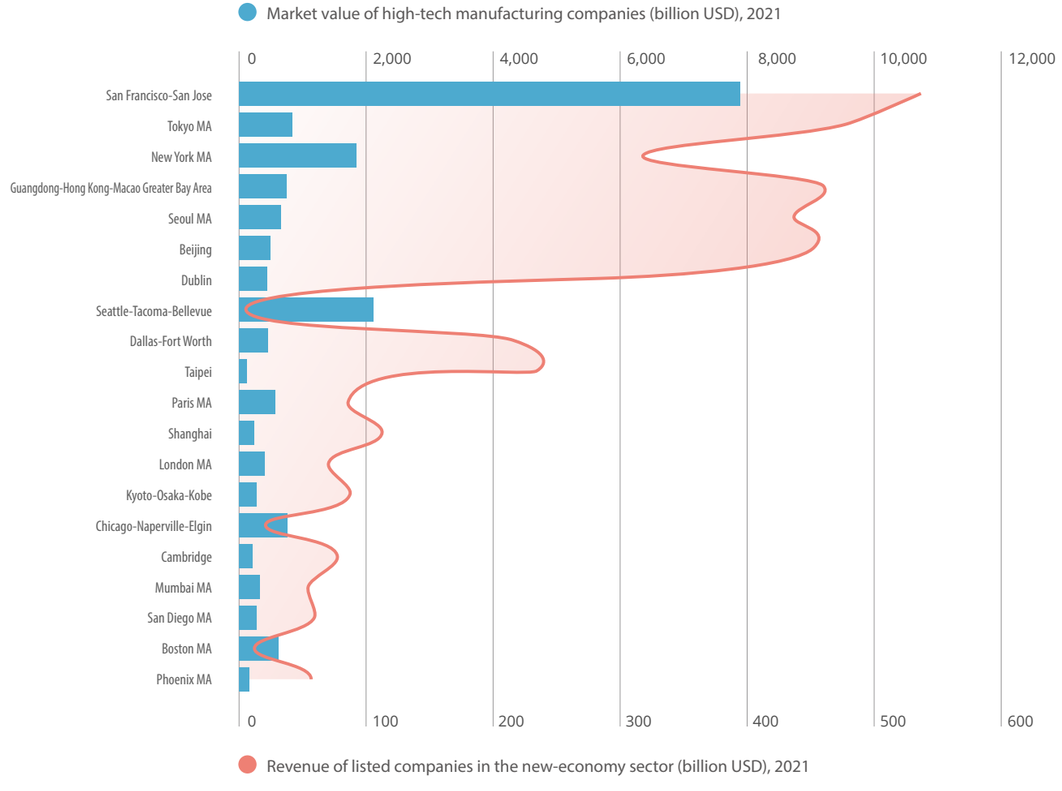
Emerging industries refer to high-tech manufacturing and new industries that help sustain the competitive edge of the economy, which include biomedicine, high-end equipment manufacturing, and next-generation information technology. The top five cities/metropolitan areas in emerging industries are San Francisco-San Jose, Tokyo MA, New York MA, Guangdong-Hong Kong-Macao Greater Bay Area, and Seoul MA. New York MA is up from seventh in 2021 to third as a result of its effective transformation in high-tech industries such as bioscience, smart city, and information technology in recent years.

The top three cities in the market value of high-tech manufacturing companies are all in the United States: San Francisco-San Jose, Seattle-Tacoma-Bellevue, and New York MA. By sector, the high-tech manufacturing industry in the United States is dominated by IT software and services, biomedicine, and health facilities and services, showcasing the vitality of these emerging industries despite the challenges presented by the COVID-19 pandemic.

By the revenue of listed companies in new economy industries, Asian cities appear to be more competitive. Although San Francisco-San Jose tops the list, the second to fifth cities are all in Asia: Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, and Seoul MA. Asian cities take up six spots among the top 10, suggesting that they are growing quickly and catching up in emerging industries related to the digital economy.

FIGURE 13

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



4.5
Economic growth

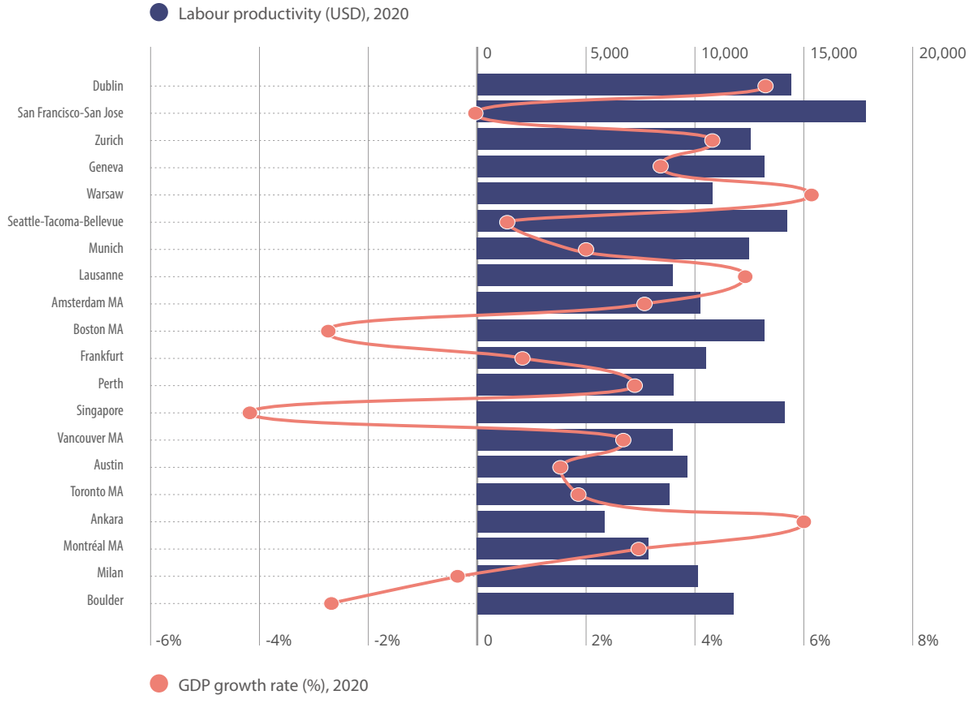
Innovation drives high-quality economic growth, which reflects a city's development and innovation performance. This report uses the GDP growth rate, adjusted by 2020 purchasing power parity (PPP), to measure a city's overall economic growth and living standards. Labour productivity in 2020 is adopted to measure a city's social productivity. The top five cities/metropolitan areas in economic growth are Dublin, San Francisco-San Jose, Zurich, Geneva, and Warsaw, all of which are in Europe except San Francisco-San Jose. They have managed to maintain high GDP growth and labour productivity at the same time.

The impact of the COVID-19 pandemic on global economy is reflected in the GDP growth rate. Only 30% of the assessed cities maintained positive growth in 2020. Among the GIHI top 20 cities/metropolitan areas in innovation economy, ten cities have maintained positive growth. It shows that innovation economy could make GDP growth more resilient. Only three of the 23 assessed cities/metropolitan areas in the United States and 14 of the 19 cities/metropolitan areas in China have maintained positive growth. In the post-pandemic era, China's economy has withstood various challenges posed by repeated COVID-19 outbreaks and the ever-changing global situations, which would lay a solid foundation for the future development of science and technology.

In terms of labour productivity, San Francisco-San Jose, Dublin, Seattle-Tacoma-Bellevue, Singapore, and Boston MA are the top five. Geneva and Zurich in Switzerland have risen to the top 10, ranking sixth and seventh. Switzerland takes the lead in patent applications, intellectual property revenue and the manufacturing of high-end technology products, and is particularly efficient in turning innovation into applications. Its labour productivity is also very high due to flexible regulations and a conducive tax regime.

FIGURE 14

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



5 Innovation ecosystem

An innovation ecosystem could promote efficient integration and interaction between innovative subjects and elements, which is crucial to enhancing the sustainable competitiveness of a city. The GIHI examines innovation ecosystems using four level-2 indicators — openness and collaboration, support for start-ups, public services, and innovation culture — and 14 level-3 indicators.

5.1

A comprehensive analysis of innovation ecosystem

The GIHI2022 ranking in innovation ecosystem is shown in Table 9.

TABLE 9

Ranking and scores of 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**	100.00	100.00	76.05	81.21
2	London MA	**97.41**	88.72	80.10	100.00	94.76
3	New York MA	**94.52**	92.07	91.29	92.75	72.56
4	Guangdong-Hong Kong-Macao Greater Bay Area	**83.06**	95.62	71.84	86.01	66.37
5	Beijing	**82.60**	82.27	82.32	76.84	70.80
6	Toronto MA	**82.22**	77.67	70.83	82.47	86.05
7	Geneva	**82.12**	62.60	64.72	95.38	100.00
8	Boston MA	**81.88**	78.03	78.04	80.04	76.50
9	Paris MA	**81.73**	82.19	67.70	91.74	77.52
10	Singapore	**81.11**	94.42	62.45	87.11	73.90
11	Amsterdam MA	**80.34**	69.26	64.94	99.83	84.29
12	Shanghai	**79.09**	83.28	76.56	79.29	65.38
13	Munich	**78.22**	69.82	71.76	74.25	86.78
14	Seoul MA	**78.19**	87.75	65.42	83.04	70.78
15	Madrid	**77.21**	68.39	70.62	79.04	83.23
16	Los Angeles-Long Beach-Anaheim	**76.61**	73.46	68.15	88.40	72.80
17	Seattle-Tacoma-Bellevue	**76.49**	72.86	66.50	83.53	78.92
18	Baltimore-Washington	**76.37**	74.60	68.95	83.66	73.33
19	Stockholm	**76.22**	65.92	67.56	82.40	84.50
20	Tokyo MA	**75.94**	83.63	63.23	84.60	70.08
21	Frankfurt	**75.15**	62.36	69.59	87.82	78.12
22	Dallas-Fort Worth	**75.15**	69.80	64.31	90.76	75.71
23	Austin	**75.00**	66.88	66.55	78.75	83.97
24	Boulder	**74.90**	60.92	64.09	84.44	88.92
25	Zurich	**74.51**	65.75	63.32	90.86	79.20
26	Ann Arbor	**74.45**	65.28	62.21	76.56	91.54
27	Chicago-Naperville-Elgin	**74.29**	70.31	66.86	88.51	70.74
28	Cambridge	**74.02**	65.19	62.45	74.02	91.88
29	Sydney	**73.79**	71.03	66.56	82.02	73.72
30	San Diego MA	**73.78**	66.46	68.96	76.99	78.70

5 Innovation ecosystem

Rank	City/metropolitan area	Innovation ecosystem	Openness and collaboration	Support for start-ups	Public services	Innovation culture
31	Vancouver MA	73.45	66.46	65.26	75.65	83.79
32	Dublin	73.04	67.84	65.11	73.90	82.66
33	Dubai	73.00	69.13	60.45	87.60	77.60
34	Miami MA	72.87	63.93	66.36	89.51	72.91
35	Denver MA	72.85	64.42	66.25	81.08	78.72
36	Chapel Hill-Durham-Raleigh	72.73	66.76	64.14	80.03	79.68
37	Copenhagen	72.33	63.67	62.36	89.03	77.42
38	Helsinki	72.14	62.98	60.91	82.52	84.35
39	Moscow	71.95	65.71	61.26	72.80	87.70
40	Montréal MA	71.72	67.00	65.72	74.76	78.08
41	Abu Dhabi	71.51	64.78	60.00	78.33	84.98
42	Barcelona MA	71.33	66.09	66.36	82.45	71.29
43	Phoenix MA	70.72	66.30	63.11	80.86	74.91
44	Berlin MA	70.72	66.10	69.14	68.34	75.99
45	Oxford	70.72	63.24	62.50	74.55	83.49
46	Atlanta MA	70.60	67.65	64.90	82.02	69.86
47	Melbourne	70.50	69.76	64.53	77.95	70.91
48	Mexico City	70.35	63.28	76.24	69.13	67.34
49	Hamburg	70.14	63.08	64.48	66.61	85.03
50	Oslo	70.10	62.46	63.03	81.85	76.33
51	Houston MA	70.02	68.95	64.44	81.89	67.51
52	Milan	69.90	65.11	66.76	75.40	72.63
53	Vienna	69.36	63.18	62.68	83.62	72.56
54	Sao Paulo	69.28	64.65	71.11	71.22	68.29
55	Philadelphia MA	69.18	66.85	65.59	76.89	69.22
56	Rome	69.04	66.18	67.93	72.08	69.77
57	Minneapolis - Saint Paul	68.74	63.20	64.24	79.48	71.56
58	Nanjing	68.73	76.10	63.28	72.24	65.12
59	Brisbane	68.50	62.82	63.53	76.98	74.04
60	Warsaw	68.33	65.15	60.47	74.16	77.48
61	Pittsburgh	68.22	66.14	62.99	76.91	70.63
62	Lyon-Grenoble	68.11	62.89	63.20	73.33	75.93
63	Tel Aviv	67.88	62.44	73.87	64.50	67.45
64	Taipei	67.85	63.11	64.25	73.09	73.67
65	Hangzhou	67.80	70.10	65.80	71.97	65.10
66	Manchester	67.67	61.89	62.71	78.21	72.73
67	Brussels	67.44	63.49	61.46	69.22	78.74
68	Perth	67.39	61.76	62.86	76.50	73.07
69	Nagoya MA	67.02	64.32	60.43	74.67	74.05
70	Kuala Lumpur	66.34	60.84	60.96	70.78	77.67
71	Lausanne	66.27	61.46	61.44	69.12	77.40
72	Portland	66.13	61.03	62.95	77.11	69.45
73	St. Louis	65.96	62.37	62.82	76.67	68.07
74	Kyoto-Osaka-Kobe	65.78	68.83	60.48	72.95	66.95
75	Heidelberg	65.15	62.05	62.14	61.52	78.06
76	Tianjin	65.11	66.17	61.27	78.06	62.79
77	Busan	65.04	60.53	60.27	81.83	66.90
78	Daejeon	64.53	61.16	60.39	76.91	68.20
79	Bengaluru	64.40	63.67	67.67	65.85	63.32
80	Chengdu	64.39	67.50	61.82	71.61	63.27
81	Wuhan	64.36	68.11	61.79	72.10	62.23
82	Istanbul	63.81	62.27	65.61	71.56	61.62
83	Budapest	63.71	61.24	62.17	65.27	71.74
84	Changsha	63.56	66.30	62.36	70.45	62.11
85	Central National Capital Region Delhi MA	63.54	65.07	64.65	66.89	62.75
86	Suzhou	63.29	66.37	62.33	70.07	61.54
87	Xi'an	62.75	65.79	60.36	69.22	63.86
88	Hefei	62.73	66.12	60.85	70.48	61.86
89	Qingdao	62.58	65.18	60.81	70.48	62.41
90	Jinan	62.57	65.02	60.98	71.18	61.78
91	Bangkok	62.53	61.51	61.61	67.01	67.44
92	Mumbai MA	62.41	63.34	64.54	68.39	60.15
93	Dalian	62.21	63.04	62.82	69.96	61.07
94	Buenos Aires	62.08	60.65	60.65	67.43	67.97
95	Ankara	61.85	60.29	64.55	66.68	62.80
96	Chongqing	61.67	65.01	60.45	70.95	60.00
97	Jakarta	61.52	60.00	63.70	60.00	68.20
98	Harbin	61.50	63.64	60.29	70.93	61.11
99	Changchun	60.27	61.78	60.21	68.89	60.93
100	Johannesburg	60.00	62.41	60.09	64.21	63.08

5 Innovation ecosystem

An innovation ecosystem refers to an interdependent and dynamically balanced network formed among innovation subjects and supporting systems via open collaboration and non-linear co-evolution. It plays an important role in supporting scientific and technological innovation in economic, political and social systems. San Francisco-San Jose takes the lead, slightly ahead of London MA and New York MA in second and third. Guangdong-Hong Kong-Macao Greater Bay Area and Beijing rank fourth and fifth with impressive performance. Other cities/metropolitan areas in the top 20 in innovation ecosystem are Toronto MA, Geneva, Boston MA, Paris MA, Singapore, Amsterdam MA, Shanghai, Munich, Seoul MA, Madrid, Los Angeles-Long Beach-Anaheim, Seattle-Tacoma-Bellevue, Baltimore-Washington, Stockholm, and Tokyo MA. In general, the top 20 cities/metropolitan areas all score highly and show steady growth, suggesting that most of the leading GIHs have sound innovation ecosystems.

Geographically, among the 100 cities evaluated, those in Europe and the United States score relatively higher in innovation ecosystem and account for about 70% of the top 50 cities/metropolitan areas. In Asia, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, Singapore, Shanghai, Seoul MA, and Tokyo MA are among the top, whereas other cities are far behind, indicating a big gap in innovation ecosystem.

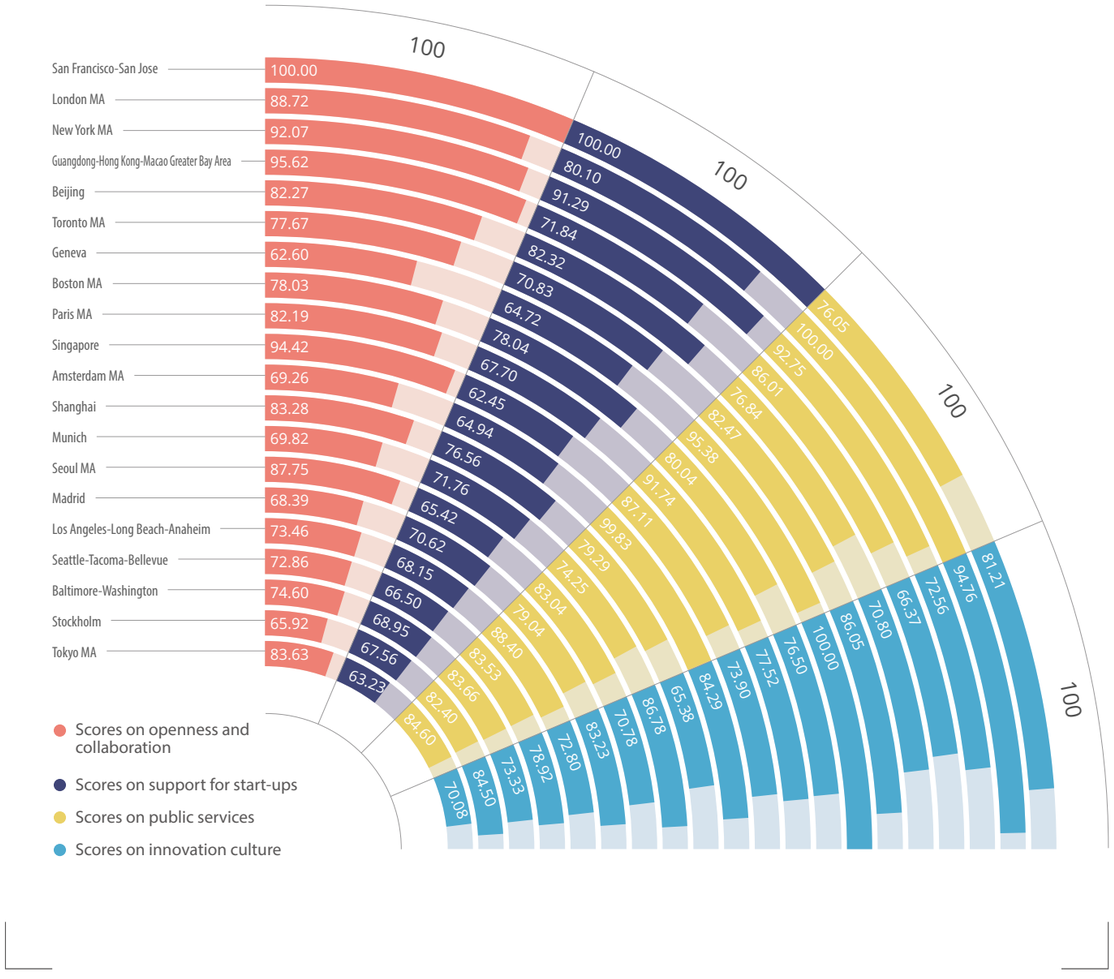
Over the past three years, the top 20 cities/metropolitan areas in innovation ecosystem have been largely unchanged. Few cities in Europe and the United States have changed their spots, thanks to their solid foundation in infrastructure services and innovation culture, which highlights the importance of strong legacy in building innovation ecosystem. In recent years, Asian cities/metropolitan areas such as Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, and Seoul MA have also risen notably, suggesting that they have become more attractive for innovative talent. Asian cities/metropolitan areas have surpassed established innovation cities in Europe and the United States with outstanding performance across indicators such as renewable energy, scientific collaboration, and e-government.

TABLE 10 A comparison of the top 20 cities/metropolitan areas in innovation ecosystem between 2020 and 2022

City/metropolitan area	Rank 2022	Rank 2021	Rank 2020
San Francisco-San Jose	1	2	1
London MA	2	1	3
New York MA	3	3	2
Guangdong-Hong Kong-Macao Greater Bay Area	4	7	N/A
Beijing	5	4	11
Toronto MA	6	16	18
Geneva	7	N/A	N/A
Boston MA	8	8	4
Paris MA	9	5	20
Singapore	10	9	8
Amsterdam MA	11	12	7
Shanghai	12	10	23
Munich	13	6	17
Seoul MA	14	21	24
Madrid	15	15	N/A
Los Angeles-Long Beach-Anaheim	16	13	6
Seattle-Tacoma-Bellevue	17	17	9
Baltimore-Washington	18	14	12
Stockholm	19	26	22
Tokyo MA	20	11	15

Figure 15 shows the performance across each indicator of the GIHI top 20 cities/metropolitan areas in innovation ecosystem. By comparison, San Francisco-San Jose is the leading city both in openness and collaboration as well as in support for start-ups. London MA has a balanced performance as it features in the top five across all four indicators. Most of the Asian cities, such as Guangdong-Hong Kong-Macao Greater Bay Area, Singapore, Beijing, Seoul MA, Shanghai, and Tokyo MA, have better performance in openness and collaboration. Geneva, Munich, and Stockholm have stronger focus on innovation culture and provide strong support for innovation.

FIGURE 15 Development patterns of the GIHI top 20 cities/metropolitan areas in innovation ecosystem



5.2 Openness and collaboration

Openness and collaboration, as an indicator of how an ecosystem exchanges material and information with the outside world, is key to the sustainable evolution of the innovation ecosystem. For GIHs, openness and collaboration could advance knowledge creation and dissemination during their scientific exploration, while attracting capital and promoting industrial radiation in their economic growth. This report, therefore, 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). In order to further measure the level of openness and collaboration of GIHs in green economy technology, the GIHI2022 has added the measurement of 'renewable energy technology' in patent collaboration network centrality, which assesses six technical patent indicators covering solar energy, wind energy, biomass energy, geothermal energy, tidal energy, and nuclear fusion energy.

San Francisco-San Jose, Guangdong-Hong Kong-Macao Greater Bay Area, Singapore, New York MA, and London MA are the top five cities/metropolitan areas in openness and collaboration. Among the top 20 cities/metropolitan areas, eight of them are in Asia, seven in the United States, and three in Europe. Asian cities such as Guangdong-Hong Kong-Macao Greater Bay Area, Singapore, and Seoul MA stand out in paper co-authorship network centrality and patent collaboration network centrality, and boast strong capital attraction. Cities/metropolitan areas in the United States vary greatly on this indicator, with San Francisco-San Jose and New York MA ranking first and fourth due to balanced performance across each sub-indicator in openness and collaboration. Other leading cities only perform well in capital spillover and attraction. Cities/metropolitan areas in Europe have shown diversified development patterns in openness and collaboration. Figure 16 shows paper co-authorship network centrality of GIHs, which maps the network of academic exchanges among co-authors. The node size indicates the importance of a city/metropolitan area in the global co-authorship network, and is determined by the number and significance of the links it has. Cities such as New York MA, Boston MA, Beijing, Baltimore-Washington, and San Francisco-San Jose stand out as core niches in the innovation collaboration networks.

FIGURE 16

The GIHI paper co-authorship network centrality, 2021

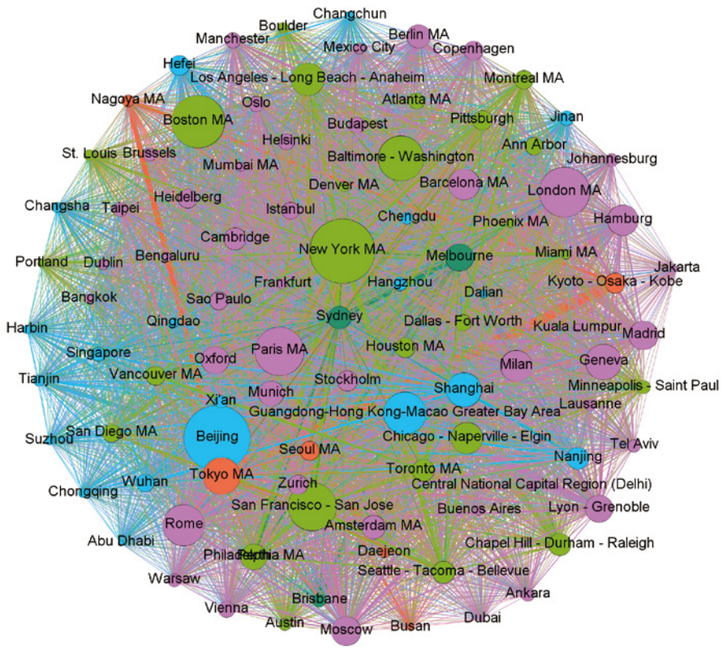


FIGURE 17

The GIHI patent collaboration network centrality, 2021

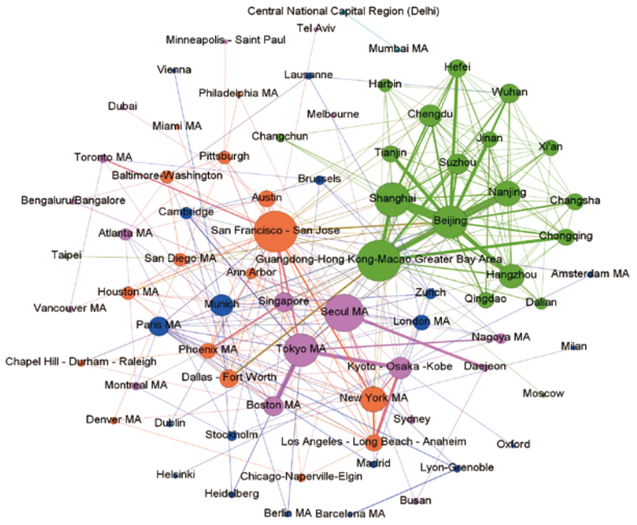
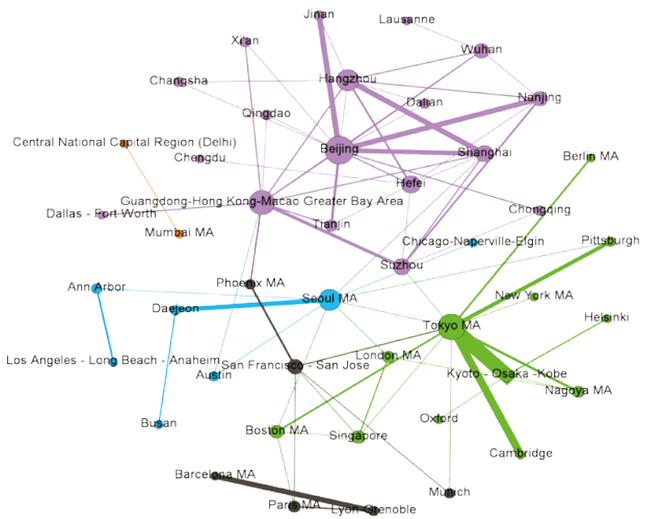


FIGURE 18

The GIHI renewable energy technology collaboration network centrality, 2021



The paper co-authorship network as a whole is characterized by the co-evolution of three innovation sub-networks in the United States, China, and Europe. The network in the United States, centred around New York MA, Boston MA, and San Francisco-San Jose, occupies a more important niche. The network in Europe, centred around Paris MA, London MA, and Rome, features more extensive collaboration. And the network in China, centred around Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, and Shanghai, features increased number of nodes and collaboration intensity, as well as rapid expansion. The trend reveals the impact of multidimensional proximity factors, such as current international politics and geography on innovation.

Figure 17 depicts patent collaboration network centrality of GIHs, which maps the network of technical exchanges among patentees. Overall, the network is composed of 'the sub-network of collaboration between cities in Europe and the United States' and 'the sub-network of collaboration between cities in China'. Guangdong-Hong Kong-Macao Greater Bay Area has made rapid breakthroughs and enjoyed a broader scope of collaboration in the overall network. It plays an essential role in forming connections together with San Francisco-San Jose. 75% of the top 10 cities (including those tied for the same ranking) in patent collaboration network centrality are in Asia, six of which are in China.

Chinese cities have performed particularly well in openness and collaboration in renewable energy technology, forming 'an openness and collaboration network of renewable energy technology' centred around Beijing and Guangdong-Hong Kong-Macao Greater Bay Area, with most of the technical collaboration nodes in the network being Chinese cities/metropolitan areas. Beijing is leading with a higher degree of centrality, and eight of the top 10 cities are in China. It shows that Chinese cities attach great importance to and actively adopt the concept of 'green and low-carbon' development.

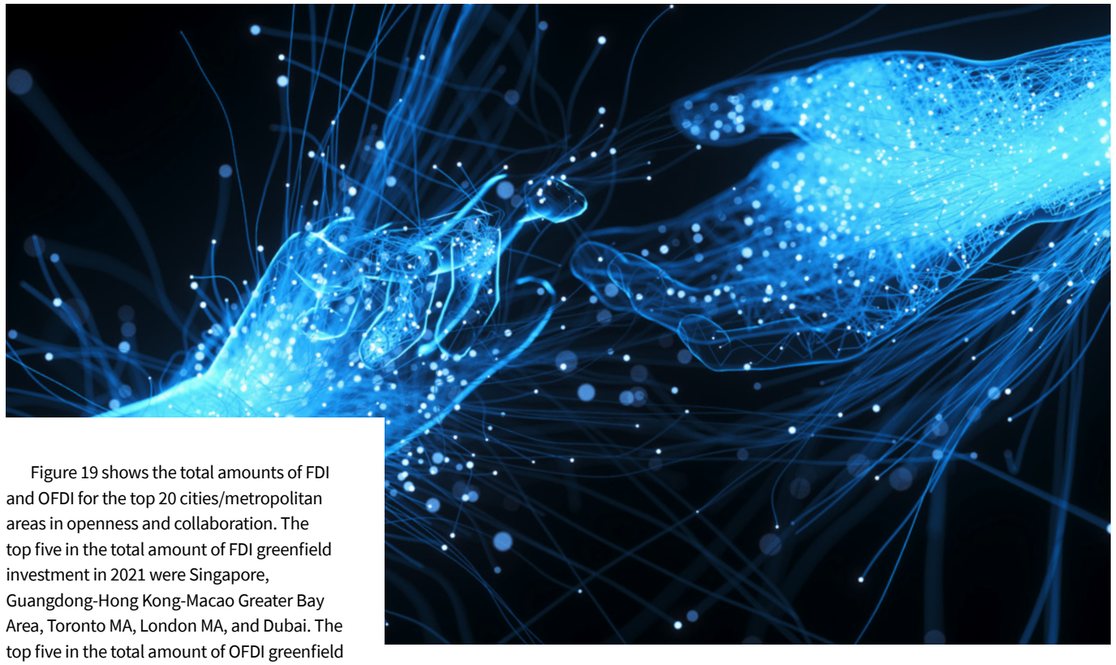


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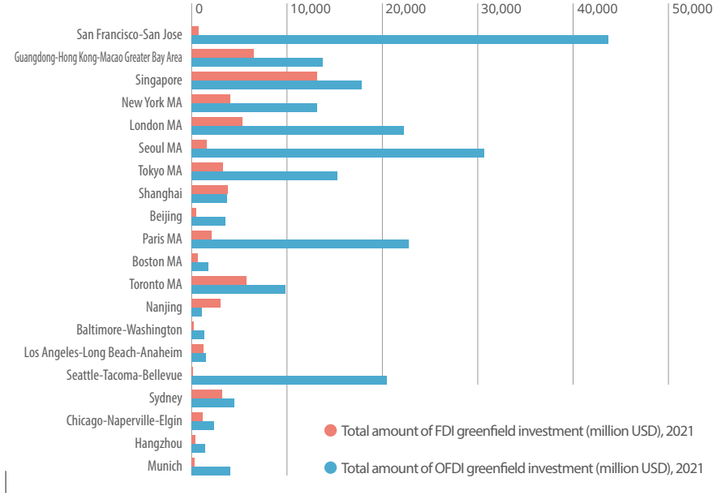
Figure 19 shows the total amounts of FDI and OFDI for the top 20 cities/metropolitan areas in openness and collaboration. The top five in the total amount of FDI greenfield investment in 2021 were Singapore, Guangdong-Hong Kong-Macao Greater Bay Area, Toronto MA, London MA, and Dubai. The top five in the total amount of OFDI greenfield investment are San Francisco-San Jose, Seoul MA, Paris MA, London MA, and Seattle-Tacoma-Bellevue.

They are mostly cities that have high-tech industries or are important international shipping centres, and have significant advantages in investment environment, market access and investment initiatives. Their abilities to attract industrial capital and to spill over their impact are rapidly increasing in a new wave of scientific and technological revolution. Cities that rely on the information industry and digital economy, such as San Francisco-San Jose, Seoul MA, Seattle-Tacoma-Bellevue, have come to the fore and seen exponential increases in total outward foreign investment, surpassing traditional financial cities and promoting global expansion of emerging technology 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 a greater willingness in outward investment and strong capital spillover effects of leading GIHs.

FIGURE 19 **Total amounts of foreign direct investment (FDI) and outward foreign direct investment (OFDI)** for the GIHI top 20 cities/metropolitan areas in openness and collaboration



5.3 Support for start-ups

Support for start-ups is not only essential for their growth, but also important for technological revolution and industrial development. This report evaluates the role of venture capital by measuring levels of venture capital (VC) and private equity (PE). It also examines the legal environment for start-ups using the number of registered lawyers (per million people).

The top five cities/metropolitan areas in support for start-ups are San Francisco-San Jose, New York MA, Beijing, London MA, and Boston MA. The top 20 cities/metropolitan areas are more evenly distributed, with six in the United States, seven in Europe, and four in Asia. Cities/metropolitan areas in the United States have significantly increased the total amount of funding for start-ups, and European cities/metropolitan areas provide a sound legal environment for businesses. Although financial support for start-ups in Asia is growing quickly, most Asian cities lag behind because of the small size of funding, implying that there is more room for growth.

Figure 20 shows the total VC and PE investment for the top 20 cities/metropolitan areas in support for start-ups. Compared with 2020, when the COVID-19 pandemic first hit, the total amounts of VC and PE investment had a swift rebound in 2021, and leading cities have almost recovered to the pre-pandemic level. The comprehensive ecosystem and environment for starting businesses, open-ended investment, and profound legacy of innovation have enabled the San Francisco Bay Area to efficiently attract global venture capital. It has become 'the place where dreams come true' for global start-ups and has maintained a strong lead for a long time.

Despite a grim macroeconomic outlook across the world, Chinese cities still demonstrate a high degree of innovation and entrepreneurship, with strong growth potential. Beijing, Shanghai, and Guangdong-Hong Kong-Macao Greater Bay Area rank third, fourth, and seventh globally in total investment. Most Chinese cities have maintained steady and rapid growth, for example, emerging cities such as Nanjing and Chengdu have increased their investment by more than 300%, indicating a promising future.

FIGURE 20 **Total venture capital (VC) and private equity (PE) investment** for the GIHI top 20 cities/metropolitan areas in support for start-ups

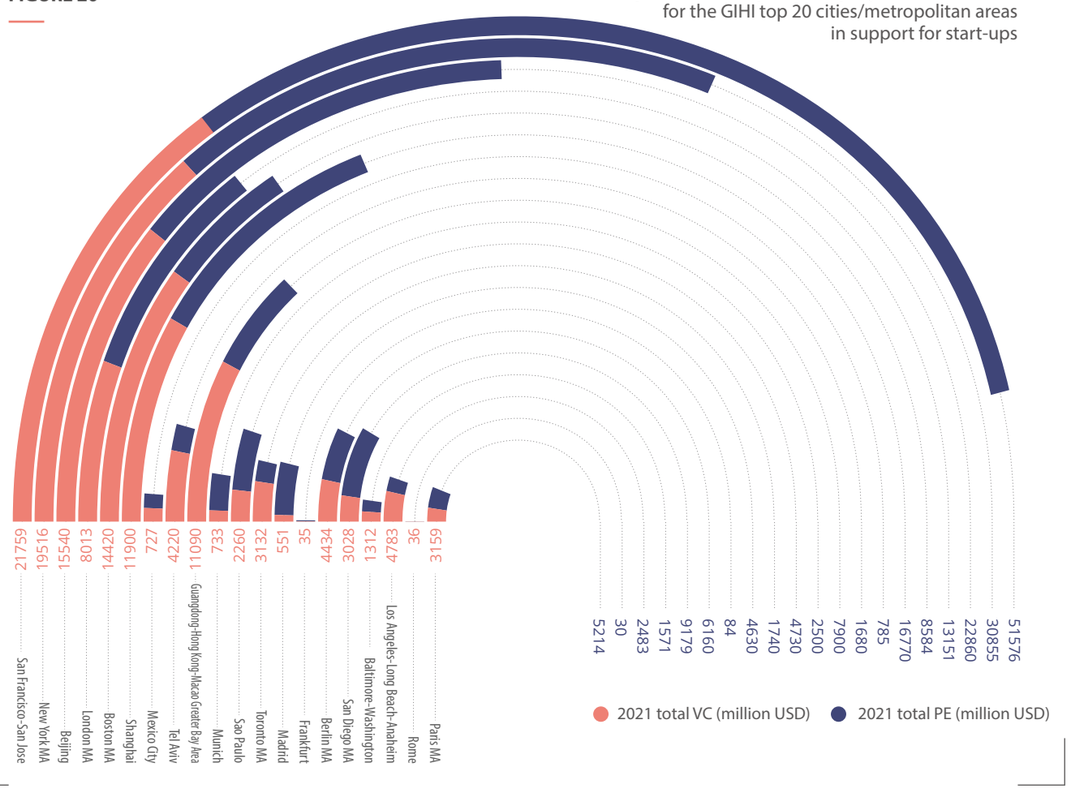
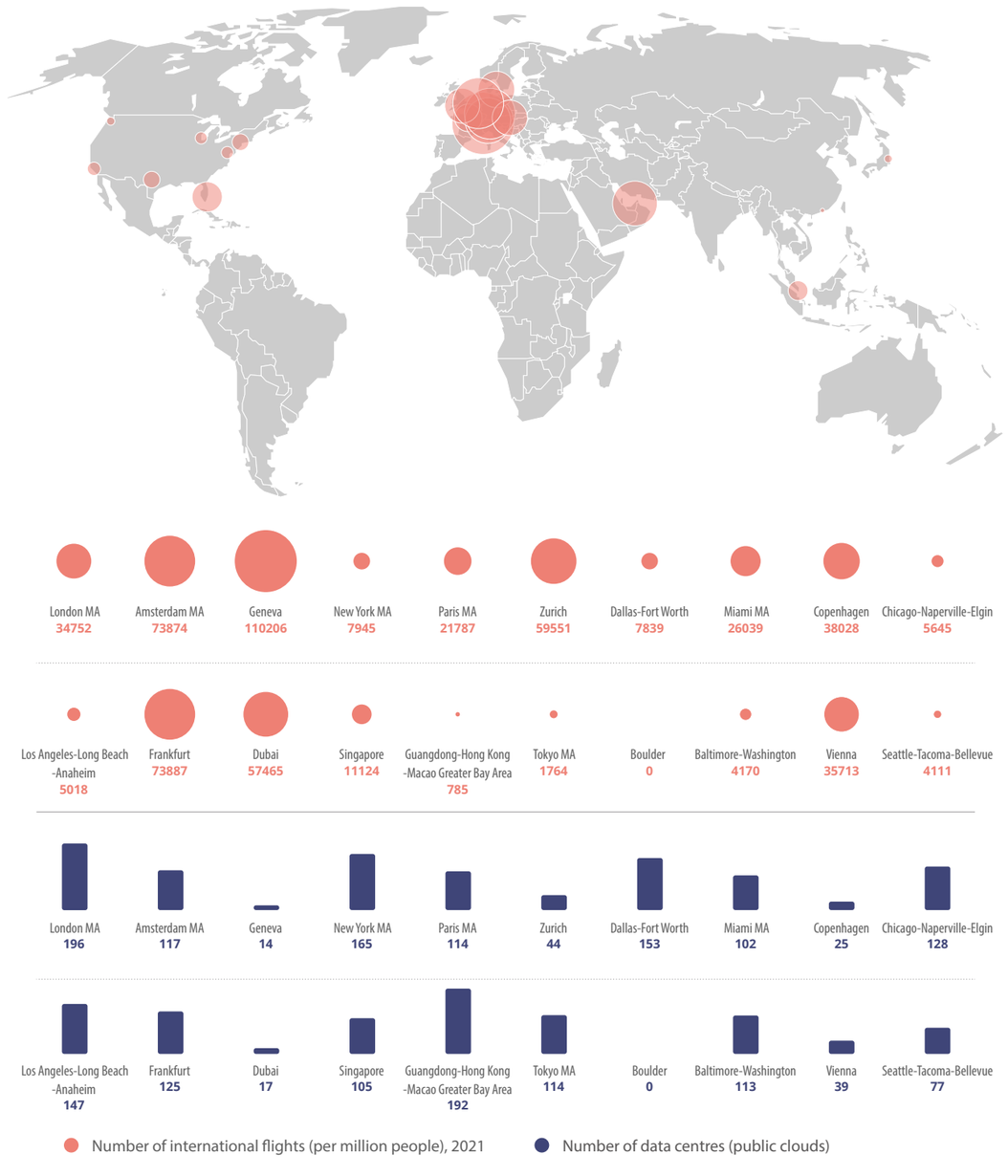


FIGURE 21

Numbers of international flights (per million people) and of data centres (public clouds)
for the GIHI top 20 cities/metropolitan areas in public services



5.4
Public services

Urban public services are the infrastructure and facilities provided by cities to support innovation and start-ups. The GIHI2022 uses the number of data centres (public clouds), the broadband connection speed, and the number of international flights (per million people) to measure the level of public services in a city/metropolitan area. The Local Online Service Index, released by the United Nations Department of Economic and Social Affairs, is used to measure a region's e-governance level. Data storage capacity and the broadband connection speed could reflect the maturity of a city's network infrastructure and the efficiency of data access.

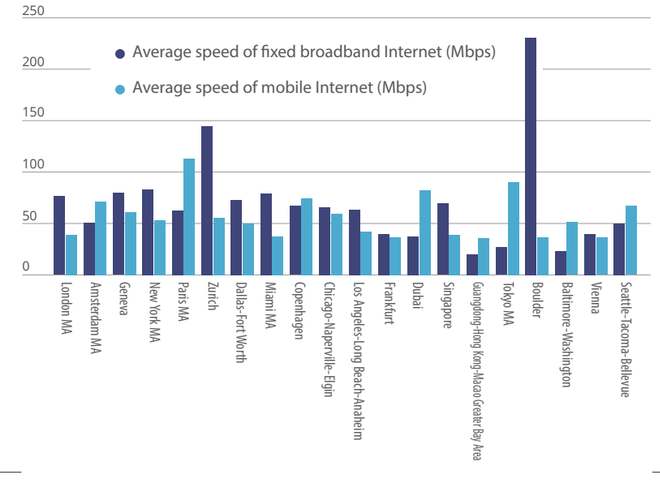
The top five cities/metropolitan areas in public services are London MA, Amsterdam MA, Geneva, New York MA, and Paris MA. Almost all leading cities/metropolitan areas are in Europe and the United States, and European cities/metropolitan areas generally score higher than those in the United States. Dubai, Singapore, Guangdong-Hong Kong-Macao Greater Bay Area, and Tokyo MA are the only Asian cities/metropolitan areas among the top 20. European cities/metropolitan areas outperform others in data centres (public cloud) and air services (number of flights), indicating long-term development of public services in traditional innovation hubs. Asian cities focus on digitalization and informatization, and are making rapid progress in e-government services and data centres (public clouds). The overall public services for supporting innovation in Asian cities, however, is relatively weak, so there is still large scope for improvement.

London MA, as a financial hotspot in Europe controls major global data centre markets. Meanwhile, with Internet Exchanges like LINX and LoNAP, London MA has become a data hub for Europe. Guangdong-Hong Kong-Macao Greater Bay Area, New York MA, Dallas-Fort Worth, and Los Angeles-Long Beach-Anaheim rank in the top five with a large number of data centres. The number and market size of data centres (public cloud) in the United States rank first in the world, suggesting its laser focus on data innovation and extensive application.

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 Boulder leading at 230.75 mbps. In terms of the average mobile network speed, Tianjin leads the world at 123.42 mbps. Chinese cities/metropolitan areas have made rapid advances in communication technologies, such as 5G, in recent years, leading to remarkable improvement in mobile terminal connection speed. For the number of international flights, European cities such as Amsterdam MA scores higher.

FIGURE 22

Average speed of fixed broadband Internet and of mobile Internet
for the GIHI top 20 cities/metropolitanareas in public services



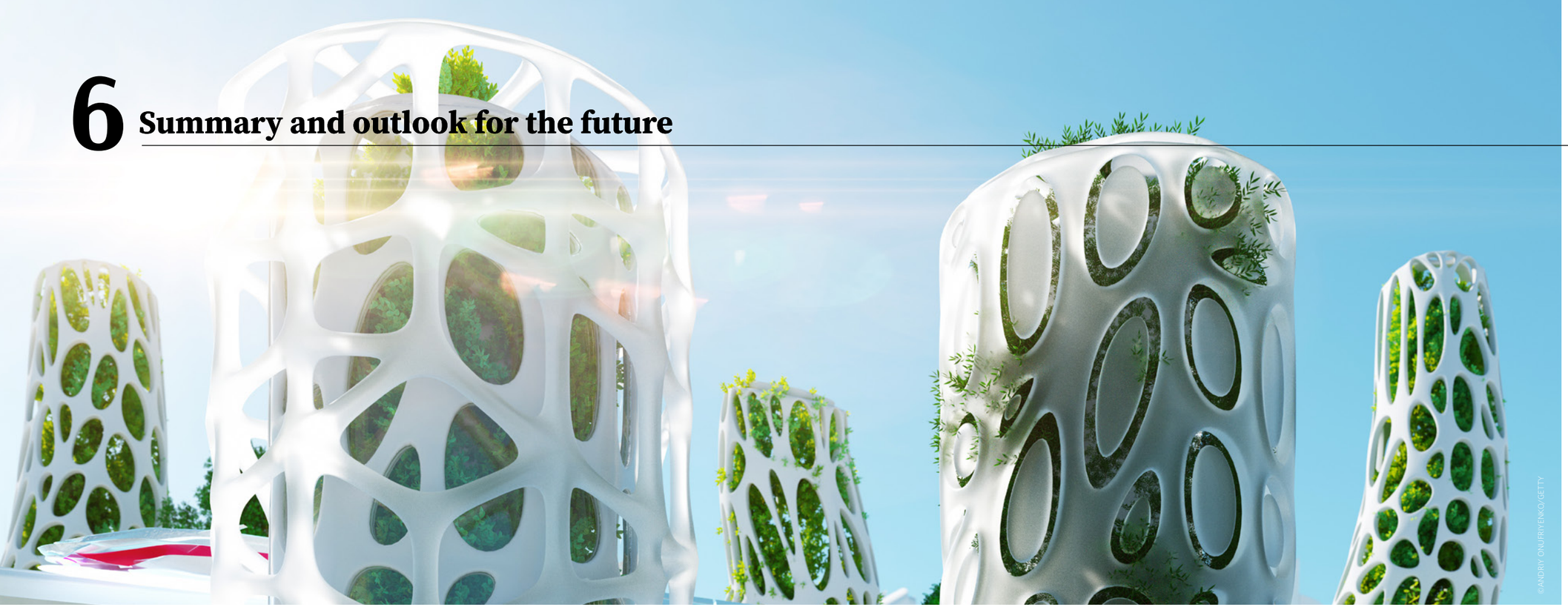
5.5
Innovation culture

Innovation culture is a key external condition required for enhancing a city's competitiveness and long-term prosperity. The GIHI2022 measures a city's innovation culture by examining the professional talent inflow (per million people), the number of creative talent (per million people), and the number of public museums and libraries (per million people).

The top five cities/metropolitan areas in innovation culture are Geneva, London MA, Cambridge, Ann Arbor, and Boulder. Twelve out of the top 20 cities/metropolitan areas are in Europe. Geneva and London MA are the top two cities for their rich innovation culture heritage, talent attractiveness, and well-established public cultural infrastructure. Fewer cities in Asia and the United States are in the top list, indicating a large capacity for growth.

In terms of the number of professional talent inflow (per million people), cities/metropolitan areas in Europe and the United States, such as Austin and Boulder, have a stronger attraction to global talent. In the number of creative talent (per million people), Moscow ranks first, and other leading cities/metropolitan areas are mostly capital cities, indicating the significant advantages of capitals in gathering innovative talent. The top performers in the number of public museums and libraries are mostly traditional European cities/metropolitan areas, underpinned by rich public cultural heritage.

6 Summary and outlook for the future



Global economy continues to face major challenges in the post-pandemic world and is impacted by geopolitical conflicts. Innovation, however, could provide impetus for economic growth and strengthen economic resilience amid uncertainty.

The GIHI2022 assessment shows that San Francisco-San Jose and New York MA still dominate the top two positions in overall ranking, whereas Beijing replaces London MA as third, with London MA ranking fourth and Boston MA fifth. New York MA has maintained its position as the highest-ranked city in research innovation, with San Francisco-San Jose second and Boston MA third. Beijing and Guangdong-Hong Kong-Macao Greater Bay Area are rapidly rising up the ranks, and an array of mini-hubs are among the top 20. San Francisco-San Jose, Tokyo MA, and Beijing have maintained their lead in innovation economy, and New York MA and Munich have also made significant progress. San Francisco-San Jose, London MA, and New York MA are the top three cities in innovation ecosystem, with Asian cities/metropolitan areas rising significantly.

Main conclusions

The following conclusions are drawn from the GIHI2022 ranking:

First, the international innovation landscape is moving towards multipolarity and a low-carbon future, with Asian cities gaining competitive edge in innovation economy, and the Bay Areas and mini-hubs demonstrating unique innovation characteristics.

As a new centre of innovation, Asia stands out in renewable energy technology. Asian cities sweep up six spots among the top 20 in overall ranking, and have strong performance in green low-carbon development: seven out of the leading 10 cities/metropolitan areas for the total number of valid patents for renewable energy technology and five out of the top 10 for the number of PCT patents are in Asia. Cities/metropolitan areas including Beijing, Tokyo MA, Seoul MA, Hangzhou, Guangdong-Hong Kong-Macao Greater Bay Area, and Kyoto-Osaka-Kobe are important nodes in the collaboration network of renewable energy technology patents, leading the world in a global shift towards green development.

An increasing number of Chinese cities have boosted their innovation capability and become GIHs, providing new power for global development. There are a total of 19 Chinese cities/metropolitan areas in the list. They are active in innovation economy and rapidly growing in research innovation and innovation ecosystem, resulting in improved innovation capability across the board.

The Bay Areas hold prominent advantages in innovation resource integration. Four out of the GIHI2022 top 10 cities/metropolitan areas overall are in Bay Areas. In addition to the three Bay Areas of San Francisco, New York, and Tokyo, Guangdong-Hong Kong-Macao Greater Bay Area, which has overtaken Tokyo Bay Area for the first time, ranks sixth in the list and has become a new innovation hub in Asia.

The mini-hubs have made an excellent debut in the global innovation landscape with strong research performance. They are all located in the world's top science hubs in Europe or the United States. Having access to unmatched scientific talent resources, all seven mini-hubs are among the top 20 cities overall and the top five for the number of active researchers (per million people).

Second, GIHs have strong agglomeration and spillover effects.

Cities vary in their abilities in agglomerating innovation elements and exerting spillover effect. San Francisco-San Jose, New York MA, Beijing, and Boston MA have a heavier concentration of innovation elements, while London MA, Geneva, Paris MA, Seattle-Tacoma-Bellevue, Seoul MA, Baltimore-Washington, and Amsterdam MA have a stronger impact on the innovation capability of surrounding areas.

Third, in uncertain environments, global research is becoming more concentrated, and the competitive heterogeneity in research innovation among different regions has increased.

The GIHI2022 ranking in research innovation has changed significantly. On one hand, repeated COVID-19 outbreaks and geopolitical conflicts have increased economic and social risks for countries and regions. As GIHs provide stable and favourable conditions for conducting research, high-level talent and resources are rapidly flowing to these hubs such as New York MA, Beijing, and San Francisco-San Jose. On the other hand, the difference in GIHs' research innovation is becoming more distinct. The United States, known for its science and technology human resources and knowledge creation, has 11 cities both in the top 20 cities in science and technology human resources, and in the top 20 cities in knowledge creation. The United States has a strong capacity for knowledge creation, as well as a comprehensive research ecosystem and a well-developed knowledge transfer system. Asian cities enjoy comparative advantage in research institutions and scientific infrastructure, with five Chinese cities among the top 20 on this indicator. With research planning and investment, Asian cities are picking up speed in building major scientific and technological infrastructure, and have established a comprehensive system of institutions that covers the whole knowledge chain and industry chain. European cities record balanced performance on all indicators for research innovation.

Fourth, in innovation economy, GIHs have demonstrated economic resilience despite the COVID-19 pandemic and unprecedented changes in the international situation, serving as an important engine for driving global growth.

Despite a decline in capital and talent flows, the 80-20 rule is even more evident in GIHs. Digital information technology, biotechnology, and renewable energy technology are the major technology domains, while high-tech manufacturing and emerging industries are the main industrial sectors for driving growth. The rapid growth of leading innovation enterprises and emerging industries stands in stark contrast to the global economic downturn.

Fifth, in innovation ecosystem, cities across Europe and the United States are in the lead with their unique innovation culture, and Asian cities are gaining by fostering an innovation ecosystem for emerging industries.

European cities outperform others in innovation ecosystem, highlighting its long-established innovation environment and culture throughout the history of innovation. European cities have relatively strong performance in public services and innovation culture. Cities in the United States stand out in openness and collaboration and support for innovation, showcasing their strengths in global attraction and spillover effect. Although Asian cities, a late starter in innovation ecosystem, score relatively lower in this indicator, they stand out in renewable energy technology, innovation industry concentration, and digital information technology. A multi-dimensional innovation ecosystem network with Asian cities at its core is taking shape and expanding rapidly, which has an immediate impact on the global innovation ecosystem and facilitates its diversification.

Summary

GIHI2022 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, providing much-needed references for building GIHs in China. 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.

References

1. Boschma, R. A., & Fritsch, M. (2009). Creative class and regional growth: Empirical evidence from seven European countries. Economic geography, 85(4), 391-423.
2. Brady, C., Cummings, R., Hickson, T., Hockaday, T., Naylor, L., Raven, T., Rowland, C., & Tarhan, C. (2015). UK University Technology Transfer: Behind the Headlines. University of Cambridge. https://www.enterprise.cam.ac.uk/news/uk-university-technology-transfer-behind-the-headlines/.
3. C. Petta, & Ugo Becciani. (2019). New Frontiers in Computing and Data Analysis - the European Perspectives. *Radiation Effects and Defects in Solids*, 174(11-12), 1020-1030.
4. Cambridge centre for risk studies. (2018). Cambridge Global Risk Outlook 2018 Methodology. Cambridge Centre for Risk Studies.
5. Clarivate. (2021). Top100 Global Innovators 2021. Clarivate.
6. Cornell University, INSEAD, and WIPO (2020). The Global Innovation Index 2020: Who Will Finance Innovation? Ithaca, Fontainebleau, and Geneva.
7. Florida, R. (2012). The rise of the creative class: revisited. Basic books.
8. GovGrant. (2021). The University Spinout Report 2021. GovGrant. https://www.govgrant.co.uk/university-spinout-report/.
9. Grassano, N., Hernandez Guevara, H., Tuebke, A., Amoroso, S., Dosso, M., Georgakaki, A. and Pasimeni, F.(2020). The 2020 EU Industrial R&D Investment Scoreboard. Publications Office of the European Union.
10. Hollanders, H., Nordine, E. S., et al. (2021). European Innovation Scoreboard 2021. European Commission.
11. INSEAD (2020): The Global Talent Competitiveness Index 2020: Global Talent in the Age of Artificial Intelligence, Fontainebleau, France.
12. Institute for urban strategies. (2020). *Global Power City Index 2020*. The Mori Memorial Foundation.
13. Intralink, & the UK's Department for International Trade. (2019). South Korea Smart Cities 2019. https://www.intralinkgroup.com.
14. Intralink. (2019). South Korea Smart Cities 2019. The UK's Department for International Trade.
15. Kearney. (2020). 2020 Global Cities Report: New Priorities for a New World. Kearney.
16. Mincer, Jacob. (1974). *Schooling, Experience, and Earnings*. NBER.
17. Nature Index. (2020). Science Cities 2020. Nature.
18. Nelson, R. R., & Phelps, E. S. (1966). Investment in Humans, Technological Diffusion, and Economic Growth. *The American Economic Review*, 56, 69–75.
19. OECD/Eurostat (2018), Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation,4th Edition, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg.
20. Sassen, S. (1991). The Global City. Princeton, NJ: Princeton University Press.
21. Schultz, T. W. (1960). Capital Formation by Education. *Journal of Political Economy*, 68.
22. Schwab, K., & Zahidi, S. (2020). The Global Competitiveness Report 2020: How Countries are Performing on the Road to Recovery. World Economic Forum.
23. Djankov, S., La porta, R., Lopez-de-silanes, F., & Shleifer, A. (2002). The Regulation of Entry. *The Quarterly Journal of Economics*, 117(1), 1–37.
24. The economist intelligence unit. (2019). Safe Cities Index 2019: Urban Security and Resilience in an Interconnected World. The Economist.
25. United Nations Department of Economic and Social Affairs. (2020). E-Government Survey 2020: Digital Government in the Decade of Action for Sustainable Development. United Nations.
26. Valley, J. V. S. (2021). 2021 Silicon Valley Index. Joint Venture Silicon Valley.
27. Cai, F. & Wang, D. (2002). Comparative Advantages: Differences, Changes and Their Inpact on Reginal Disparity. Social Sciences in China, (05), 41-54.
28. Ma Jiyuan, Overview of South Korea Smart City. Institute of Scientific and Technological Information of Shanghai. http://www.istis.sh.cn/list/list.aspx?id=12739.
29. Ni, P., Kamiya, M., Guo, J. & Zhang, Y. (2021). Global Urban Competitiveness Report (2020-2021), National Academy of Economic Strategy, CASS.
30. Shanghai Economic Information Centre. (2021). Global Scientific and Technological Innovation Centers Evaluation Report 2021, Shanghai Economic Information Centre.
31. Seoul Solution. (2021). https://seoulsolution.kr/zh-hans/egov
32. Wang, T. (2020). Building Computing Power Infrastructure to Support Innovation Development. Zhangjiang Technology Review, (3),20-23.
33. Wang, Y. & Bai, Y. (2020). Developing Mega-science Facility to Lead the Innovation Globally. Management World, V36(05), 17+192-208.
34. Guidelines for Investment Policies in Singapore (Administrations, Policies and Laws). (2020). Singapore News. https://www.xinjiapo.news/news/17140#:~.
35. Xue, L., Chen, L., Wang, G., Jiang, L. (2016). A comparison of the industrial innovation capacity between China and the U.S. based on expert surveys in the IC design industry. Science Research Management, V37(004), 1-8.
36. Zheng, F., Wang, Z., Wei, H. (2019). The Rule-of-Law Index of Business Environment: An Evaluation System and A Case Study in Guangdong. Social Science in Guangdong, (005), 214-223.

Appendix

Appendix I: Adjustments to the GIHI Indicators

We have made some adjustments to the index system based on feedback gathered from experts, the media and the general public after the release of GIHI2021. These changes will help us adapt to new trends of scientific development, taking into account such factors as stability and authority of the index system, as well as the availability and compatibility of the index data. Based on the research, we have made the following adjustments to the GIHI indicators:

GIHI2021	Adjustment	GIHI2022	Descriptions
04. Number of top 200 world-class universities	Term of indicator	04. Number of world-leading universities	Only term of indicator has been changed.
10. Total number of valid patents (per million people)	Statistical connotation	10. Total number of valid patents (per million people)	The scope of measurement has been expanded. The 'renewable energy technology patents' has been added to the previous patent indicators of 'artificial intelligence patents' and 'integrated circuit manufacturing patents'.
11. Number of patent cooperation treaty (PCT) patents	Statistical connotation	11. Number of patent cooperation treaty (PCT) patents	The scope of measurement has been expanded. The 'renewable energy technology patents' has been added to the previous patent indicators of 'artificial intelligence patents' and 'integrated circuit manufacturing patents'.
12. Number of top 2,500 companies in R&D investment	Data source	12. Number of leading innovative companies	The data source has been adjusted to include established lists such as the Derwent Top 100 Global Innovators and Fortune Global 500 (only science and technology enterprises are being selected) in additional to the EU Industrial R&D Investment Scoreboard to measure the number of enterprises that have ability to drive innovation and exert spillover effects to surrounding regions.
19. Patent collaboration network centrality	Statistical connotation	19. Patent collaboration network centrality	The scope of measurement has been expanded. The 'renewable energy technology patents' has been added to the previous patent indicators of 'artificial intelligence patents' and 'integrated circuit manufacturing patents'.
26. Broadband connection speed	Data source and statistical connotation	26. Broadband connection speed	The scope of measurement has been expanded to include the 'mobile Internet speed' in addition to the 'fixed broadband Internet speed'.
29. Professional talent inflow	Data source and statistical connotation	29. Professional talent inflow (per million people)	The absolute value is replaced with relative value, and the data source has been expanded. As LinkedIn shut down its China platform in October 2021, it's impossible to compare data of Chinese cities with that of other countries. Therefore, the data of Chinese cities is collected from Zhaopin.com.
30. Residents' average years of schooling	Indicator replacement	30. Number of creative talent (per million people)	The GIHI2021 measured the residents' average years of schooling using the Subnational Human Development Index (HDI) published by the United Nations, which hasn't been updated this year. The 'number of creative talent (per million people)' is used instead as a measurement of innovative human capital.
31. Number of international conferences	Indicator removed		The previous indicator of the 'number of international conferences' used city-level data from the International Congress and Convention Association (ICCA), which hasn't been updated in 2020 and 2021 due to the COVID-19 pandemic. The indicator is therefore removed.

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 2017 and 2021 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. Percentage of highly cited scientists

Definition: the percentage of highly cited scientists out of the number of active researchers in the assessed city between 2016 and 2020, with a highly cited scientist defined as a researcher who has published at least one paper in the top 1% citation range in his or her field in these five years. If a researcher is regarded as a highly cited scientist multiple times in five years, he/she will be counted only once.
Data sources: Digital Science – Dimensions

03. Number of winners of top scientific awards

Definition: the top scientific awards refer to the Nobel Prize (for Physics, Chemistry, and Physiology or Medicine), 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 winner work part-timely 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 June 14, 2022.

04. 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) 2021 to characterize a city's leading universities.
Data sources: Shanghai Ranking's Academic Ranking of World Universities (ARWU) 2021
(https://www.shanghairanking.cn/rankings/arwu/2021)

05. Number of top 200 world-class research institutions

Definition: The number of top 200 scientific institutions in scientific publications according to the Nature Index 2021. 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

06. 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.

07.Number of top 500 supercomputers

Definition: A supercomputer is a computer consisting of hundreds or more processors (machines) 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 source: Global Top 500 Supercomputers, data as of November 2021 (https://www.top500.org/statistics/sublist/)

08. Percentage of highly cited papers

Definition: The number of highly cited papers in the top 1% of each subject as a percentage of the total number of articles published by the city between 2000 and 2020. 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

09. Proportion of papers cited in patents, policy reports and clinical trials

Definition: The proportion of scientific papers published by the city between 2017 and 2021 that are cited in patents, policy reports and clinical trials from other database sources, an indicator that looks at the impact of scientific papers outside the academic community, and the level of knowledge transfer.
Data sources: Digital Science – Dimensions

B. Innovation economy

10. 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 the newly added field of 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 in 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 1956-2021 for AI, 1965-2021 for IC, and 1970-2021 for renewable energy technology, respectively. By removing duplicate data, 376,468 patents for AI applications, 1,223,331 patents for IC, and 287,913 for renewable energy technology have been obtained.

This study focuses on the stock of valid patents, which are defined in two ways: one is patents that are still in force after the patent application has been granted (the patent is still within the legal term of protection and patentee is required to have paid the required annual fee. This is the usual category of valid patents). The other category refers to patents that have passed the preliminary examination and are in the public phase, although the patent has not yet been granted. 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, 217,227 patents in AI, 546,627 patents in IC, and 105,458 patents in renewable energy technology have been obtained to analyse a GIH's innovation capacity.
Data sources: Derwent Innovation patent database

11. Number of PCT patents

Definition: The report identifies the number of PCT patents in IC (1965-2021), AI (1956-2021), and renewable energy technology (1970-2021). By filing one international patent application under the Patent Cooperation Treaty (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.
Data sources: Derwent Innovation patent database

12. Number of leading innovative companies

Definition: This study combined the top 2,500 companies in R&D investment in 2020 published by the EU Industrial R&D Investment Scoreboard 2021, Derwent Top 100 Global Innovators 2021, and Fortune Global 500 2021 (only science and technology enterprises are included) to rank enterprises in evaluated cities, as an indicator of the enterprises' ability to drive innovation and spillover effect to surrounding regions.
Data sources: the EU Industrial R&D Investment Scoreboard, 2021; Top 100 Global Innovators 2021 by Clarivate; Fortune Global 500, 2021

13. 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 2021 released by CB Insights and the 2021 Hurun Global Unicorn List. By removing duplicated companies, 1,242 unicorn companies in the assessed cities have been included in the scope of this report.
Data sources: the Complete List of Unicorn Companies published by CB Insights (https://www.cbinsights.com/research-unicorn-companies) , data as of April 8th, 2022; 2021 Hurun Global Unicorn List (https://www.hurun.cn/zh-CN/Rank/HsRankDetails?pagetype=unicorn)

14. 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 2022 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 GICS (Global Industry Classification Standard), divided into three categories: pharmaceutical and chemical enterprises, electronic information enterprises and high-end manufacturing enterprises, of which 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 defence, materials and transportations.
Data sources: Forbes China
(https://www.forbes.com/lists/global2000/?sh=1e326f185ac0)

15. Revenue of listed companies in new economy industries

Definition: The new economy industry is a forward-looking industry with three characteristics: high human capital investment, high-tech investment, light assets, 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 2021 operating incomes of the listed companies in new economy industries of the cities.

Definition of the new-economy industries
(based on the Global Industry Classification Standard (GICS))

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	Semiconductor and semiconductor equipment
50 Communication services	5010 elecommunications 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, a library of publicly listed companies worldwide

16. GDP growth rate

Definition: This study uses the GDP growth rate in 2020 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 dollars that are generated based on the constant prices and purchasing power in 2015. Due to missing data, the GDP growth rate for 2019 are used for Vienna, Berlin MA, Frankfurt, Heidelberg, Munich, Dublin, Milan, Rome, Amsterdam MA, Warsaw, Barcelona MA, Mumbai MA, Nagoya MA, Tokyo MA, Busan, Daejeon, Seoul MA, Brisbane, and Johannesburg, and the GDP growth rate for 2018 are used for Montréal MA, Toronto MA, Vancouver MA, Oslo, Geneva, Lausanne, Zurich, and Kyoto-Osaka-Kobe.
Data sources: (1) GDP data are from OECD and statistics offices of countries and cities, such as Chinese National Bureau of Statistics, U.S. Bureau of Economic Analysis, and Eurostat; (2) Purchasing power parities (PPP) index and GDP deflator are from the World Bank.

17. 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 2020 (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. As data is unavailable for the following cities/metropolitan areas, the labour productivity for 2019 is used for Berlin MA, Frankfurt, Hamburg, Heidelberg, Munich, Dublin, Milan, Rome, Amsterdam MA, Oslo, Warsaw, Barcelona MA, Mumbai MA, Nagoya MA, Tokyo MA, Busan, Daejeon, and Seoul MAA, and the labour productivity for 2018 is used for Montréal MA, Toronto MA, Vancouver MA, Vienna, Geneva, Lausanne, Zurich, Kyoto-Osaka-Kobe, Brisbane, and Johannesburg.
Data source: workforce data collected from departments of statistics of each country and city

C. Innovation ecosystem

18. 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 2021 intercity paper publication collaboration matrix of the 100 evaluated cities. The importance of a node in the eigenvector centrality depends on both the number of neighboring nodes (i.e., 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

19. 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:

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

Data sources: Derwent Innovation patent database

20. Foreign Direct Investment (FDI)

Definition: This study measures a city's attraction to foreign investment by its foreign direct investment (FDI) in greenfield projects in 2021. 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/)

21. Outward Foreign Direct Investment (OFDI)

Definition: The total amount of Outward Foreign Direct Investment (OFDI) made by companies located in the assessed city in 2021, 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/).

22. Venture capital investment (VC)

Definition: This study measures the venture capital activities by measuring the amount of venture capital investment received in 2021, 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/)

23. Private equity (PE)

Definition: Private Equity (PE) refers to the growth capital received during the Pre-IPO period of a proposed public company. In this study, the investment activity is measured by the total amount of private equity investment in 2021. 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/)

24. Number of registered lawyers (per million people)

Definition: The number of registered lawyers (per million people) in assessed city in 2020. 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 Helsinki, Oslo, Tel Aviv, Kuala Lumpur, Bangkok, Buenos Aires, and Sao Paulo, the country-level data are used instead; for Sydney, Brisbane, Melbourne, Perth, Cambridge, Manchester, Oxford, Bengaluru, and Heidelberg, data from the state or province are used instead.
Data source: lawyer associations in countries and cities; ministries of justice in countries

25. 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 in order 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 June 13th, 2022

26. 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 in the Internet era. This study uses the average upload and download rates (Mbps).
Data sources: Broadband connection speed was measured at https://testmy.net/list on April 27th, 2022; mobile terminal connection speed was measured at Speedtest (https://www.speedtest.net) on May 20th, 2022

27. Number of international flights (per million people)

Definition: the number of all direct flights departing from and arriving at the city in 2021.
Data sources: Official Aviation Guide (OAG), an aviation intelligence provider (https://www.oag.com/)

28. 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 2020 Online Services Questionnaire (OSQ) consists of 148 questions, related to health, education, social protection, gender equality, and employment. It examines whether such information is provided on these online service portals.
Data sources: E-Government Development Index (EGDI) 2020 from the United Nations

29. Professional talent inflow (per million people)

Definition: In this study, the professional talent inflow into the assessed city, as recored on Zhaopin.com; LinkedIn Talent Insights between April 2021 and April 2022, is used to measure the attraction of the city/metropolitan areas to talents. For Busan, Daejeon, Seoul MA, Dubai, 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 Taipei) 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 April 23th, 2022.

30. Number of creative talent (per million people)

Definition: The creative talent is constituted by members engaged in work fields whose function is to "create meaningful new forms" and is divided into two distinct components: Super-Creative Core and Creative Professionals. The Super-Creative Core refers to people who works in computer and mathematics, architecture and engineering, life science, physical science and social science, education, training and libraries, arts, design, entertainment, sports, and media; and the Creative Professionals are people who work in management, business and financial services, the legal industries, healthcare, and high-end sales and sales management (Florida, 2012). As classification of occupations varies from country to country and detailed data on skill level 4 is unavailable, this report considers the creative talent defined by Boschma & Fritsch (2009) and the International Standard Classification of Occupations (ISCO-88), and then related it to the skill level 2 in International Standard Classification of Occupations (ISCO-08). The creative talent assessed in the report are city-level data in 2020, which includes all skill level 2 occupations covered by "1. managers", "2. professionals", and "3. technicians and associate professionals".
Data sources: International Labour Organization (https://www.ilo.org/shinyapps/bulkexplorer26/?lang=en&segment=indicator&id=EMP_TEMP_SEX_ECO_NB_A), offices for national (regional) statistics, and statista website (https://www.statista.com/)

31. 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 2021 is used to measure the public service environment for arts and culture in a city.
Data sources: (1) Public museums: official museum directories, official tourism welcome pages, platforms for museum-goers and web maps. (2) Public libraries: official statistical yearbooks or bulletins, official library websites, government websites, official tourism welcome pages and web maps (including the number of libraries open to the public, excluding university libraries).

Appendix III: Data standardization

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

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

y_{ij}^{s} is the standardized value of the Z-score for the i-th level-3 indicator for city j. x_{ij} is the raw data for the i-th level-3 indicator for city j. $\bar{x_{\iota}}$ is the mean of the raw data for the i-th level-3 indicator for all cities, and Std(xi) 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=31, 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 are selected via the following steps: first select the top 100 science cities in the Nature Index 2021 Science Cities, the top 100 cities in the 2021 Global Cities Index by Kearney, the top 48 cities in the Global Power City Index 2021 by the Mori Memorial Foundation, the top 100 cities in the WIPO Global Innovation Index 2021, and the top 100 cities in the Innovation Cities™ Index 2021 by 2thinknow; then select cities/metropolitan areas that feature in at least two of the five lists as the final 100 cities/metropolitan areas to be assessed. These 100 cities/metropolitan areas are from 35 countries in 6 continents, covering 295 major administrative cities. Among them, there are 37 Asian cities, 29 European cities, 27 North American cities, 4 Oceanian cities, 2 South American cities and 1 African city.

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
3	Vancouver MA	Vancouver	Canada
		Surrey	Canada
		Burnaby	Canada
		Richmond	Canada
		Coquitlam	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 D.C.	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
13	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
14	Denver MA	Denver	United States
		Aurora	United States
		Lakewood	United States
		Arvada	United States
		Westminster	United States
		Centennial	United States
15	Houston MA	Houston	United States
		Pearland	United States
		Pasadena	United States

16	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
17	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
18	Minneapolis - Saint Paul	Minneapolis	United States
		Saint Paul	United States
19	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
20	Philadelphia MA	Philadelphia	United States
21	Phoenix MA	Phoenix	United States
		Mesa	United States
		Chandler	United States
		Gilbert	United States
		Glendale	United States
		Scottsdale	United States
		Tempe	United States
22	Pittsburgh	Pittsburgh	United States
23	Portland	Portland	United States
24	San Diego MA	Vista	United States
		San Diego	United States
		Escondido	United States
		El Cajon	United States
		Chula Vista	United States
		Carlsbad	United States
25	San Francisco - San Jose	Berkeley	United States
		Concord	United States
		Antioch	United States
		San Jose	United States

25	San Francisco - San Jose	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
26	Seattle - Tacoma - Bellevue	Tacoma	United States
		Seattle	United States
		Renton	United States
		Kent	United States
		Everett	United States
		Bellevue	United States
27	St. Louis	St. Louis	United States
28	Vienna	Vienna	Austria
29	Brussels	Brussels	Belgium
30	Copenhagen	Copenhagen	Denmark
31	Helsinki	Helsinki	Finland
32	Paris MA	Paris	France
		Cergy	France
		Pontoise	France
		Saint-Quentin-en-Yvelines	France
33	Lyon-Grenoble	Lyon	France
		Grenoble	France
34	Berlin MA	Berlin	Germany
		Potsdam	Germany
35	Frankfurt	Frankfurt	Germany
36	Hamburg	Hamburg	Germany
37	Heidelberg	Heidelberg	Germany
38	Munich	Munich	Germany
39	Budapest	Budapest	Hungary
40	Dublin	Dublin	Ireland
41	Milan	Milan	Italy
42	Rome	Rome	Italy
43	Amsterdam MA	Amsterdam	The Netherlands
		Hoofddorp	The Netherlands
		Haarlem	The Netherlands
		Almere Stad	The Netherlands
44	Oslo	Oslo	Norway
45	Warsaw	Warsaw	Poland
46	Moscow	Moscow	Russia
47	Barcelona MA	Barcelona	Spain
		Badalona	Spain
48	Madrid	Madrid	Spain
49	Stockholm	Stockholm	Sweden
50	Geneva	Geneva	Switzerland
51	Lausanne	Lausanne	Switzerland
52	Zurich	Zurich	Switzerland
53	Cambridge	Cambridge	UK
54	London MA	London	UK
		Watford	UK
		Croydon	UK
		Enfield Town	UK
55	Manchester	Manchester	UK
56	Oxford	Oxford	UK
57	Beijing	Beijing	China
58	Changchun	Changchun	China
59	Changsha	Changsha	China
60	Chengdu	Chengdu	China

61	Chongqing	Chongqing	China
62	Dalian	Dalian	China
63	Hangzhou	Hangzhou	China
64	Harbin	Harbin	China
65	Hefei	Hefei	China
66	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
67	Jinan	Jinan	China
68	Nanjing	Nanjing	China
69	Qingdao	Qingdao	China
70	Shanghai	Shanghai	China
71	Suzhou	Suzhou	China
72	Taipei	Taipei	China
73	Tianjin	Tianjin	China
74	Wuhan	Wuhan	China
75	Xi'an	Xi'an	China
76	Bengaluru	Bengaluru	India
77	Central National Capital Region Delhi MA	Delhi	India
		Faridabad	India
		Ghāziābād	India
		New Delhi	India
		Noida	India
		Greater Noida	India
		Gurgaon	India
78	Mumbai MA	Mumbai	India
		Navi Mumbai	India
79	Jakarta	Jakarta	Indonesia
80	Tel Aviv	Tel Aviv	Israel
81	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
82	Kyoto - Osaka - Kobe	Kyoto	Japan
		Osaka	Japan
		Kobe	Japan
83	Tokyo MA	Tokyo	Japan
		Asaka	Japan
		Zama	Japan
		Kamakura	Japan
		Chigasaki	Japan
		Ōme	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
		Narita	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
84	Kuala Lumpur	Kuala Lumpur	Malaysia
85	Singapore	Singapore	Singapore
86	Busan	Busan	South Korea
87	Daejeon	Daejeon	South Korea
88	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
89	Bangkok	Bangkok	Thailand
90	Ankara	Ankara	Turkey
91	Istanbul	Istanbul	Turkey
92	Abu Dhabi	Abu Dhabi	United Arab Emirates
93	Dubai	Dubai	United Arab Emirates
94	Brisbane	Brisbane	Australia
95	Melbourne	Melbourne	Australia
96	Perth	Perth	Australia
97	Sydney	Sydney	Australia
98	Buenos Aires	Buenos Aires	Argentina
99	Sao Paulo	Sao Paulo	Brazil
100	Johannesburg	Johannesburg	South Africa

Note: The 100 cities/administrative 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

Appendix VI: Measurement of element agglomeration and spillover effect

Taking into account the characteristics of each indicator, this report uses 14 level-3 indicators of element agglomeration, such as the number of active researchers (per million people), the percentage of highly cited scientists, 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 patent cooperation treaty (PCT) patents, the number of leading innovative companies, the number of unicorn companies, foreign direct investment (FDI), venture capital investment (VC), private equity (PE), professional talent inflow (per million people), and number of creative talent (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 percentage of highly cited papers, the proportion of papers cited in patents, policy reports and clinical trials, the paper co-authorship network centrality, the patent collaboration network centrality, outward foreign direct investment (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:

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

y_{ij}^{s} is the standardized value of the Z-score for the i-th level-3 indicator for city j. x_{ij} is the raw data for the i-th level-3 indicator for city j. $\bar{x_i}$ is the mean of the raw data for the i-th level-3 indicator for all cities, and Std(xi) 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.

Calculate the mean of the 14 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. In order to make comparison between cities, this report uses min-max normalization on the basis of the Z-score to map the evaluated cities' scores to the [0,1] range.

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

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}、Y_{Bj}.

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

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

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