# Global Innovation Hubs Index 2021

清华大学产业发展与环境治理研究中心
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# Executive summary

**The Global Innovation Hubs Index 2021 (GIHI2021) was released by the Center for Industrial Development and Environmental Governance (CIDEG) at Tsinghua University and Nature Research on September 25, 2021. It tracks the innovation performance of 50 cities/metropolitan areas around the world, and the development of global innovation hubs (GIHs).**

**The GIHI2021 applies scientific, objective, independent and impartial principles in selecting candidate cities. Some indicators and data have been improved in the following aspects:**

**First, the number of evaluated cities has increased from 30 to 50, while the selection criteria and methods remain unchanged, shining a light on more 'second-tier' cities.** Shenzhen, Hong Kong, Guangzhou and a few other Chinese cities are now collectively evaluated as the Guangdong-Hong Kong-Macao Greater Bay Area.

**Second, to ensure continuity and keep looking forward,** 12 level-2 indicators remain unchanged, and 14 out of 31 level-3 indicators are optimized, and a new level-3 indicator named 'E-governance Level' has been added.

**Third, the granularity and accuracy of data have been improved.** For instance, the 'number of active researchers (per million people)' measures the number of researchers who have had publications over the past five years in different cities/metropolitan areas. The 'number of professional talent inflows' measures the number of professionals entering into cities/metropolitan areas in the past year as reflected by changes in 'LinkedIn' resumes.

**Fourth, focus is put on emerging digital economy and cutting-edge technologies.** For instance, the innovation capability of cities/metropolitan areas and the evolution of global innovation network are measured by the number of patents granted in two enabling technologies: artificial intelligence (AI) and integrated circuits (ICs).

**The GIHI2021 takes a comprehensive view and evaluates GIHs via research innovation, innovation economy, and innovation ecosystem. The results are as follows:**

**For the overall GIHI2021 ranking, the top 20 cities/metropolitan areas are** San Francisco-San Jose, New York MA, London MA, Beijing, Boston MA, Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, Paris MA, Seattle-Tacoma-Bellevue, Baltimore-Washington, Munich, Los Angeles-Long Beach-Anaheim, Singapore, Shanghai, San Diego MA, Amsterdam MA, Chicago-Naperville-Elgin, Chapel Hill-Durham-Raleigh, Dallas-Fort Worth, and Copenhagen.

**The GIHI2021 top 20 cities/metropolitan areas in research innovation are** New York MA, Boston MA, San Francisco-San Jose, Baltimore-Washington, London MA, Beijing, Chapel Hill-Durham-Raleigh, Copenhagen, Los Angeles-Long Beach-Anaheim, Guangdong-Hong Kong-Macao Greater Bay Area, Paris MA, Chicago-Naperville-Elgin, San Diego MA, Seattle-Tacoma-Bellevue, Stockholm, Amsterdam MA, Munich, Atlanta MA, Pittsburgh, and Houston MA.

**The GIHI2021 top 20 cities/metropolitan areas in innovation economy are** San Francisco-San Jose, Tokyo MA, Beijing, Guangdong-Hong Kong-Macao Greater Bay Area, New York MA, Seoul MA, Kyoto-Osaka-Kobe, Boston MA, Seattle-Tacoma-Bellevue, Austin, Dublin, Dallas-Fort Worth, Shanghai, San Diego MA, Paris MA, Singapore, London MA, Bengaluru, Los Angeles-Long Beach-Anaheim, and Munich.

**The GIHI2021 top 20 cities/metropolitan areas in innovation ecosystem are** London MA, San Francisco-San Jose, New York MA, Beijing, Paris MA, Munich, Guangdong-Hong Kong-Macao Greater Bay Area, Boston MA, Singapore, Shanghai, Tokyo MA, Amsterdam MA, Los Angeles-Long Beach-Anaheim, Baltimore-Washington, Madrid, Toronto MA, Seattle-Tacoma-Bellevue, Chicago-Naperville-Elgin, Dallas-Fort Worth, and Phoenix MA.

**The GIHI2021 report has drawn the following conclusions:**
**The global innovation network is changing, and emerging Asian economies are demonstrating vitality.** The United States still has an overwhelming advantage in science and technology human resources, knowledge creation, and high-tech manufacturing. European cities maintain their competitive edge in innovation ecosystem, and Asian cities are rising in innovation economy with great potential. As investment in innovation keeps growing, the global innovation network is undergoing significant changes. Research and development, and innovation activities are moving to emerging economies, especially Asian cities. Digital technologies, such as artificial intelligence, are reshaping industrial labour division and innovation landscape around the world.

**Chinese cities are emerging as new GIHs.** Despite the COVID-19 pandemic, China maintains strong economic momentum and sees the emergence of innovative companies with huge potential. Beijing still leads in the innovation economy and makes significant progress in research innovation and innovation ecosystem. Guangdong-Hong Kong-Macao Greater Bay Area makes an excellent debut in the list,

## Executive summary

particularly in the innovation ecosystem and innovation economy indicators. Other Chinese cities, such as Nanjing, Hangzhou, Wuhan, Hefei, and Chengdu, are active in innovation economy and are soon expected to become GIHs.

**GIHs have varied patterns and positioning in innovation development.** San Francisco-San Jose and New York MA achieve balanced and complementary progress in three level-1 indicators while other cities/metropolitan areas have respective advantages as measured by different indicators. GIHs take unique development strategies and paths based on their regional resource endowment and characteristics.

**Gathering top science and technology talents and enhancing the level of knowledge creation are key to laying a strong foundation for GIHs.** Cities in the United States dominate in research innovation for their excellent performance in knowledge creation and concentration of top talents. This shows the key to strengthening the foundation of GIHs during the new round of technological and industrial revolutions is to stay on the cutting edge, serve national and market demand, gather top science and technology personnel, and improve knowledge creation.

**GIHs have their respective strengths in integrated circuits (ICs) and artificial intelligence (AI).** Cities/metropolitan areas in the United States, Japan and South Korea are far ahead of others in the number of IC patents. For instance, Tokyo MA, San Francisco-San Jose and Seoul MA host a concentration of the world's leading semiconductor chip manufacturers, and Chinese cities/metropolitan areas are catching up in AI.

**Emerging industries are gaining momentum in Chinese cities with a dynamic innovation and entrepreneurial environment.** Beijing, Greater Bay Area and Shanghai are among the top 10 cities in innovative enterprises, the number of unicorn companies on the list in Hangzhou exceeds those in cities/metropolitan areas including Tokyo MA, Paris MA, and Munich, suggesting that Chinese cities enjoy certain advantages in emerging digital technologies like AI and are riding the new economy momentum.

**The digital economy is booming.** Despite the total operating income of industries slumping in 2020 due to the social and economic impacts of the COVID-19 pandemic, the digital economy has boomed. The pharmaceutical and chemical industries, digital healthcare industry, and remote working industry have experienced explosive growth during the pandemic, and digital-related industries including data service and software service have recorded high growth in operating income, indicating great potential.

**An innovation ecosystem is the basis of sustaining competitive advantage of GIHs.** European cities generally score well in innovation ecosystem for their residents' relatively high average education levels, large inflow of professional talents, and excellent public services. In terms of openness and collaboration, the global cooperation network keeps expanding, and Asian cities are playing an increasingly important role in the cooperation network of publications and patents. The broadband network will be an essential building block in fostering the innovation ecosystem in the era of digital economy with expanding applications and increasing demand for e-government platforms.

**Acknowledgement**
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# Introduction

Throughout history, society has been driven by intellectual movements and technological revolutions. Cities are the physical centres of human social development, full of the vitality of technological innovation and the disruptive power of change. Cities are an important force in human evolution and the innovation landscape, and their interaction with each other shapes urban innovation and value networks.

The digital technology and economy wave sweeping the world is redistributing global innovation resources and redefining the competitive landscape. How cities and countries occupy the forefront of scientific research, foster a benign innovation ecosystem, and leverage unprecedented innovation paradigms to become first-movers are central to a city's development and innovation. A strategic move by countries taking part in the scientific and technological revolution is to drive and control the mobility of global innovation by planning and building cities into global innovation hubs (GIHs) that could impact surrounding areas.

To this end, it's crucial to establish a comprehensive index system to measure global innovation hubs. The system will provide the rankings of leading GIHs in scientific research, technological innovation, and emerging industries based on objective data, which allow us to explore the key drivers behind innovative transformation, reveal the basic conditions and necessary preparations for cities to deliver global innovation value, and provide policy reference for governments on development of GIHs.

The *Global Innovation Hubs Index 2021* (GIHI2021), which tracks the innovation performance of major cities around the world and the developments of GIHs, was released by the Center for Industrial Development and Environmental Governance (CIDEG) at Tsinghua University and Nature Research on September 25, 2021.

**This report continues to uphold the principles developed for the GIHI2020 of being scientific, objective, independent and impartial, while taking into account the feedback and suggestions of industry experts, media and the public. Some adjustments to assessment scope, index system, and data samples have been made as follows:**

**First, we have expanded the assessment scope and regarded Guangdong-Hong Kong-Macao Greater Bay Area as a candidate city/metropolitan area.** In order to better observe the evolution pattern of GIHs, and to explore the power of innovation and development paths of emerging cities, the number of cities evaluated this year has grown from 30 to 50. The area of administrative divisions, the size of population, and the proportion of total GDP covered have increased significantly, and the scope of indicators, such as research institutions, science and technology human resources and unicorn enterprises (start-ups valued at or more than US$1 billion), have also expanded. The new additions include emerging cities from Asian countries, reflecting changes of second-tier cities in the global innovation network. In addition, since Guangdong-Hong Kong-Macao Greater Bay Area is well positioned to become a world-class city cluster such as San Francisco Bay Area, New York MA and Greater Tokyo Area, the GIHI2021 evaluates Guangdong-Hong Kong-Macao Greater Bay Area as a single candidate city/metropolitan area.

**Second, we have optimized the index system.** In order to focus on the new landscape and changes of GIHs, and take into account such factors as stability and authority of the index system as well as availability and compatibility of index data, the GIHI2021 has made some adjustments to the index system. The three level-1 indicators known as research innovation, innovation economy and innovation ecosystem and 12 level-2 indicators remain unchanged; 14 of the original 31 level-3 indicators are optimized, with an optimization ratio of 45%. Meanwhile, considering the impact of digital technology application and business environment on innovation ecosystem, 'E-governance Level' is added as a level-3 indicator. See Appendix I for specific descriptions of the adjustments.

**Finally, we have refined the data collection method and sample scope.** In order to make comparison between cities, we have increased the granularity of data. For example, the 'number of active researchers (per million people)' measures the number of researchers who have had publications over the past five years. The 'number of professional talent inflows' measures talent mobility data from LinkedIn. And the 'number of data centres (public clouds)' measures the city-level data of data centres. The sample scope of patent data is also expanded. Three level-3 indicators, 'total number of valid patents (per million people)', the 'patent collaboration network centrality', and the 'number of PCT patents', have expanded their sample scope from 'artificial intelligence' to 'manufacturing of integrated circuits'.

We hope that the GIHI2021 can 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). The GIHI assesses the development of GIH cities/metropolitan areas 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, while sharing infrastructure, thereby reducing risks and costs. Global science centres naturally emerge as research activities and innovation resources continue to aggregate, with their impact spilling over to surrounding regions as well as globally. Therefore, the effect of research innovation includes science and technology human resources, research institutions, scientific infrastructure, and knowledge creation.

**Second, a GIH features thriving innovation activities and a vibrant innovation economy.** As a cluster of innovative 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-up companies, and enhances the growth efficiency of the innovation economy. Therefore, the dimension of innovation economy includes technological innovation capacity, innovative enterprises, emerging industries, and economic growth.

**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, public services, and innovation culture. 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 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.

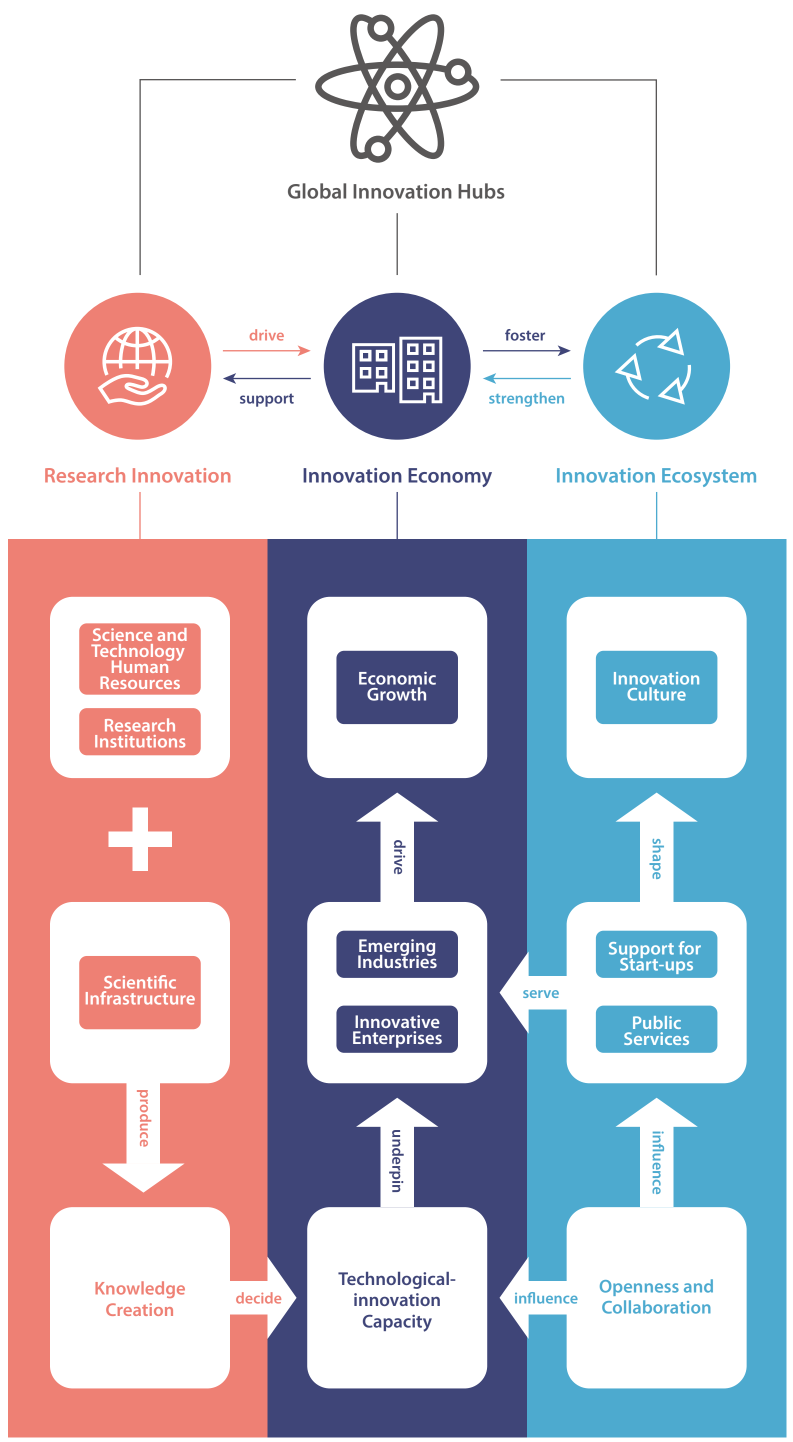
**Second, consider the index's current performance and future potential.** The index system should capture historic strengths and existing innovation capacities of GIHs, as well as their dynamic development, and the future trends in emerging technologies and frontier fields.

**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 the existing indicators.

**Four, be inherently logical and consistent.** Among different innovation subjects, huge disparities exist in their conversion efficiency between innovation input and output. In order to objectively evaluate innovation capacity and performance, indicators related to innovation input in the innovation measures, such as R&D expenditure, financial investment, and industrial policies, are not included in this 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 counter-intuitive or difficult to interpret are reexamnied 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 top 200 world-class 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 top 2,500 companies in R&D investment |
| | | | | 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. Labor 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 |
| | | | | 30. Residents' average years of schooling |
| | | | | 31. Number of international conferences |
| | | | | 32. 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 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 definition and data sources of GIHI indicators, and see Appendix III for the data standardization).

## 1.4 Subjects of evaluation

In order to align with the connotation of GIHs and stay in line with the development pattern of urban spatial systems, while keeping 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. A metropolitan area usually consists of multiple administrative divisions, such as cities, towns, suburbs, counties, and districts; some metropolitan areas seem to have blurred geographic boundaries between individual administrative cities. For example, some European metropolitan areas may even have cross-national boundaries, and are often defined by their citizens' commute time and mode.

To ensure objectivity, comprehensiveness and validity of the coverage of evaluation subjects, this report first selects the top 100 cities in Nature Index Science Cities 2020 and compares them with those in similar assessment reports. 137 candidate cities are selected after excluding those with a population of less than one million. Then, the overall ranking by core indicators and categories of the 137 candidate cities are generated to conduct secondary selection and cross comparison. The final list of cities (see Table 2) comprising 50 cities/metropolitan areas is generated after removing 30 overlapping cities (See Appendix IV for the GIH selection process).

The 50 cities/metropolitan areas evaluated come from 22 countries on five continents, covering 225 major administrative divisions (see Appendix V for a list of major GIHs). Accounting for only 7% of the world's total population, they boast almost 80 of the top 200 world-class universities, about 100 of the top 200 world-class research institutions, nearly 800 unicorn enterprises, and around 1,500 enterprises in the global top 2,500 R&D investors. They have attracted 247 winners of Nobel Prizes, Turing Awards, Fields Medals, and other top scientific awards. These 50 cities/metropolitan areas have secured the world's best innovation resources and achievements, and are leaders in scientific research, the innovation economy, and the innovation ecosystem.

**Table 2** **List of the cities/metropolitan areas evaluated in GIHI2021 (50)**

| Number | City / Metropolitan Area | Country |
|---|---|---|
| 1 | New York MA | United States |
| 2 | Boston MA | United States |
| 3 | San Francisco - San Jose | United States |
| 4 | Baltimore - Washington | United States |
| 5 | Los Angeles - Long Beach - Anaheim | United States |
| 6 | Chicago - Naperville - Elgin | United States |
| 7 | San Diego MA | United States |
| 8 | Houston MA | United States |
| 9 | Atlanta MA | United States |
| 10 | Seattle - Tacoma - Bellevue | United States |
| 11 | Austin | United States |
| 12 | Dallas - Fort Worth | United States |
| 13 | Pittsburgh | United States |
| 14 | Phoenix MA | United States |
| 15 | Chapel Hill - Durham - Raleigh | United States |
| 16 | Toronto MA | Canada |
| 17 | Paris MA | France |
| 18 | London MA | United Kingdom |
| 19 | Berlin MA | Germany |
| 20 | Munich | Germany |
| 21 | Madrid | Spain |
| 22 | Stockholm | Sweden |
| 23 | Amsterdam MA | Netherlands |
| 24 | Dublin | Ireland |
| 25 | Copenhagen | Denmark |
| 26 | Beijing | China |
| 27 | Guangdong-Hong Kong-Macao Greater Bay Area | China |
| 28 | Shanghai | China |
| 29 | Wuhan | China |
| 30 | Hefei | China |
| 31 | Hangzhou | China |
| 32 | Suzhou | China |
| 33 | Chengdu | China |
| 34 | Nanjing | China |
| 35 | Tokyo MA | Japan |
| 36 | Kyoto - Osaka - Kobe | Japan |
| 37 | Nagoya MA | Japan |
| 38 | Bengaluru | India |
| 39 | Central National Capital Region Delhi MA | India |
| 40 | Mumbai MA | India |
| 41 | Seoul MA | South Korea |
| 42 | Singapore | Singapore |
| 43 | Tel Aviv | Israel |
| 44 | Istanbul | Turkey |
| 45 | Bangkok | Thailand |
| 46 | Dubai | The United Arab Emirates |
| 47 | Abu Dhabi | The United Arab Emirates |
| 48 | Jakarta | Indonesia |
| 49 | São Paulo | Brazil |
| 50 | Sydney | Australia |

# 2 Overall GIHI ranking



## 2.1 Individual ranking

Overall GIHI ranking is shown in Table 3.

Table 3

Overall ranking of the Global Innovation Hubs (GIHs)

| City/metropolitan area | Overall | | Research innovation | | Innovation economy | | Innovation ecosystem | |
|---|---|---|---|---|---|---|---|---|
| | Score | Ranking | Score | Ranking | Score | Ranking | Score | Ranking |
| San Francisco - San Jose | 100 | 1 | 97.13 | 3 | 100 | 1 | 94.32 | 2 |
| New York MA | 87.25 | 2 | 100 | 1 | 71.49 | 5 | 91.85 | 3 |
| London MA | 82.97 | 3 | 86.95 | 5 | 65.50 | 17 | 100 | 1 |
| Beijing | 82.68 | 4 | 85.78 | 6 | 75.87 | 3 | 86.22 | 4 |
| Boston MA | 82.43 | 5 | 97.21 | 2 | 69.69 | 8 | 82.57 | 8 |
| Tokyo MA | 79.86 | 6 | 73.46 | 27 | 82.22 | 2 | 81.30 | 11 |
| Guangdong-Hong Kong-Macao Greater Bay Area | 79.67 | 7 | 82.43 | 10 | 73.04 | 4 | 84.32 | 7 |
| Paris MA | 77.05 | 8 | 82.33 | 11 | 66.25 | 15 | 85.74 | 5 |
| Seattle - Tacoma - Bellevue | 75.75 | 9 | 81.72 | 14 | 69.23 | 9 | 78.41 | 17 |
| Baltimore - Washington | 75.40 | 10 | 87.21 | 4 | 63.49 | 27 | 79.72 | 14 |
| Munich | 75.40 | 11 | 79.89 | 17 | 64.62 | 20 | 85.41 | 6 |
| Los Angeles - Long Beach - Anaheim | 74.71 | 12 | 82.76 | 9 | 64.62 | 19 | 80.52 | 13 |
| Singapore | 74.26 | 13 | 77.92 | 22 | 65.69 | 16 | 82.49 | 9 |
| Shanghai | 73.92 | 14 | 76.23 | 24 | 66.87 | 13 | 81.53 | 10 |
| San Diego MA | 73.89 | 15 | 82.07 | 13 | 66.85 | 14 | 75.71 | 24 |
| Amsterdam MA | 73.75 | 16 | 81.16 | 16 | 63.13 | 30 | 81.23 | 12 |
| Chicago - Naperville - Elgin | 73.28 | 17 | 82.09 | 12 | 63.60 | 25 | 78.25 | 18 |
| Chapel Hill - Durham - Raleigh | 72.33 | 18 | 84.49 | 7 | 63.31 | 29 | 73.42 | 30 |
| Dallas - Fort Worth | 72.28 | 19 | 73.29 | 28 | 67.97 | 12 | 78.01 | 19 |
| Copenhagen | 71.91 | 20 | 83.25 | 8 | 62.31 | 35 | 74.75 | 25 |
| Seoul MA | 71.70 | 21 | 69.45 | 36 | 70.80 | 6 | 76.22 | 21 |
| Dublin | 71.47 | 22 | 72.75 | 30 | 68.07 | 11 | 75.97 | 22 |
| Austin | 71.40 | 23 | 75.54 | 25 | 68.27 | 10 | 72.74 | 32 |
| Toronto MA | 71.06 | 24 | 76.35 | 23 | 62.18 | 38 | 79.17 | 16 |
| Stockholm | 70.68 | 25 | 81.39 | 15 | 61.62 | 46 | 73.81 | 26 |
| Atlanta MA | 70.33 | 26 | 79.07 | 18 | 62.55 | 33 | 73.80 | 27 |
| Houston MA | 70.26 | 27 | 78.79 | 20 | 62.62 | 32 | 73.76 | 28 |
| Phoenix MA | 70.19 | 28 | 73.19 | 29 | 63.73 | 23 | 77.58 | 20 |
| Kyoto - Osaka - Kobe | 70.14 | 29 | 71.43 | 32 | 70.06 | 7 | 70.58 | 33 |
| Sydney | 69.06 | 30 | 78.10 | 21 | 60.49 | 47 | 73.73 | 29 |
| Berlin MA | 69.06 | 31 | 73.94 | 26 | 62.03 | 39 | 75.74 | 23 |
| Pittsburgh | 68.48 | 32 | 78.89 | 19 | 61.98 | 40 | 69.19 | 34 |
| Madrid | 68.44 | 33 | 68.27 | 38 | 61.90 | 42 | 79.67 | 15 |
| Nanjing | 65.54 | 34 | 72.35 | 31 | 63.55 | 26 | 64.68 | 42 |
| Tel Aviv | 65.46 | 35 | 70.77 | 33 | 61.89 | 43 | 68.26 | 35 |
| Dubai | 65.28 | 36 | 65.39 | 42 | 61.73 | 44 | 73.25 | 31 |
| Hangzhou | 65.13 | 37 | 68.54 | 37 | 64.24 | 21 | 66.29 | 38 |
| Wuhan | 64.84 | 38 | 70.75 | 34 | 63.49 | 28 | 64.23 | 45 |
| Hefei | 63.64 | 39 | 69.80 | 35 | 62.78 | 31 | 62.53 | 47 |
| Nagoya MA | 63.36 | 40 | 65.97 | 41 | 62.52 | 34 | 65.83 | 39 |
| Abu Dhabi | 62.94 | 41 | 65.22 | 43 | 62.18 | 37 | 65.75 | 40 |
| Chengdu | 62.70 | 42 | 67.72 | 40 | 62.23 | 36 | 62.51 | 48 |
| São Paulo | 62.60 | 43 | 65.16 | 44 | 60 | 50 | 67.75 | 36 |
| Bengaluru | 62.50 | 44 | 61.91 | 48 | 64.67 | 18 | 64.34 | 43 |
| Central National Capital Region Delhi MA | 62.43 | 45 | 62.65 | 47 | 64.00 | 22 | 64.30 | 44 |
| Suzhou | 62.24 | 46 | 68.19 | 39 | 61.69 | 45 | 61.42 | 49 |
| Mumbai MA | 62.01 | 47 | 61.49 | 49 | 61.96 | 41 | 66.96 | 37 |
| Bangkok | 61.28 | 48 | 63.38 | 45 | 60.17 | 48 | 65.32 | 41 |
| Istanbul | 60.35 | 49 | 62.98 | 46 | 60.08 | 49 | 63.03 | 46 |
| Jakarta | 60 | 50 | 60 | 50 | 63.72 | 24 | 60 | 50 |

## 2.2 Overall analysis

The results show that San Francisco-San Jose is once again the top-ranked GIH, scoring much higher than other cities/metropolitan areas. New York MA and London MA, scoring 87.25 and 82.97, rank second and third, respectively. Other cities/metropolitan areas in the top 20 are Beijing, Boston MA, Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, Paris MA, Seattle-Tacoma-Bellevue, Baltimore-Washington, Munich, Los Angeles-Long Beach-Anaheim, Singapore, Shanghai, San Diego MA, Amsterdam MA, Chicago-Naperville-Elgin, Chapel Hill-Durham-Raleigh, Dallas-Fort Worth, and Copenhagen.

Geographically, the United States remains the leader in science and technology innovation, with 10 cities/metropolitan areas in the top 20 list. UK/Europe has five cities in the top 20, with London MA and Paris MA being the most prominent. Five Asian cities/metropolitan areas, Beijing, Tokyo MA, Guangdong-Hong Kong-Macao Greater Bay Area, Singapore, and Shanghai have made it to the top 20, suggesting that Asia is a strong force in science and technology with a tangible momentum.

Three of the world's major bay areas have entered the top 10, with San Francisco-San Jose and New York MA being the top two and Tokyo MA ranking 6th. Equipped with sound economic structures, efficient resource allocation capacity, strong concentration and spillover capacity, and advanced international exchange networks, these cities/metropolitan areas are gradually becoming leaders in technological innovation by blazing new trails. Since China started building the Guangdong-Hong Kong-Macao Greater Bay Area in 2016, the Greater Bay Area has witnessed rapid development in industrial systems, supporting facilities, trade advantages, fin-tech, and population size. It is now ranked among the top 10, second only to Tokyo MA, and is expected to rival the three major bay areas by becoming a positive force in driving innovation and opening up to the outside world.

Looking at Chinese cities, Nanjing, Hangzhou, Wuhan, Hefei, Chengdu, and Suzhou have also become new GIHs, ranking 34th, 37th, 38th, 39th, 42nd and 46th respectively, indicating that China's emerging GIHs are on the rise. Among them, cities such as Nanjing, Hangzhou, and Wuhan are listed in the middle range of all assessed cities in innovation economy, although further improvement is needed in terms of research innovation and innovation ecosystem.

**FIGURE 2**

**Development patterns**
of the GIHI top 10 cities/metropolitan areas in overall ranking

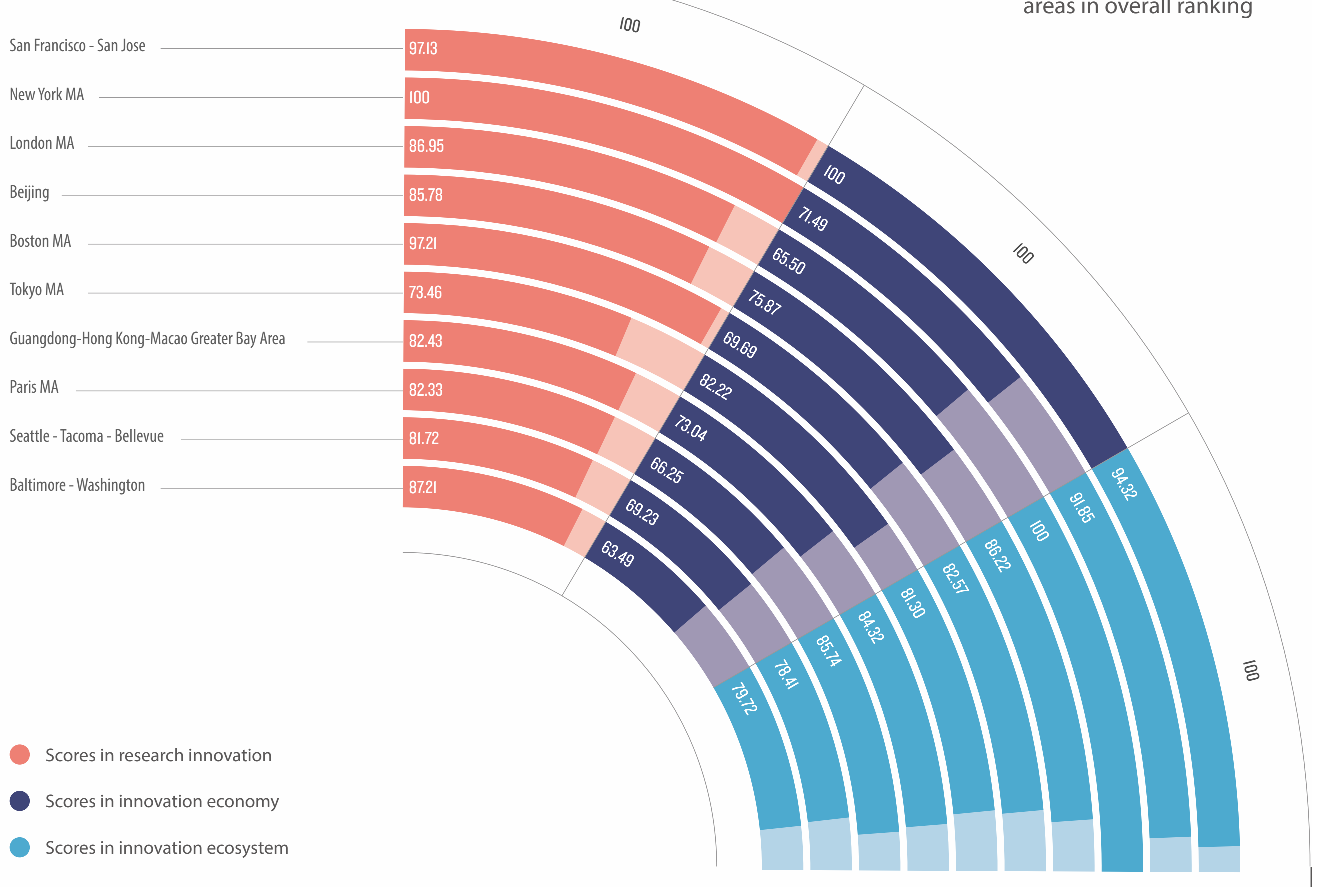



**FIGURE 3**

**Scatter plot**
of scores on the GIHI level-1 indicators

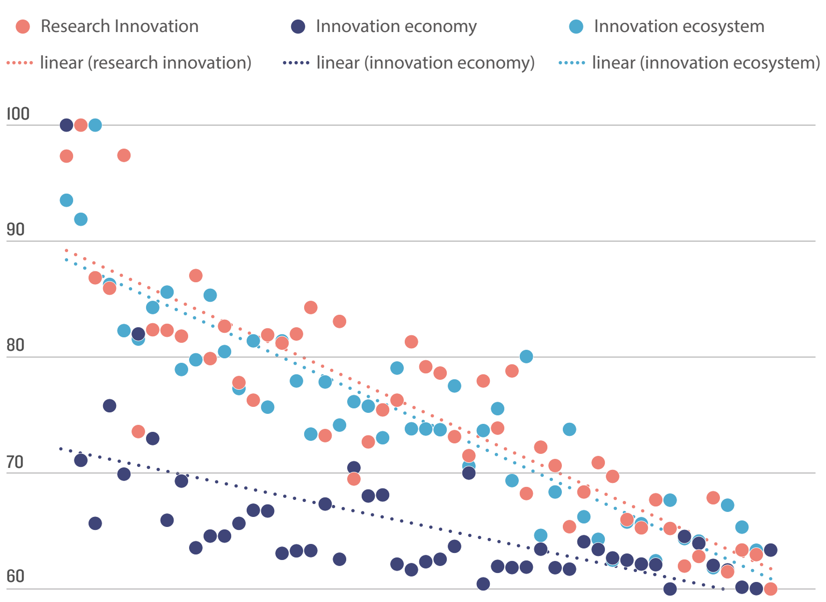
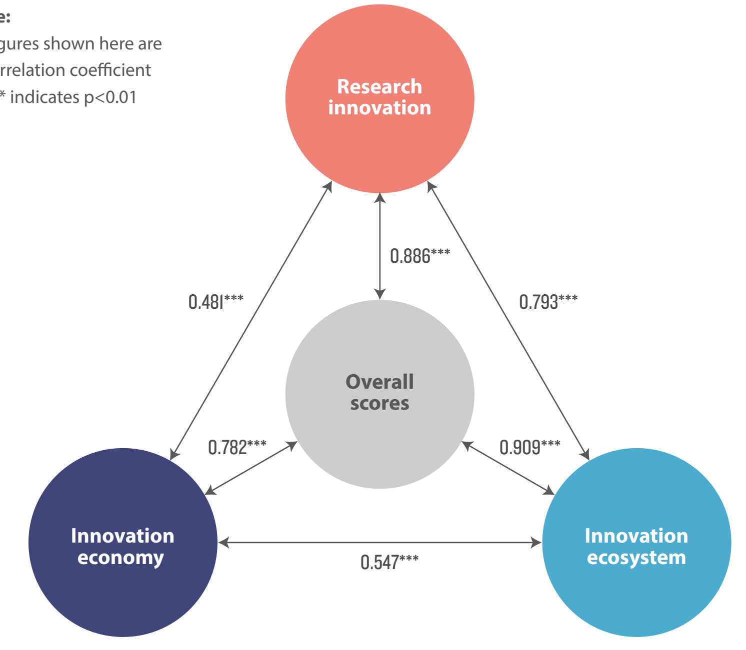



**FIGURE 4**

**Correlations**
between the GIHI level-1 indicators

**Note:**
1. Figures shown here are correlation coefficient
2. *** indicates p<0.01




In terms of development patterns, GIHs follow a varied distribution. Among the top 10 cities/metropolitan areas in overall scores, San Francisco-San Jose, at the top, shows balanced and complementary development in all three level-1 indicators. Other cities/metropolitan areas have respective strengths in different indicators. Four cities/metropolitan areas in the United States (New York MA, San Francisco-San Jose, Boston MA and Baltimore-Washington) stand out the most in research innovation, providing substantial support for such activities. London MA performs exceptionally well in innovation ecosystem. Beijing and the Greater Bay Area both have excellent research innovation and innovation ecosystem, and are particularly competitive in innovation economy. Tokyo MA stands out for its strengths in innovation economy. Paris MA, as an important GIH, relies on its innovation ecosystem to form a healthy environment for innovation. The development patterns of the GIHI top 10 cities/metropolitan areas in overall ranking is shown in Figure 2.

Analysis using Pearson's correlation shows that scores on each of the three GIHI level-1 indicators are significantly correlated with the overall scores ($p<0.01$). Specifically, the correlation between innovation ecosystem and the overall scores is the strongest, with a coefficient of 0.909, followed by that between research innovation and the overall scores at a coefficient of 0.886. The innovation economy has the weakest correlation with the overall scores at 0.782. Detailed analysis of the correlation between three level-1 indicators shows that the correlation between research innovation and innovation ecosystem is the strongest, with a coefficient of 0.793 ($p<0.01$), indicating that a good innovation ecosystem facilitates research innovation. Research innovation and innovation economy are also significantly correlated, with a coefficient of 0.481 ($p<0.01$), suggesting that scientific research plays a positive role in stimulating the growth of innovation economy. There is also a significant correlation between innovation ecosystem and innovation economy, with a coefficient of 0.547 ($p<0.01$), indicating that a healthy innovation ecosystem is conducive to supporting the growth of innovation economy. A scatter plot of scores on the GIHI level-1 indicators is shown in Figure 3.

# 3 Research innovation



**Scientific research is the source of innovative ideas. As frontiers of scientific research, GIHs assume an important role in knowledge creation and technological 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
### Top 20 cities/metropolitan areas in research innovation

New York MA is top-ranked in research innovation, followed by Boston MA and San Francisco-San Jose. London MA ranks fifth, and Beijing and the Greater Bay Area in China rank sixth and tenth, respectively. Other cities in the leading 20 are Chapel Hill-Durham-Raleigh, Copenhagen, Los Angeles-Long Beach-Anaheim, Paris MA, Chicago-Naperville-Elgin, San Diego MA, Seattle-Tacoma-Bellevue, Stockholm, Amsterdam MA, Munich, Atlanta MA, Pittsburgh, and Houston MA. Scores of the GIHI top 20 cities/metropolitan areas in research innovation are shown in Figure 5.

**FIGURE 5**

**Scores of the GIHI** top 20 cities/metropolitan areas in research innovation

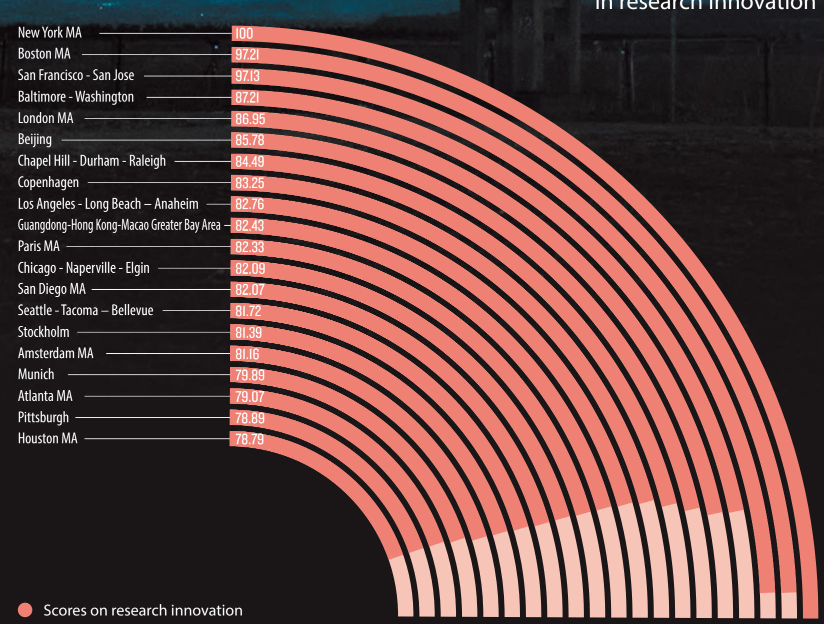





**FIGURE 6**

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

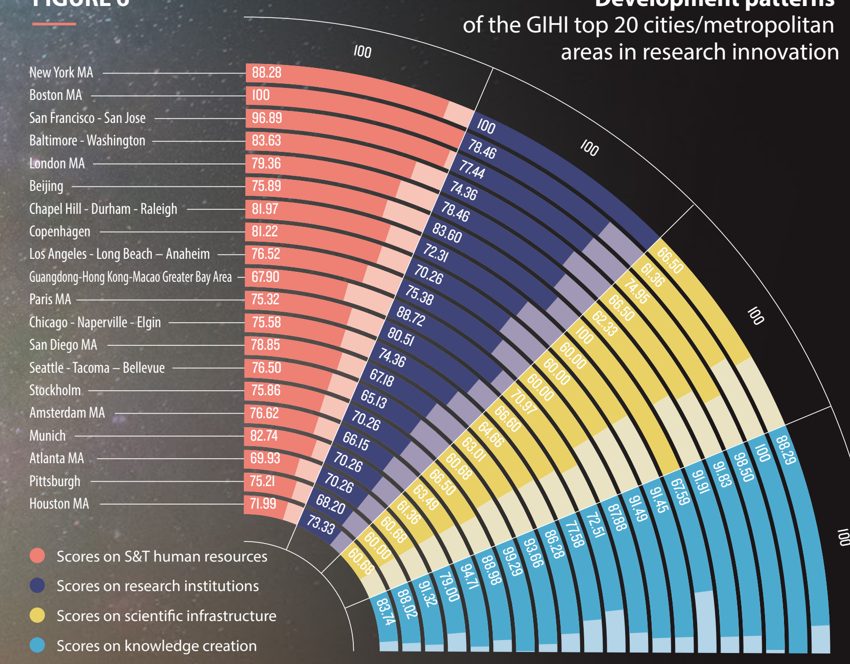



Figure 6 shows the development patterns of the GIHI top 20 cities/metropolitan areas in research innovation. With 12 cities/metropolitan areas in the top 20, the United States dominates in research innovation, especially in three level-2 indicators — science and technology human resources, research institutions, and knowledge creation. The cluster of universities and research institutions, together with the world's top talents in science and technology, has given the United States great potential for knowledge creation, although it falls slightly short in scientific infrastructure.

Scientific institutes and infrastructure help cities/metropolitan areas in China, such as Beijing and the Greater Bay Area, stand out in research innovation. In particular, Beijing, as the highest-ranked GIH in China, has moved up the list due to its edge in the number of large scientific facilities and supercomputers, as well as many globally influential universities such as Tsinghua University, Peking University, and the Chinese Academy of Sciences. Research innovation in the Greater Bay Area is accelerated by the advancement of the Greater Bay Area development strategy and the completion of multiple research institutes and facilities. Nevertheless, cities/metropolitan areas in China still have a lot to catch up to in terms of science and technology human resources and knowledge creation.

## 3.2
### Science and technology human resources

Talent is an important resource for innovation. The size of the science and technology workforce and the number of high-impact researchers determine the quality of output, its sustainability, and future trends. Taking into account factors such as the distribution of talent from different professional levels, their mobility, and the time period for the transformation of scientific achievements into productivity, GIHI2021 uses three measures — 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 7 shows the number of active researchers and the percentage of highly cited scientists for the GIHI top 20 cities/metropolitan areas in science and technology human resources. Cities in UK/Europe and the United States dominate the list, taking up 17 spots. The top five cities/metropolitan areas are Boston MA, San Francisco-San Jose, New York MA, Baltimore-Washington, and Munich. Having many of the world's prestigious universities and research institutions, and a strong research environment, along with a track record of remarkable achievements, these cities have become the preferred destination for many highly cited scientists.

**FIGURE 7**

**Number of active researchers and percentage** of highly cited scientists for the GIHI top 20 cities/metropolitan areas in science and technology human resources

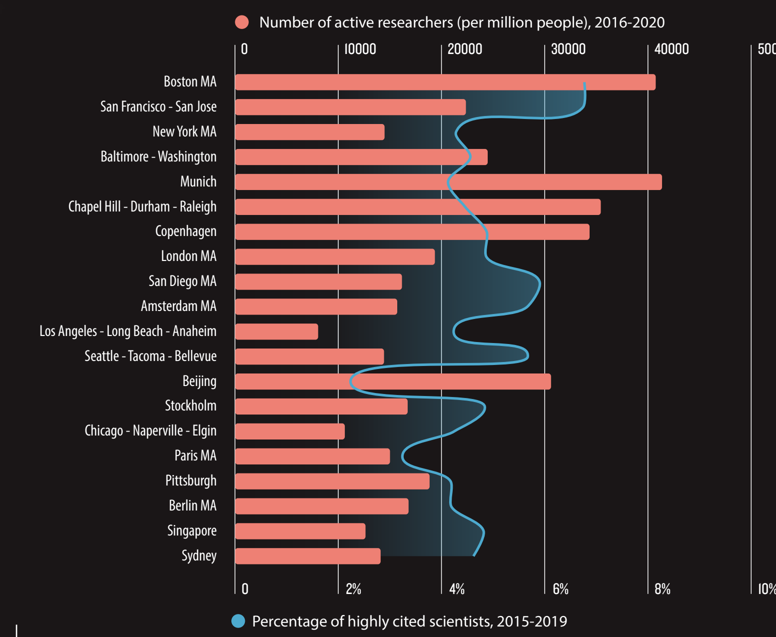


**FIGURE 8**

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


Munich leads the world in the number of active researchers (per million people), at 41,353, with Boston MA and Chapel Hill-Durham-Raleigh, ranked second and third, respectively. With a total population of just 1.5 million, Munich, home to the headquarters of the renowned Fraunhofer Society, has attracted a large number of researchers who provide contract services for enterprises, universities, and government agencies, and has performed particularly well on this indicator. Boston MA boasts many prestigious universities and a considerable number of active researchers. Beijing ranks fifth and Nanjing is among the global top 10 on this indicator.

For the percentage of highly cited scientists, Boston MA tops the list at 6.77%, followed by San Francisco-San Jose, San Diego MA, Seattle-Tacoma-Bellevue, and Amsterdam MA, each with a percentage of more than 5%. Cities in the United States have an average of 4.61% on this indicator, exceeding the global average of 3.14%. The percentage of highly cited scientists for Beijing is 2.24%, ranking 32nd.

In order to reflect the mobility of top talents in science and technology, GIHI2021 has fine-tuned the counting of winners of top scientific awards by taking into account the cities where they hold part-time positions. The awards included are the Fields Medal, the Turing Award, and Nobel Prizes (in Physics, Chemistry, and Physiology or Medicine). Together, the 15 assessed cities/metropolitan areas in the United States have 198 top award winners, and China has 15. These top talents have helped enhance the regions' fundamental research capacity, and attract more high-level academic teams. The number of winners of top scientific awards for the GIHI top 20 cities/metropolitan areas in science and technology human resources is shown in Figure 8.

## 3.3 Research institutions

Research institutions are important actors in knowledge creation and original innovation, and are largely responsible for conducting fundamental studies and making key technological advancements. This report measures the performance of universities and research institutions in a city by taking into account the top 200 research institutions in the Nature Index and the ARWU top 200 universities.

Figure 9 shows the number of top 200 world-class universities and top 200 world-class research institutions for the GIHI top 20 cities/metropolitan areas in research institutions. The top five cities in research institutions are New York MA, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing, Paris MA, and Shanghai.

In research institutions, New York MA comes out on top of the ranking with nine top 200 research institutions and seven top 200 universities. Chinese cities/metropolitan areas stand out with three spots among the top five. Among which, the Greater Bay Area ranks second with eight top 200 research institutions and four top 200 universities; Beijing comes third with seven top 200 research institutions and three top 200 universities. The Chinese cities of Nanjing and Wuhan, also home to many prestigious universities and research institutions, have entered the top 20 on this indicator.

**FIGURE 9**

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

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## 3.4 Scientific infrastructure

Scientific infrastructure provides the technological platform for researchers to carry out high-quality, innovative scientific research. This report uses the numbers of large scientific facilities and supercomputers listed in the Global TOP 500 Supercomputers, a list that tracks the world's fastest supercomputers, as proxies for the development of scientific infrastructure in cities/metropolitan areas. Supercomputers and data infrastructure are important pillars of research and innovation (Beccianiu U., & Petta C. 2019), they both demonstrate the scientific and technological strength of a region, and play an important role in attracting global innovation resources. High-performance computers are an important indicator for measuring innovation capacity, and are an area of competition among developed nations (Wang Tao, 2020).

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, Hefei, and Shanghai.

Tokyo MA, a world-renowned cluster of such facilities, takes an absolute lead in the number of large scientific facilities. Since the 1960s, Japan has been supporting the construction of large scientific facilities. Since 2001, its annual budget for large scientific facilities has been maintained at nearly 200 billion yen. The key investment areas include atomic energy, oceans, and information technology. As a result, Tokyo MA has become a well-known cluster of large scientific facilities, which has greatly boosted both the city's and country's technological competence, making a significant contribution to industrial and economic prosperity.

In recent years, China has focused on the aggregation of large scientific facilities by promoting the construction of comprehensive national science centres in places such as Huairou in Beijing, Zhangjiang in Shanghai, the Greater Bay Area, and Hefei, hoping to drive an original innovation economy. Newly-built large scientific facilities (including those under construction) in Beijing include the Earth System Science Numerical Simulator Facility (EarthLab), the High Energy Photon Source (HEPS), and multimodal cross-scale biomedical imaging facilities. While deploying large science facilities, Beijing also emphasizes the development of technological service platforms and other cross-disciplinary platforms to support incubation in high-tech industries, and establishes an open operation mechanism for large science facilities. These are of great significance in attracting top innovation talents, enhancing basic research, and strengthening the capacity for original innovation and industrialization.

In terms of supercomputers, Asia performs exceptionally well with seven cities/metropolitan areas in the top 10. Beijing leads the world with 40 supercomputers in the top 500 supercomputers list, and Hangzhou surpasses Tokyo MA as the world's second. In recent years, a booming digital economy and an established urban network infrastructure in Asia, led to an increased demand for computing power, which accelerated the building of supercomputer centres. During the past 40 years, the Chinese government completed the preliminary construction of an autonomous and controllable supercomputing ecosystem, and has since entered the world's premier league in terms of infrastructure and key computing technologies. The 'Tianhe' and 'Sunway' series of supercomputers have been built, along with eight national supercomputing centres across the country. As a strong force in the global supercomputing competition, Japan once led the United States in cutting-edge products. Its supercomputer, 'Fugaku', ranked first in the world on several occasions. The Japanese government places great importance on the development of supercomputing: in 2014 its Ministry of Education, Culture, Sports, Science and Technology launched an exascale supercomputer development project, which lists next-generation supercomputers as the 'national foundational (key) technology', putting Japan in a leading position in supercomputing centres.



## 3.5 Knowledge creation

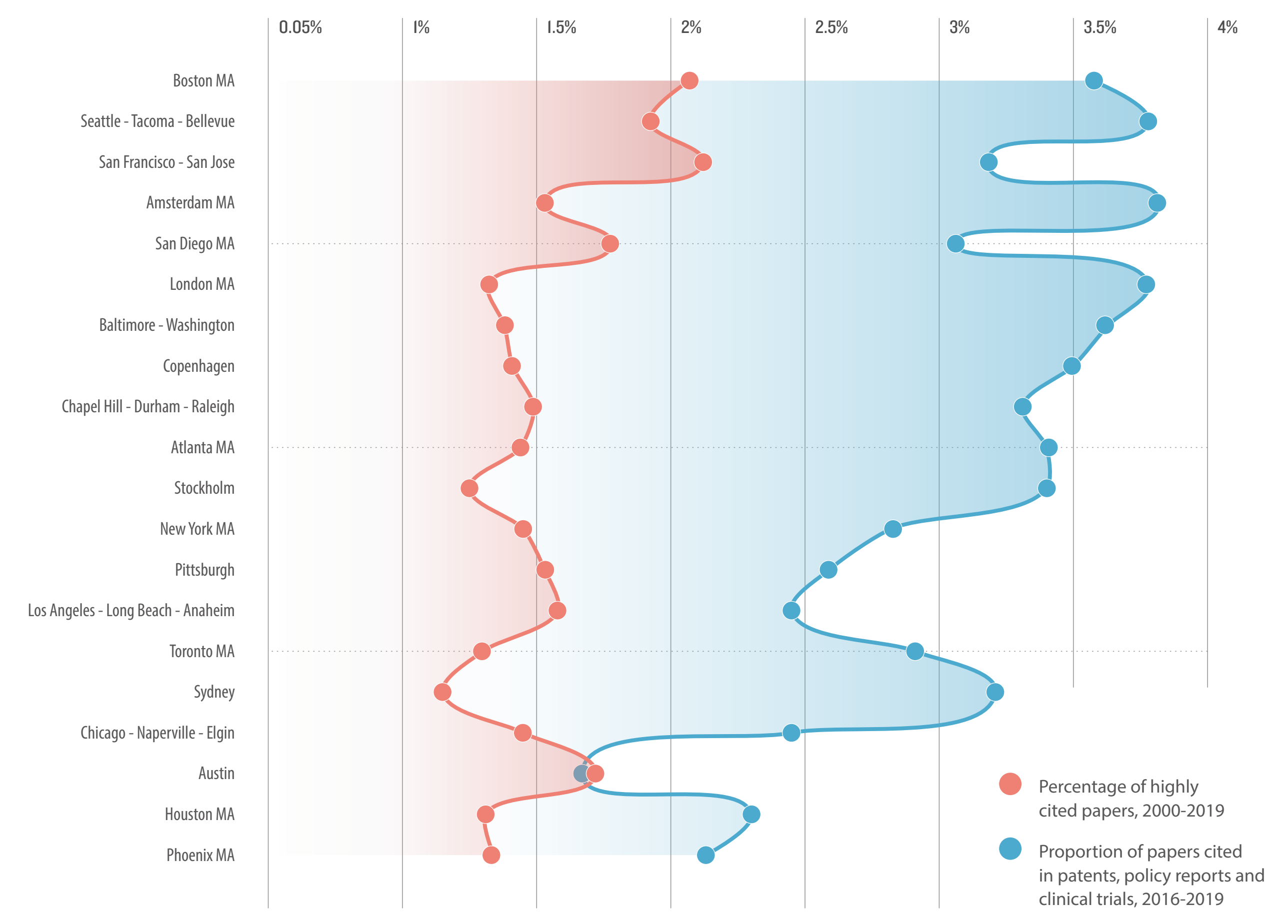
Knowledge creation is an important indicator of research strength and can be measured by the number of high-quality publications. This report uses the percentage of highly cited papers published by a city's researchers to measure their overall quality and academic impact. It uses the proportion of scientific papers cited in patents, policy reports and clinical trials to measure the application potential the publications would have in industry and society.

Figure 10 shows the 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. The top five cities/metropolitan areas in knowledge creation are Boston MA, Seattle-Tacoma-Bellevue, San Francisco-San Jose, Amsterdam MA, and San Diego MA.

Cities in UK/Europe and the United States enjoy remarkable advantages in knowledge creation, whereas Asian cities are lagging. Cities/metropolitan areas in the United States perform exceptionally well on this indicator: 14 of the 15 assessed cities/metropolitan areas are among the top 20 in knowledge creation with an average score of 90.12, much higher than that of all assessed cities (at 78.21).

Looking at the percentage of highly cited papers, defined here as the percentage of the top 1% highly cited papers in the fields of the city's total publications, the United States leads the world with eight cities/metropolitan areas among the top 10 and an average level of 1.6%, much higher than the global average of 1.04%. Among them, San Francisco-San Jose and Boston MA account for the biggest share, at 2.12% and 2.07% respectively. Singapore is the only Asian city entering the top 20. As a traditional scientific power, the United States has a strong research environment and substantial support from the government for basic research. Its established funding system and national research and innovation systems have driven its theoretical research and technological innovation.

**FIGURE 10** **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

**A strong and active innovation economy is essential if a city/metropolitan area is to become a global innovation hub. 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-three indicators.**

## 4.1 Top 20 cities/metropolitan areas in innovation economy

GIHs play an important role in driving the innovation economy. The top-ranked city for innovation economy is San Francisco-San Jose, well ahead of Tokyo MA and Beijing, which ranked second and third, respectively. Other cities/metropolitan areas in the top 20 are the Greater Bay Area, New York MA, Seoul MA, Kyoto-Osaka-Kobe, Boston MA, Seattle-Tacoma-Bellevue, Austin, Dublin, Dallas-Fort Worth, Shanghai, San Diego MA, Paris MA, Singapore, London MA, Bengaluru, Los Angeles-Long Beach-Anaheim, and Munich. The scores of the GIHI top 20 in innovation economy are shown in Figure 11.

San Francisco-San Jose performs well in all indicators of innovation economy. In emerging industries, such as information and biomedicine, it connects and supports technologies, enterprises, markets, capital, and talents. As a result, San Francisco-San Jose takes the lead in technological innovation capacity, innovation enterprises, and emerging industries, strengthening its dominant position in innovation economy. Tokyo MA, as a traditional global power of science and technology innovation, despite its sluggish economic growth, remains at the forefront due to the outstanding performance of its enterprises in technological innovation.

**FIGURE 11**

**Scores of the GIHI** top 20 cities/metropolitan areas in innovation economy

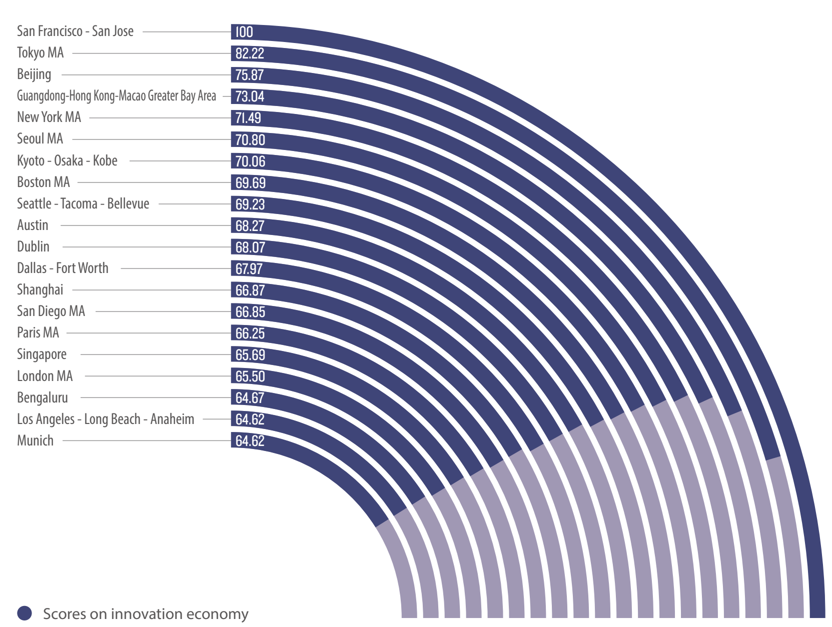
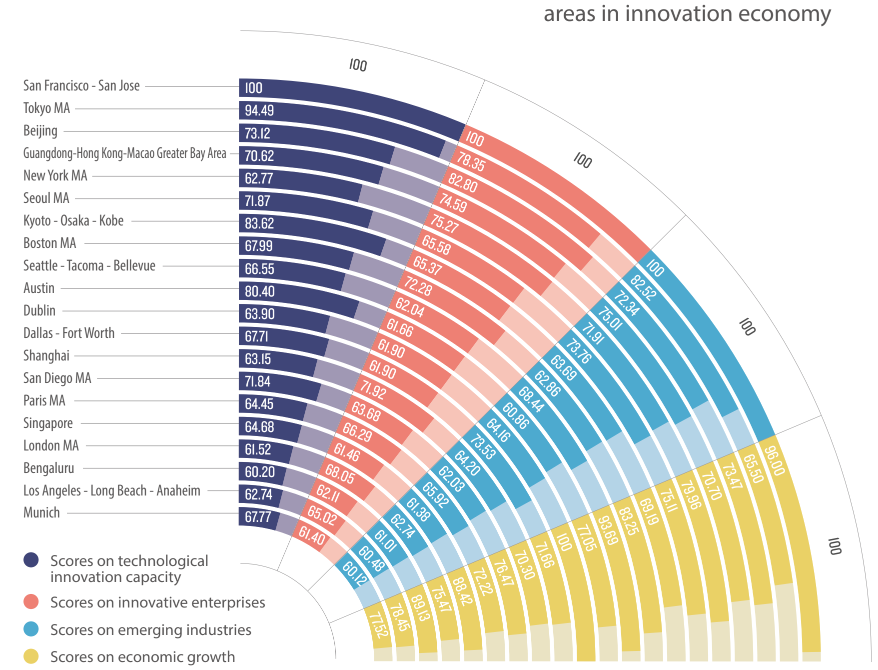



**FIGURE 12**

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




Like Tokyo MA, many of the top 20 cities/metropolitan areas in innovation economy (such as Beijing, Seoul MA, the Greater Bay Area, Kyoto-Osaka-Kobe) also have discrepancies between their scores in the innovation economy and economic growth (measured by labour productivity and GDP growth rate). Further comparison of the scores on four level-two indicators of the innovation economy shows that the top 20 cities/metropolitan areas tend to score highly on technological innovation capacity, innovation enterprises, and emerging industries, but their scores in economic growth demonstrates the highest dispersion among these four indicators. It suggests that even though there is economic growth support, to create a strong innovation economy, GIHs must make an effort to produce high-quality science and technology, to cultivate key players in technological innovation, and to enhance independent innovation and creativity. Cities/metropolitan areas with different economic levels could explore their own ways of developing an innovation economy based on local resources and industrial structure.

Figure 12 illustrates the development patterns of the GIHI top 20 cities/metropolitan areas in innovation economy. The top five are San Francisco-San Jose, Tokyo MA, Beijing, the Greater Bay Area, and New York MA. San Francisco-San Jose has a relatively balanced performance in four level-3 indicators, and is ranked first in technological innovation capacity, innovative enterprises and emerging industries, and second in economic growth.

Others in the top 20 list show varied development patterns. For instance, Tokyo MA, Beijing, and the Greater Bay Area are among the top 10 in technological innovation capacity, innovative enterprises, and emerging industries, although their ranking for economic growth is relatively behind. Though falling behind in other level-2 indicators, Dublin, whose economy is driven by a single dimension, excels in labour productivity and GDP growth rate, and its estimated economic growth level tops the world. Known as the Silicon Valley of Europe, Dublin has attracted numerous tech giants in recent years. Despite a small-scale economy, it has gradually become Europe's innovation engine with a large data centre market and a vigorous economy.

## 4.2 Technological innovation capacity

Patents are an important indicator of technological innovation capacity. Artificial Intelligence (AI), a form of cutting-edge digital technology, and Integrated Circuits (ICs), a basic technology for growing digital industry, are two examples of enabling technologies. To improve the accuracy and coverage of measurement, the GIHI2021 evaluates technological innovation capacity using the number of valid patents (per million people) and Patent Cooperation Treaty (PCT) patents for AI and IC.

The top five cities/metropolitan areas in technological innovation capacity are San Francisco-San Jose, Tokyo MA, Kyoto-Osaka-Kobe, Austin, and Beijing.

When it comes to the number of valid invention patents (per million people) for AI and IC, San Francisco-San Jose boasts 3,575 patents, followed by Austin and Kyoto-Osaka-Kobe at 2,519 and 1,950, respectively. Tokyo MA and Seoul MA rank fourth and fifth. Beijing has only 939 patents, though it ranks high. China, as an emerging economy, performs better in AI than in IC.

In terms of the number of PCT patents for AI and IC, Japanese cities/metropolitan areas demonstrate significant advantages. Tokyo MA leads the world with 8,981 patents, Kyoto-Osaka-Kobe ranks third with 3,811 patents, and San Francisco-San Jose comes second with 5,808 patents. The Greater Bay Area and Beijing rank fourth and fifth at 3,384 and 2,458, respectively. Figure 13 shows the total number of valid patents (per million people) and PCT patents for the GIHI top 20 in technological innovation capacity.

## 4.3 Innovative enterprises

Enterprises are the major actors of technological innovations. To expand the sample coverage and data stability and to show the dynamic of innovative enterprises, this report uses the numbers of the top 2,500 R&D investors and unicorn companies to measure their investment and growth.

The top five cities/metropolitan areas in innovative enterprises are San Francisco-San Jose, Beijing, Tokyo MA, New York MA, and Guangdong-Hong Kong-Macao Greater Bay Area. Although San Francisco-San Jose still maintains a strong lead, the absolute dominance of Western enterprises has been challenged, with Asian cities accounting for almost half of the top 20 list.

In the top 2,500 R&D investors, Tokyo MA and San Francisco-San Jose boast 202 and 188 enterprises, respectively. Beijing and the Greater Bay Area tie for third, while Boston MA ranks fifth.

Chinese cities performed well in terms of the number of unicorn companies. Beijing, Shanghai and the Greater Bay Area own 112, 62 and 41 unicorn companies, mainly in the field of digital economy, such as AI, e-commerce, sharing economy and social media. Hangzhou, as a new first-tier city and hub for internet-based e-commerce firms, is home to 23 unicorn companies on the list, exceeding those in Tokyo MA, Paris MA, and Munich (19 in total). Figure 14 shows numbers of the top 2,500 R&D investors and unicorn companies for the top 20 cities/metropolitan areas in innovative enterprises.

FIGURE 13

**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

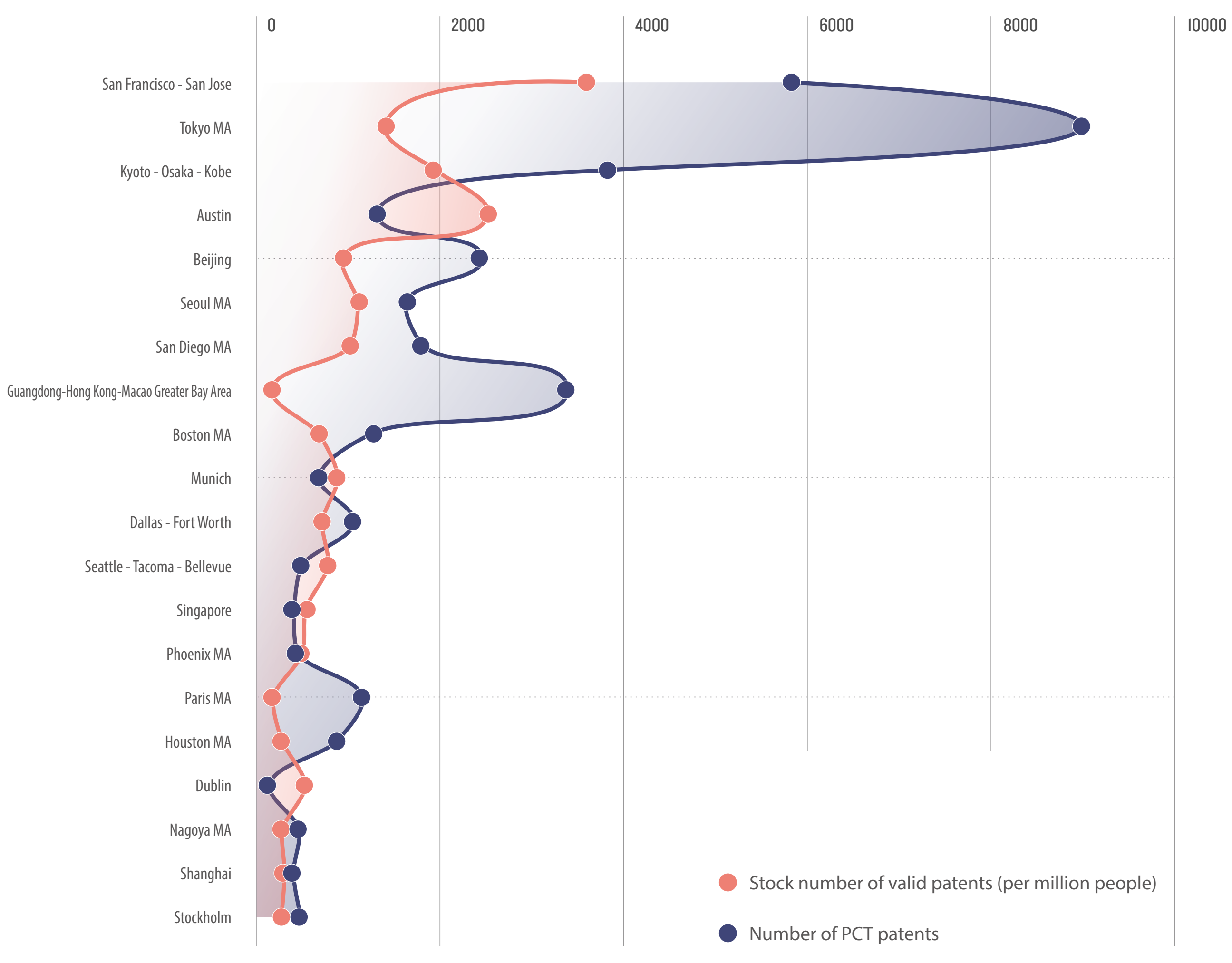
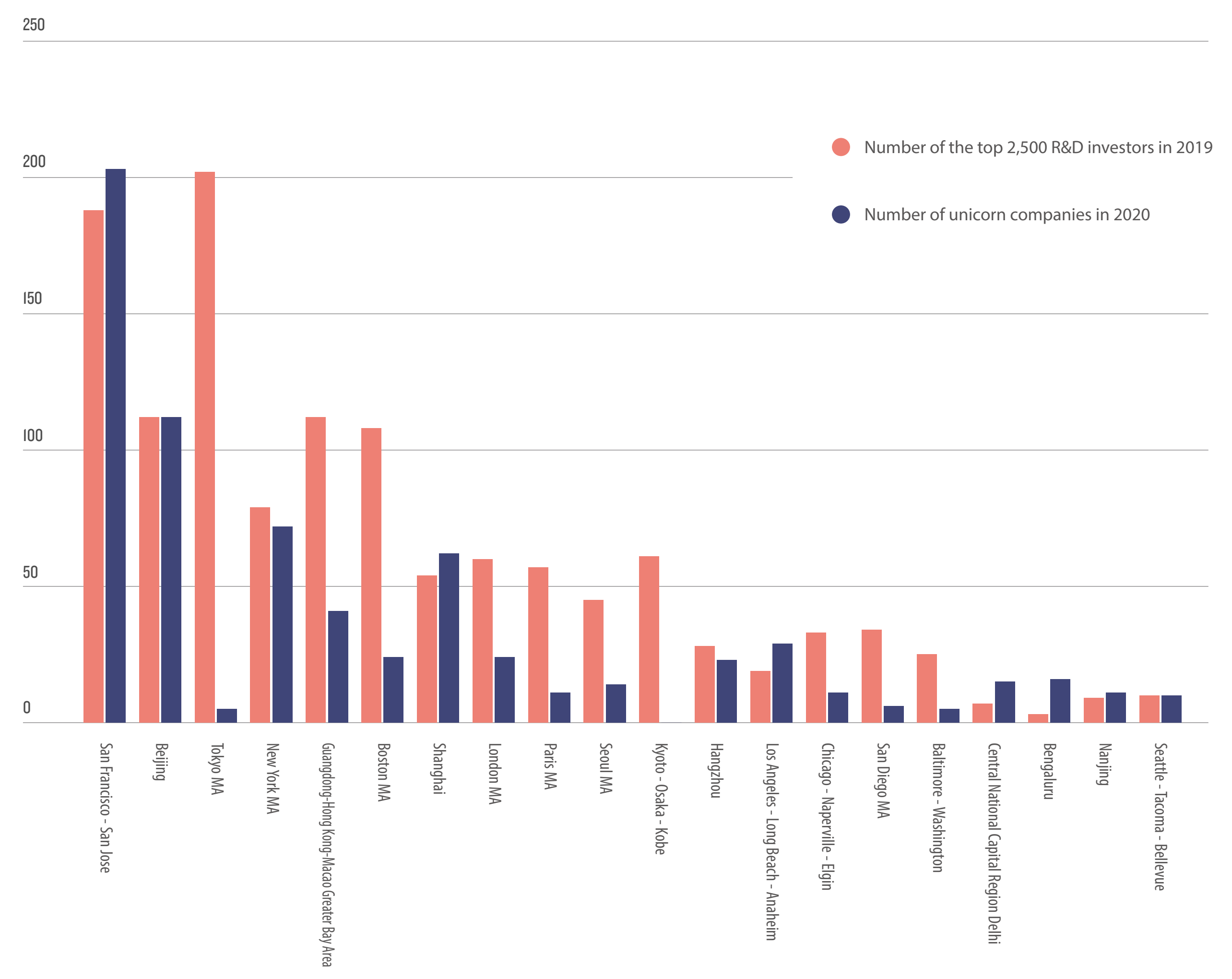



FIGURE 14

**Numbers of the top 2,500 R&D investors 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 maintain the competitiveness of the economy, which include biomedicine, high-end equipment manufacturing and new-generation information technology. This report measures emerging industries in a city using data from Forbes' Global 2000 list in 2020 on the market value of high-tech manufacturing enterprises and data from Osiris, a database of listed companies, on the revenue of listed companies in the new-economy sector in 2020.

The top five cities/metropolitan areas in emerging industries are San Francisco-San Jose, Tokyo MA, the Greater Bay Area, Seoul MA, and Dallas-Fort Worth. Dallas-Fort Worth, the fourth largest city cluster in the United States, has distinct advantages on this indicator with one of the highest concentrations of listed companies in the country.

San Francisco-San Jose still has the highest concentration of high-tech manufacturing companies, measured by its companies' total market value in 2020, which is 4.2 times as much as that of Seattle-Tacoma-Bellevue. In Asia, the Greater Bay Area demonstrates a strong growth momentum, catching up with Tokyo MA on this indicator.

In the total revenue of listed companies in the new-economy sector in 2020, Tokyo MA once again tops the list with its total revenue, coming in at first place. Its revenue is 1.5 times as much as that of San Francisco-San Jose, which comes in at second. Seoul MA, the Greater Bay Area, Beijing and Shanghai are the other Asian cities/metropolitan areas included in the top 10 for total revenue.

The United States still dominates the economic structure in the high-tech manufacturing industry with its traditional advantages. San Francisco-San Jose, Seattle - Tacoma - Bellevue, New York MA, Chicago-Naperville-Elgin and Boston MA rank higher on the market value of high-tech manufacturing enterprises than on the revenue of listed companies in the new-economy sector in 2020. GIHs like Tokyo MA, Dallas-Fort Worth, Seoul MA, the Greater Bay Area and Beijing, however, instead show great vitality in the new-economy sector. The market value of high-tech manufacturing enterprises and the revenue of listed companies in the new-economy sector for the top 20 cities/metropolitan areas in emerging industries are shown in Figure 15.

**FIGURE 15** **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

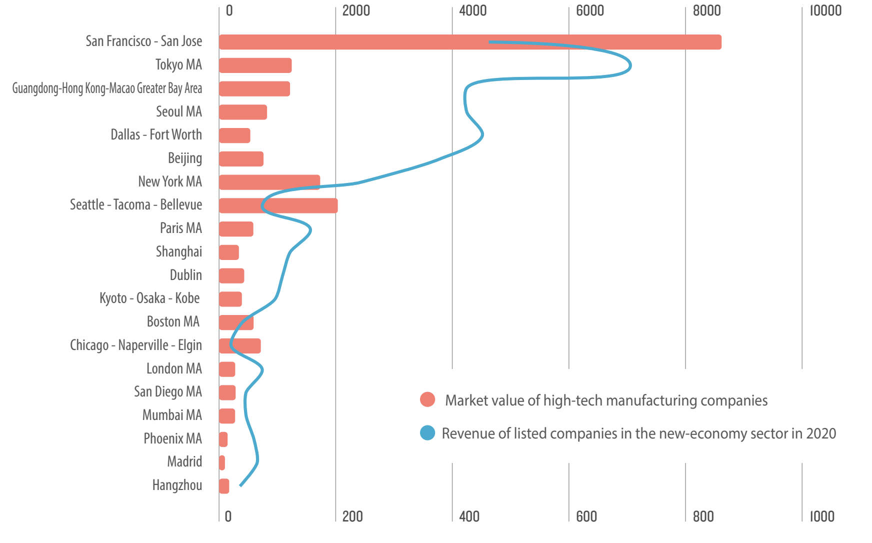
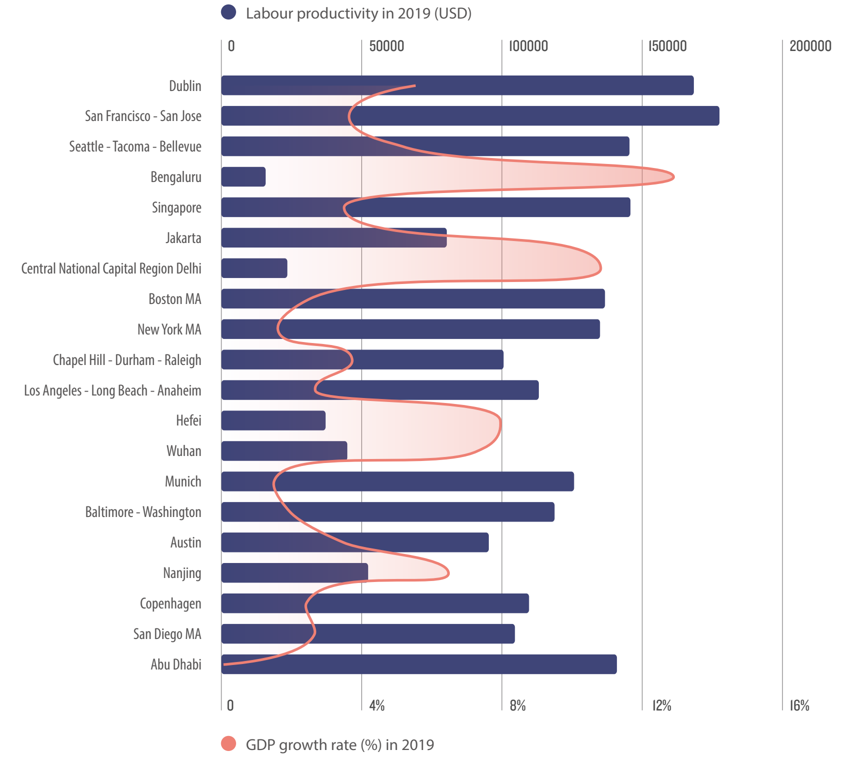



**FIGURE 16** **The GDP growth rate and labour productivity** for the GIHI top 20 cities/metropolitan areas in economic growth




## 4.5 Economic growth

Innovation drives high-quality economic growth, which reflects a city's development and potential. This report uses GDP growth rate, adjusted by 2019 purchasing power parity (PPP), to measure the overall economic growth level and living standards. Labour productivity (2019) is adopted to measure a city's social productivity.

The top five cities/metropolitan areas in economic growth are Dublin, San Francisco-San Jose, Seattle-Tacoma-Bellevue, Bengaluru, and Singapore.

The GDP growth rate in Bengaluru and Central National Capital Region Delhi are above 10%, mainly attributed to the Indian government's economic reforms and efforts to encourage the revival of manufacturing. China's second-tier cities notably maintain a relatively high GDP growth rate, and cities such as Hefei, Wuhan, Chengdu, Nanjing, and Hangzhou, have all entered the top 10.

San Francisco-San Jose leads in labour productivity, followed by Dublin and Singapore. Dublin, the capital of Ireland, is an important cluster of high-tech companies in Europe as well as an international financial service centre, with relatively high social productivity. Abu Dhabi, the capital of the United Arab Emirates, ranks fifth on its debut, next to Seattle-Tacoma-Bellevue. Chinese cities/metropolitan areas, including Suzhou, Nanjing, Beijing, Shanghai, Hangzhou, the Greater Bay Area, Wuhan, and Hefei, rank 37th to 44th. The contrast between high GDP growth rate and relatively low labour productivity suggests that Chinese cities need to further explore potential in the development of innovation economy.

# 5 Innovation ecosystem



**An innovation ecosystem is an important foundation for science and technology innovation, as it enables a healthy flow of subjects and elements. The GIHI examines innovation ecosystems using four level-2 indicators — openness and collaboration, support for start-ups, public services, and innovation culture — and 15 level-3 indicators.**

## 5.1 Top 20 cities/metropolitan areas in innovation ecosystem

An innovation ecosystem is a network of mutual dependence, trust and evolution formed among innovation subjects and supporting systems. It refers to the economic, political, and social systems beneficial to the development of science and technology innovation. In general, the top 20 cities/metropolitan areas all score highly with small variations, suggesting that top-ranked GIHs generally attach great importance to the innovation ecosystem.

London MA takes the lead, while San Francisco-San Jose and New York MA rank second and third with close scores. Beijing ranks fourth with a score of 86.22. Other top 20 cities/metropolitan areas are Paris MA, Munich, the Greater Bay Area, Boston MA, Singapore, Shanghai, Tokyo MA, Amsterdam MA, Los Angeles-Long Beach-Anaheim, Baltimore-Washington, Madrid, Toronto MA, Seattle-Tacoma-Bellevue, Chicago-Naperville-Elgin, Dallas-Fort Worth, and Phoenix MA. Figure 17 shows the scores of the GIHI top 20 cities/metropolitan areas in innovation ecosystem.

Figure 18 demonstrates the development patterns of the GIHI top 20 cities/metropolitan areas in innovation ecosystem. Nine cities/metropolitan areas in the Unites States are among the top 20. The Asian cities/metropolitan areas in the top 20 are Beijing, the Greater Bay Area, Singapore, Shanghai and Tokyo MA. While there aren't many European cities/metropolitan areas on the list, the ones that are there rank relatively highly.

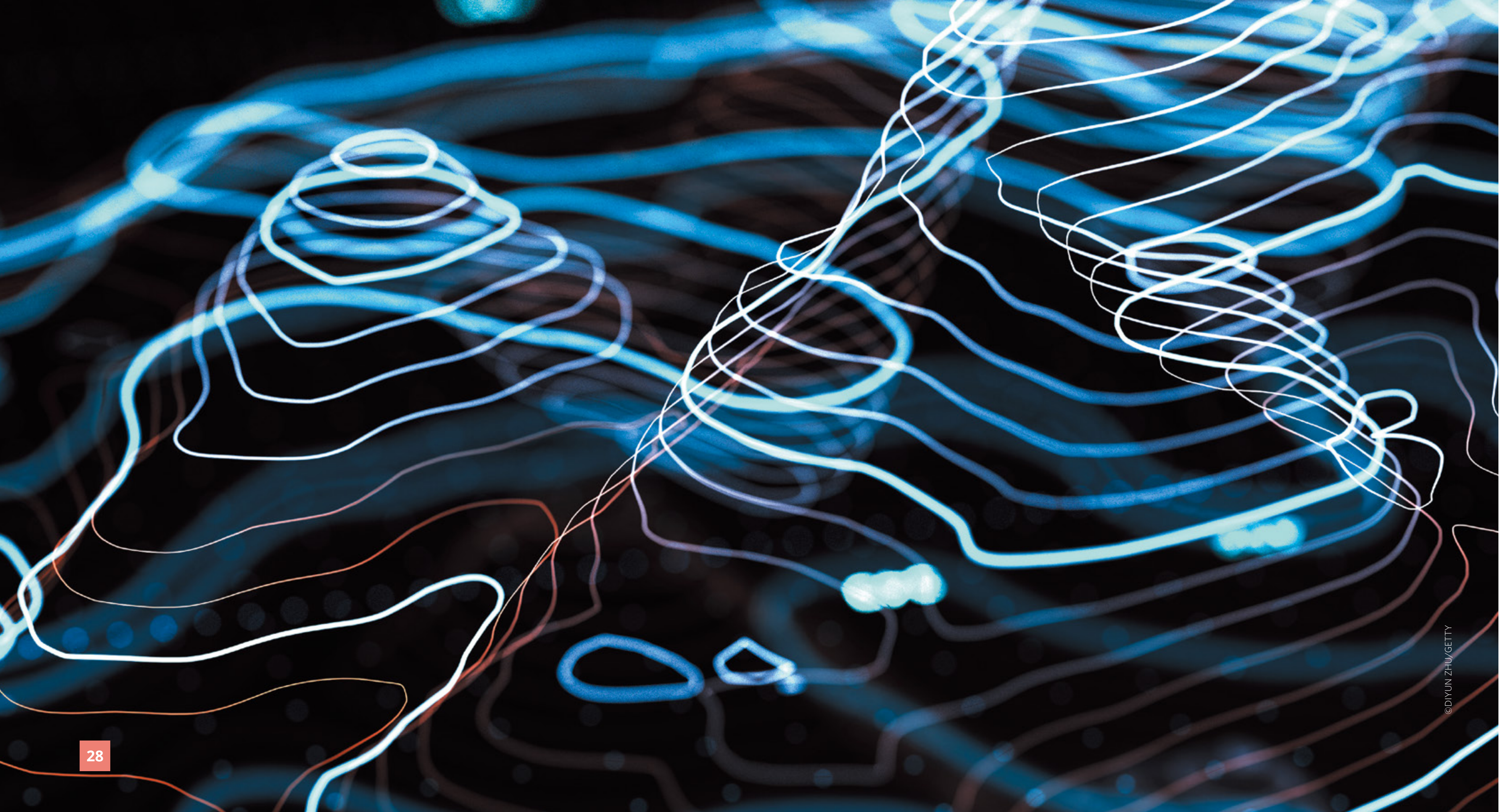




**FIGURE 17**

**Scores of the GIHI** top 20 cities/metropolitan areas in innovation ecosystem

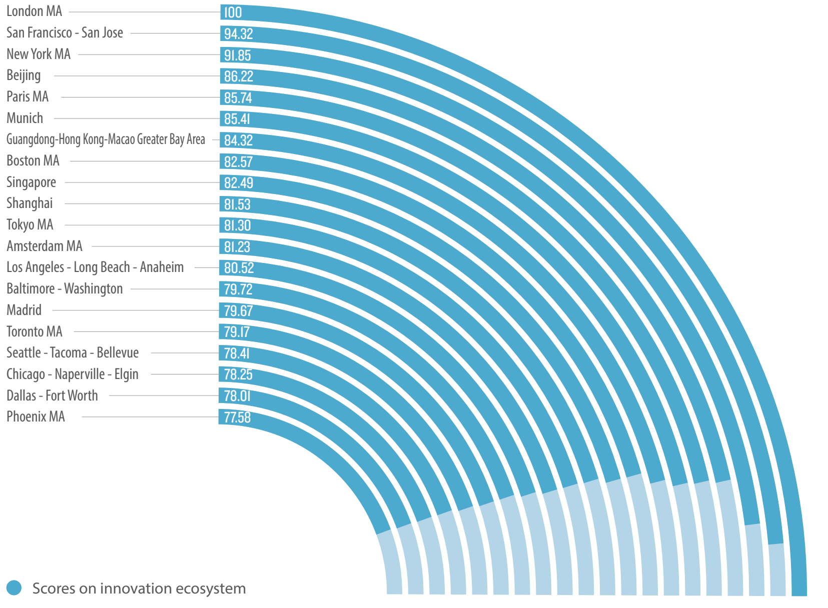
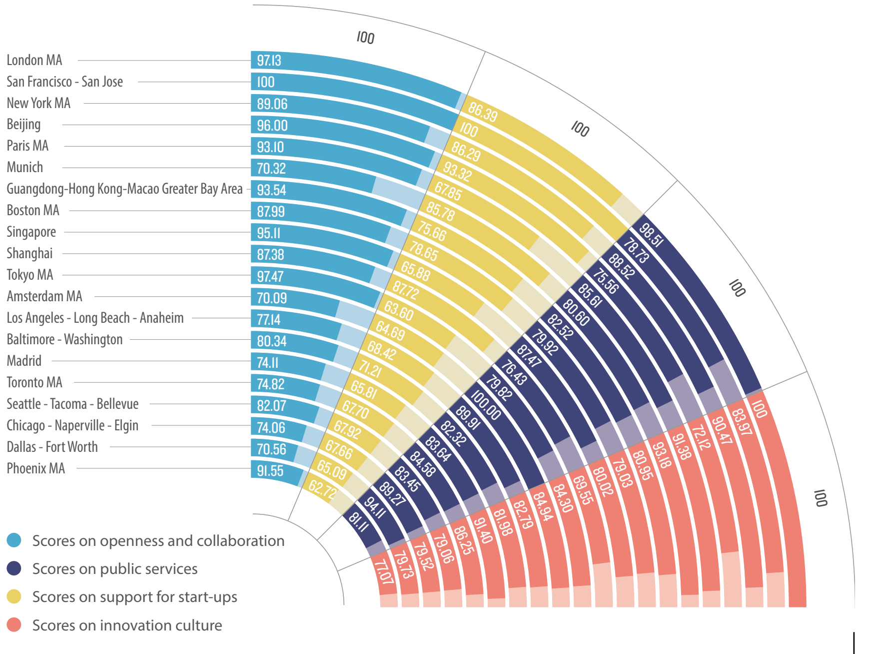



**FIGURE 18**

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



## 5.2 Openness and collaboration

Openness and collaboration indicate how cities respond to new knowledge, new technologies, and new capital, making them essential elements of a healthy innovation ecosystem. This report evaluates a city's level of openness and collaboration using four level-3 indicators — paper co-authorship network centrality, patent collaboration network centrality, foreign direct investment (FDI), and outward foreign direct investment (OFDI). The GIHI2021 has expanded the scope of patent collaboration network centrality to fields such as AI and IC, which measures a GIH's openness and collaboration in the enabling technology sector.

San Francisco-San Jose, Tokyo MA, London MA, Beijing and Singapore are the top five cities/metropolitan areas in openness and collaboration. Asian cities/metropolitan areas such as the Greater Bay Area, Shanghai, Seoul MA, and Hangzhou, rank relatively highly.

Figure 19 shows the paper co-authorship network centrality. This measure represents 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 of links it has. New York MA, Boston MA, Baltimore-Washington and Beijing stand out as major GIHs in the paper co-authorship network. The co-authorship network among Beijing, the Greater Bay Area and Shanghai is becoming increasingly important and will gradually challenge the dominance of the West.

FIGURE 19 The GIHI paper co-authorship network centrality (2020)

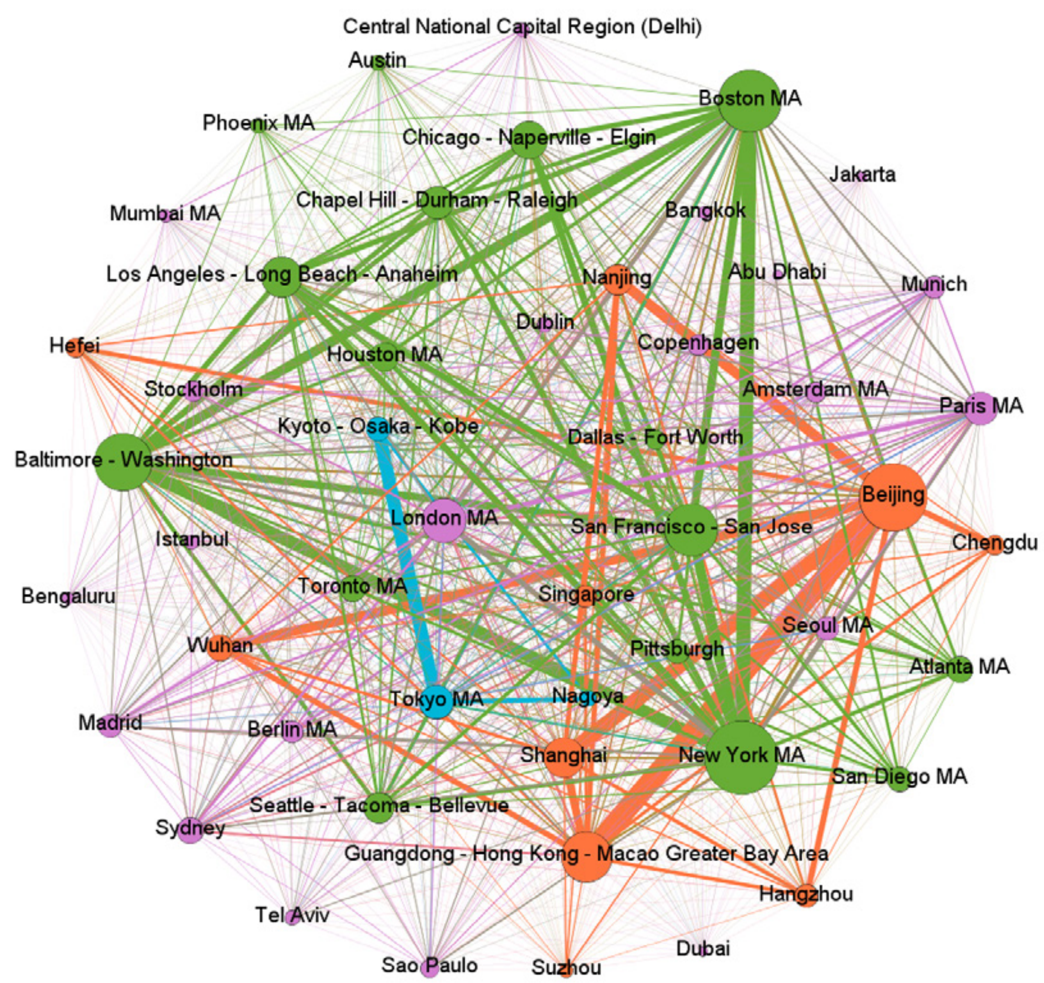



Figure 20 depicts the patent collaboration network centrality of the GIHs, which represents the network of technical exchanges among patentees. San Francisco-San Jose is outstanding in cooperation and plays a crucial role in forming the connection. The cities/metropolitan areas covered by its scope of cooperation surpass those of Tokyo MA and Beijing. The Greater Bay Area, Boston MA, Singapore, and Shanghai also perform well in cooperation. The patentee cooperation network with Chinese cities/metropolitan areas like Beijing, the Greater Bay Area and Shanghai as the core continues to grow.

FIGURE 20 The GIHI patent collaboration network centrality (2020)

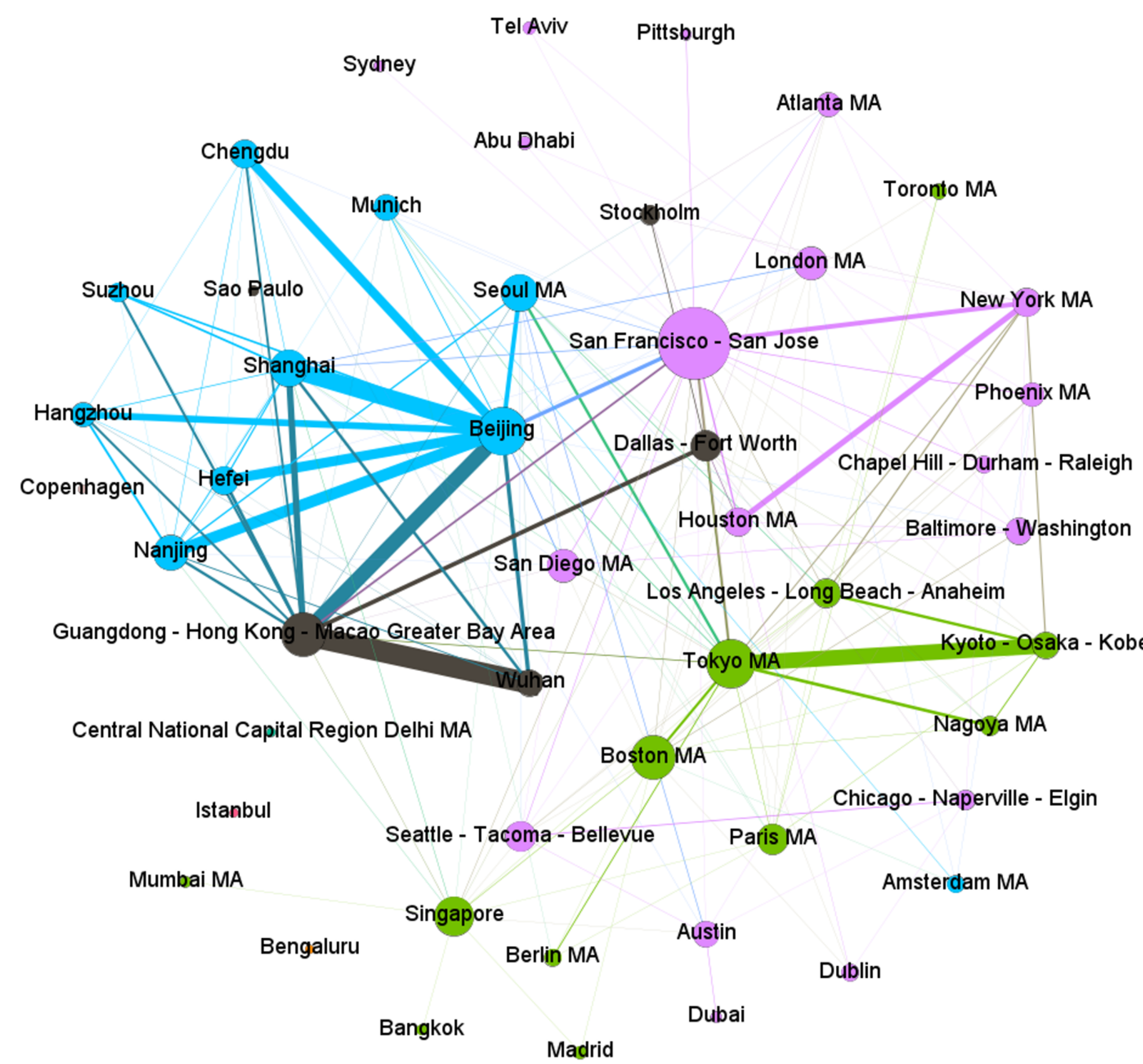


**FIGURE 21** **Total amounts of foreign direct investment (FDI) and outward foreign direct investment (OFDI)** for the GIHI top 20 cities/metropolitan areas in openness and collaboration

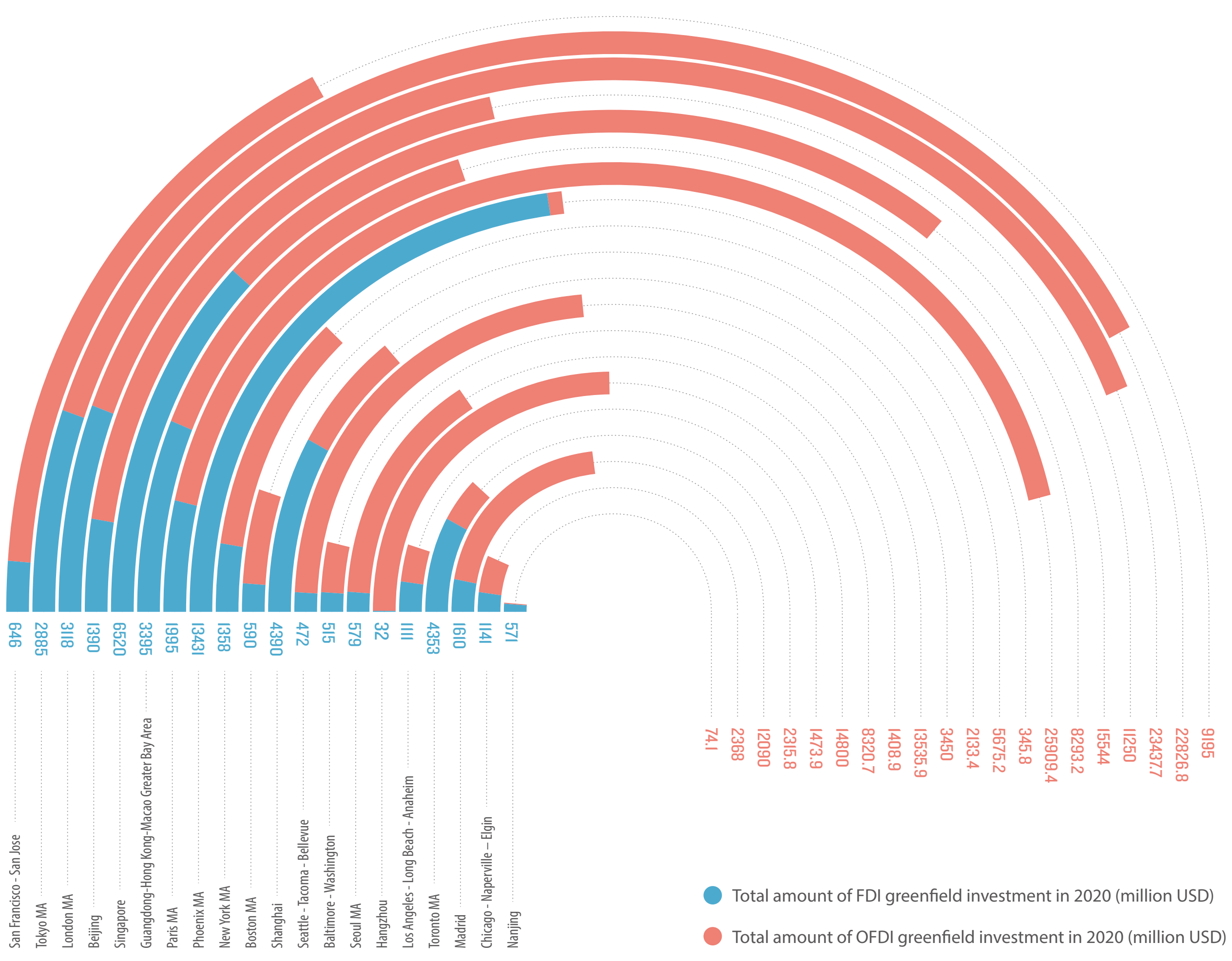



Figure 21 shows the total amounts of FDI and OFDI for the top 20 cities/metropolitan areas in openness and collaboration. The top five in the total amount of FDI greenfield investment in 2020 were Phoenix MA, Singapore, Dubai, Shanghai, and Dublin. The top five in the total amount of OFDI greenfield investment are Paris MA, London MA, Tokyo MA, Singapore, and Hangzhou.

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, and a strong ability to attract international capital and the spill-over effects of their capital.

In general, the majority of top-ranked GIHs have higher amounts of OFDI than FDI received, except Phoenix MA, Toronto MA, and Dublin. FDI greenfield investment is made to acquire more controlling interest in the invested enterprises, and OFDI shows the spill-over effects of the capital, and that of industry development, economic scale, and employment of the host country. GIHs that prioritize a digital economy like Seattle-Tacoma-Bellevue and Hangzhou perform particularly well.

## 5.3 Support for start-ups

Support for start-ups refers to the external environment for innovation and entrepreneurship. This report evaluates the extent of the venture capital activities by measuring levels of venture capital (VC) and private equity (PE). It also examines the legal environment for start-ups using a newly adjusted indicator — the number of registered lawyers (per million people). Interacting with external subjects including lawyers is an important procedure in the establishment of start-ups (Simeon, 2012). The number of a city's registered lawyers (per million people) serves as an important indicator of the external environment of business activities. (Zheng Fanghui et. al., 2019).

The top five cities/metropolitan areas in support for start-ups are San Francisco-San Jose, Beijing, Shanghai, London MA, and New York MA. Figure 22 shows the total VC and PE investment for the top 20 cities/metropolitan areas in support for start-ups.

San Francisco Bay Area tops the world in the total amounts of VC and PE as an ideal incubator for start-ups, thanks to its open environment for investment and entrepreneurship, as well as abundant funding. Beijing and Shanghai rank second and third, respectively, with a high-capital activity environment. There is a relatively wide gap between New York MA and London MA, which ranked fourth and fifth, with those higher-ranked cities, indicating an uneven distribution of venture capital across cities/metropolitan areas. The Greater Bay Area, supported by regional infrastructure and policies in favour of innovation, has witnessed rapid development and ranks sixth.

By the number of registered lawyers (per million people), Munich, Tel Aviv, London MA, Baltimore-Washington, and Dublin rank among the top five. The number of registered lawyers in cities such as Beijing and Shanghai still lags.

**FIGURE 22** **Total venture capital (VC) and private equity (PE) investment** for the GIHI top 20 cities/metropolitan areas in support for start-ups

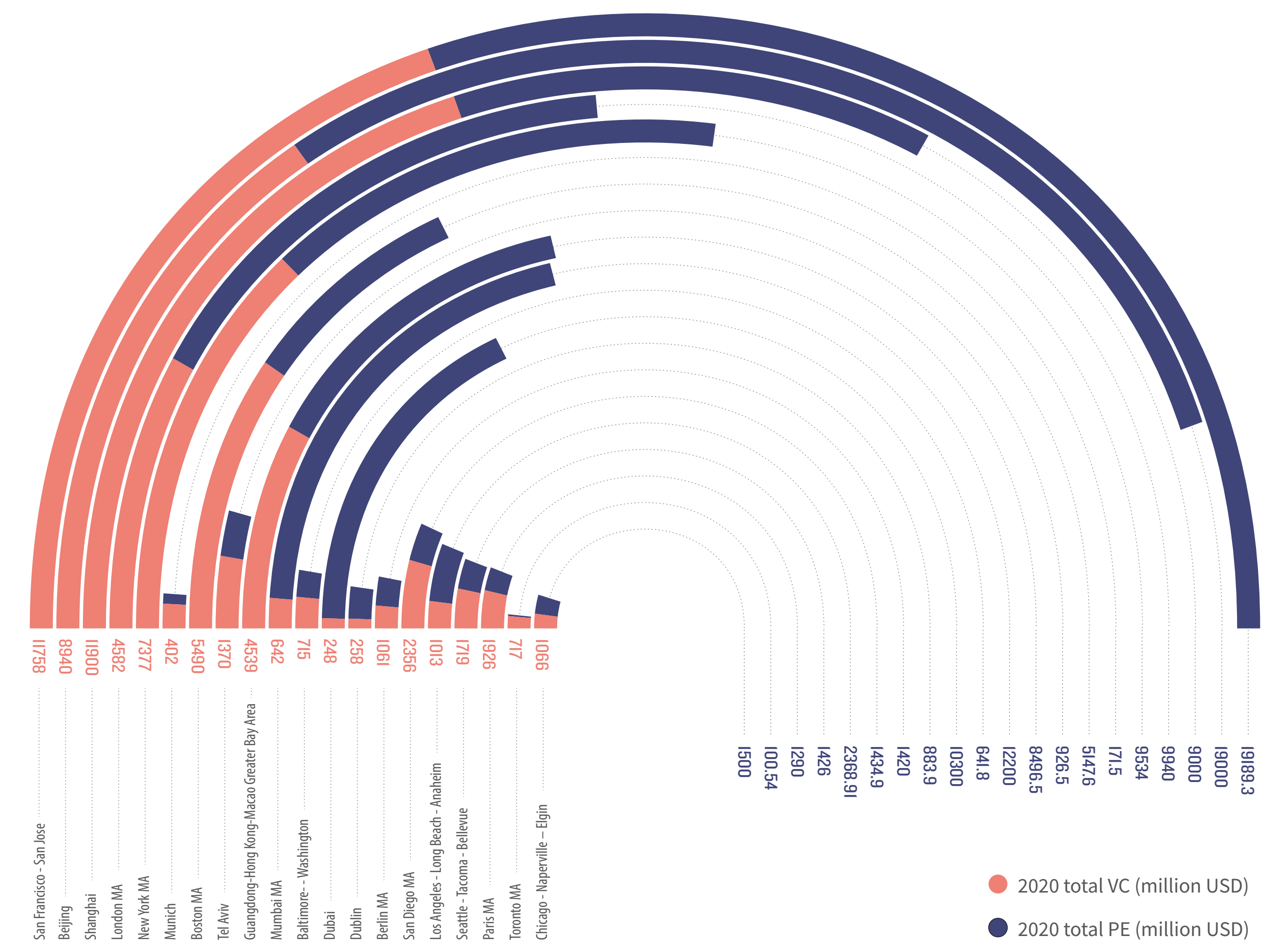
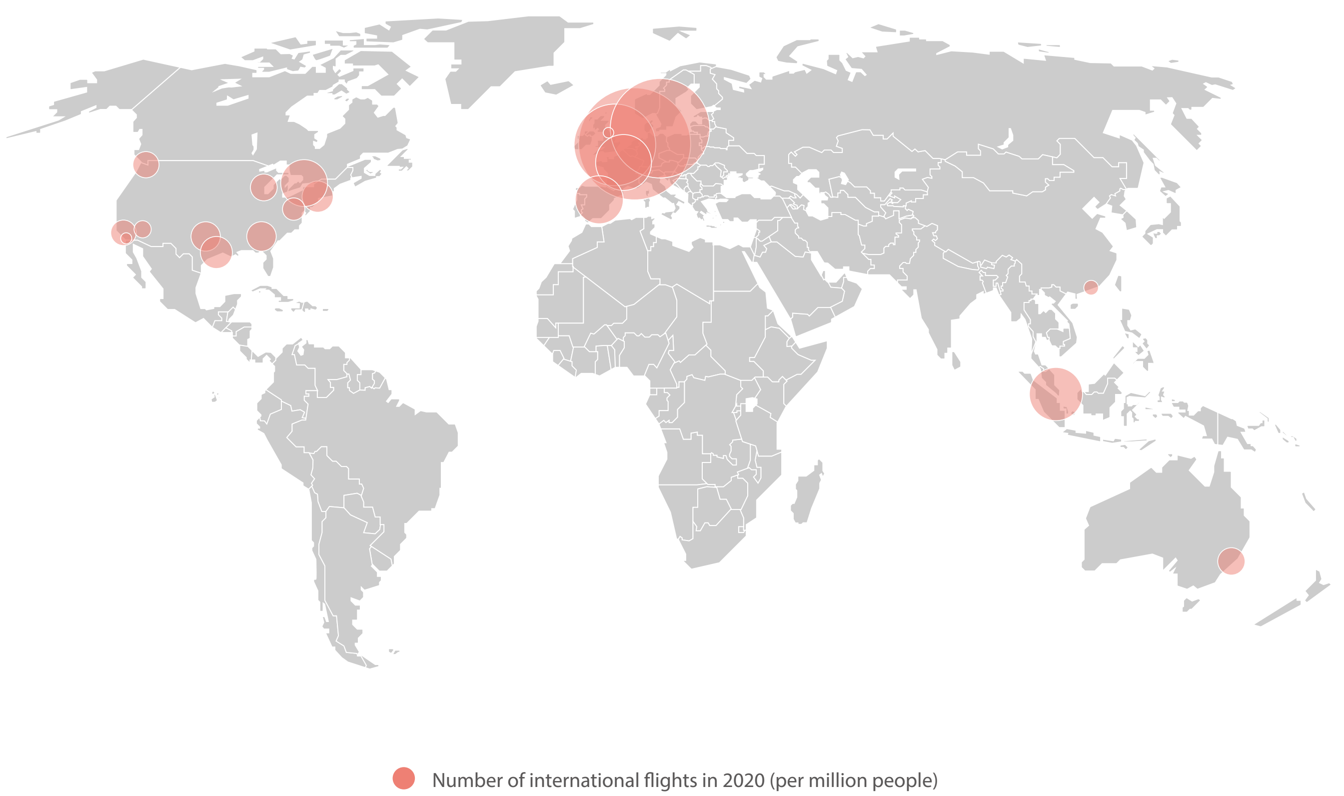
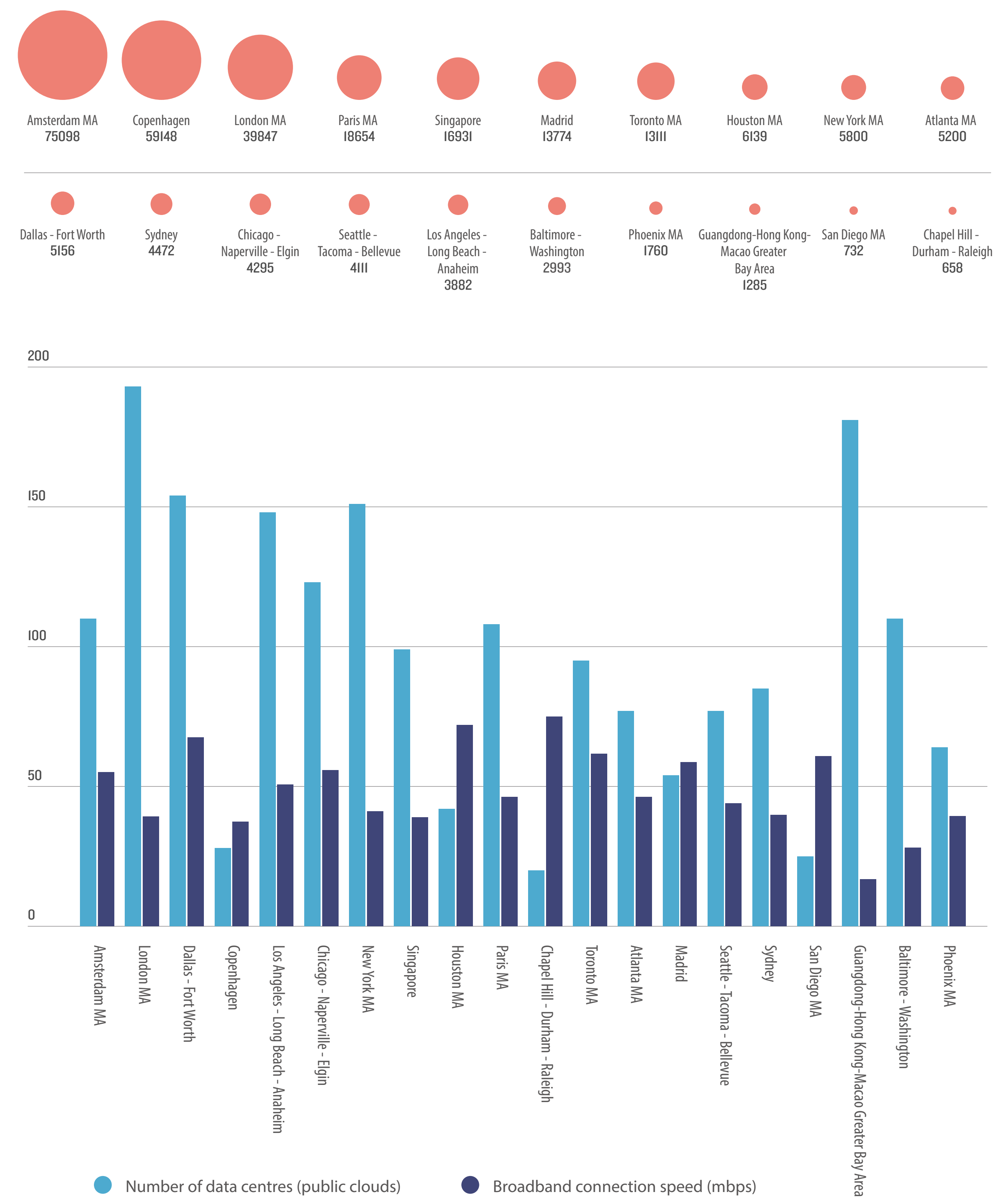


**FIGURE 23**

**Number of international flights (per million people), broadband connection speed, and number 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 entrepreneurship. The GIHI2021 uses the number of data centres (public clouds), the speed of broadband connections, and the number of international flights (per million people) to measure the level of public services in cities/metropolitan areas. The Online Service Index (OSI), released by the United Nations Department of Economic and Social Affairs, is included as a measure of e-governance level. In the digital era, data has become a production factor for innovation, and data centres have become the infrastructure for big data collaboration networks and help guarantee data safety (Shi Shuhong, 2018).

Data storage capacity and the speed of broadband connections 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 Amsterdam MA, London MA, Dallas-Fort Worth, Copenhagen, and Los Angeles-Long Beach-Anaheim.

Amsterdam MA has a well-developed air transportation system, which operates frequently, even during the COVID-19 pandemic. As a result, the number of international flights (per million people), as an individual indicator, improves Amsterdam MA's scores on public services. The GIHI 2021 looks at the number of data centres (public clouds) at the city level. London MA and the Greater Bay Area lead the world's major cities in data services, with 193 and 181 data centres, respectively. Chapel Hill-Durham-Raleigh leads in broadband connection speed at 74.9 mbps. Seoul MA ranks first in e-governance level, supported by Smart Seoul MA 2015, a strategy that attaches great importance to building smart cities and boosting the infrastructure and policy planning of 5G and the Internet of Things (IoT).

Figure 23 shows the number of international flights in 2020 (per million people), broadband connection speed, and the number of data centres (public clouds) for the top 20 cities/metropolitan areas in public services.

## 5.5
### Innovation culture

Innovation culture is a condition required for a city's long-term prosperity. The GIHI2021 measures a city's innovation culture by examining the professional talent inflow, residents' average years of schooling, the number of international conferences as well as the number of public museums and libraries. The professional talent inflow and residents' average years of schooling are newly added level-3 indicators in the GIHI2021. Human capital determines a country's ability to innovate and facilitates the dissemination of technologies (Nelson & Phelps, 1966). The average year of schooling reflects the average human capital of a society (Cai Fang & Wang Dewen, 2002), and the professional talent inflow defines a city's vitality and cultural attraction.

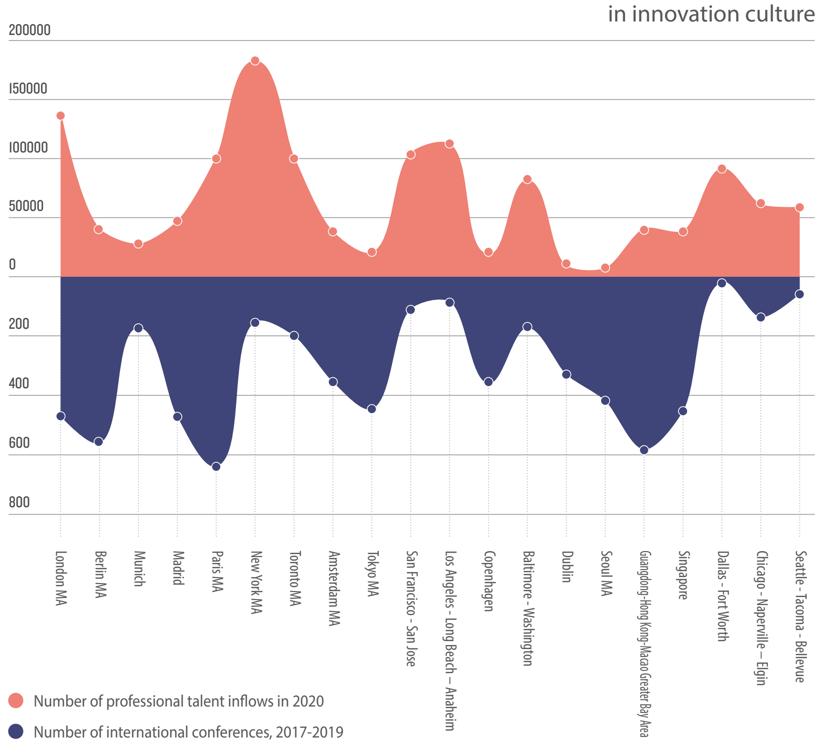
The top five cities/metropolitan areas in innovation culture are all in UK/Europe: London MA, Berlin MA, Munich, Madrid, and Paris MA.

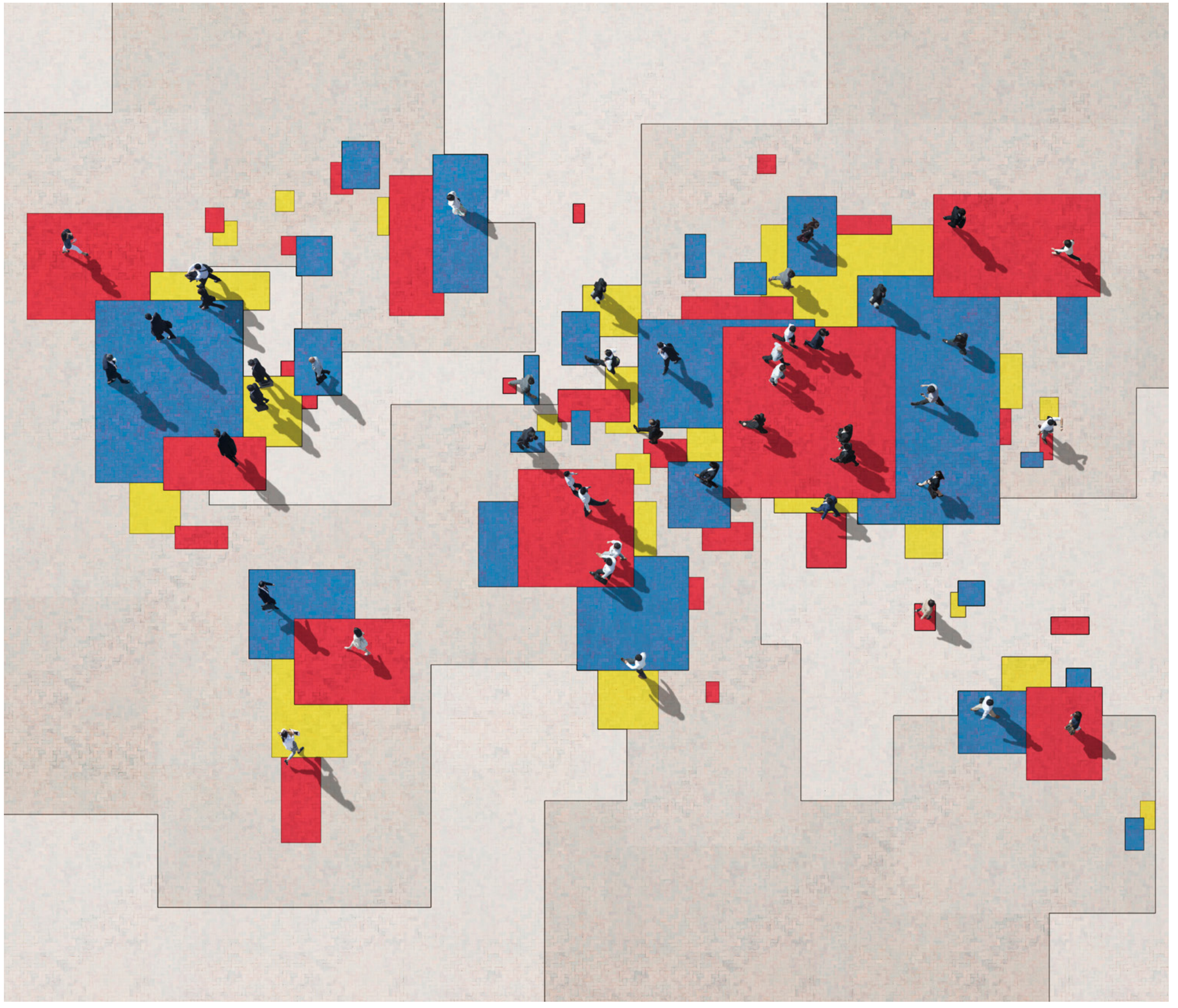
Figure 24 shows the numbers of professional talent inflows and international conferences for the top 20 cities/metropolitan areas in innovation culture. Specifically, international metropolises in UK/Europe and the United States, such as New York MA and London MA, are more appealing to talents, whereas talent inflow into cities/metropolitan areas in the Asia-Pacific region are much lower. In Germany, the United Kingdom, and the United States, residents' average years of schooling remains above 13.58 years, whereas public education in China still needs to be improved. Munich has a large number of public museums and libraries and stands out for its high scores in urban culture. As an international exchange centre, Paris MA leads in the number of international conferences, followed by the Greater Bay Area, Berlin MA, Madrid, and London MA.

Overall, European cities/metropolitan areas perform particularly well in innovation culture for their cultural heritage and attractions. Asian cities/metropolitan areas need to further improve in this regard.

FIGURE 24

**Numbers of professional talent inflows and of international conferences**
for the GIHI top 20 cities/metropolitan areas in innovation culture



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# 6 Summary and outlook for the future

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The public health crisis caused by the COVID-19 pandemic has posed challenges to the global economy, resulting in a sharp decline in the global greenfield investment and a drastic reduction in international flights. It has also dampened talent mobility, international exchange, and cooperation. However, there is still great potential for cutting-edge technologies and innovation. High-tech industries characterized by digitalization can trailblaze new opportunities for future growth.

Compared with the GIHI2020, more UK/European and Asian cities have demonstrated their advantages. In overall ranking, San Francisco-San Jose and New York MA still dominate the top two positions, whereas London MA replaces Boston MA as third, and Paris MA and Guangdong-Hong Kong-Macao Greater Bay Area enter the top 10. In research innovation, New York MA, Boston MA, and San Francisco-San Jose remain in the top three, while Copenhagen and Guangdong-Hong Kong-Macao Greater Bay Area surpass Paris MA and Tokyo MA and enter the top 10. In innovation ecosystem, London MA tops the list, beating San Francisco-San Jose and New York MA; meanwhile, Beijing, Paris MA, Munich, the Greater Bay Area, and Shanghai break into the top 10 for the first time. The following conclusions are drawn from the GIHI2021 ranking:

**1. The global innovation landscape is evolving.**

At the forefront of knowledge creation, cities from the United States have the highest concentration of research activities and overwhelming advantages in science and technology human resources, knowledge creation, and high-tech manufacturing. The UK and Europe have a well-established innovation environment, giving their cities an edge in innovation ecosystem. Asian cities demonstrate vitality and great potential in innovation economy. As investment in scientific and technological innovation continues to grow, the global innovation network has had significant changes: R&D and innovation activities are moving towards emerging economies, especially Asian cities. Digital technologies such as AI are booming, which help to reshape the global division of labour and innovation landscape.

Asian cities are catching up in technology and Chinese cities are emerging as new GIHs. Asian economies continue to gain momentum. Five cities/metropolitan areas have entered the top 20 in overall ranking and eight cities/metropolitan areas are among the top 20 in innovation economy. Many excellent start-ups have sprung up, releasing their innovative potential. Beijing, the Greater Bay Area, and Shanghai rank fourth, seventh, and fourteenth, respectively, in overall ranking. Specifically, Beijing has maintained its edge in innovation economy while making significant progress in innovation research and innovation ecosystem. The Greater Bay Area performs surprisingly well for a debut GIH, particularly in innovation ecosystem and innovation economy. Other Chinese cities with active performance in innovation economy, such as Nanjing, Hangzhou, Wuhan, Hefei, and Chengdu, have become new GIHs.

**2. In development paths, GIHs show varied patterns and positioning in innovation development and are getting increasingly globalized.**

Similar to the results of the GIHI2020, GIHs have varied development patterns and paths. San Francisco-San Jose and New York MA have balanced and complementary performance on three level-1 indicators, while other cities/metropolitan areas stand out on different indicators. For instance, Boston MA and Baltimore-Washington perform exceptionally well in research innovation. Tokyo MA shows strong performance in innovation economy for the number of listed enterprises in the new-economy sectors and the technological advantages of its innovative companies. London MA does strikingly well in innovation ecosystem. GIHs have found their own unique development strategies and paths based on their resources and characteristics.

**3. In research innovation, gathering top science and technology talents and enhancing the level of knowledge creation are key of laying a strong foundation for GIHs.**

Fifteen out of the top 20 cities/metropolitan areas in the overall ranking have entered the top 20 in research innovation, with 12 among the top 20 in knowledge creation. The United States cities/metropolitan areas boast 198 top award winners, with an average score of 90.12 for knowledge creation, much higher than that of 78.21 for all sample cities; the proportion of papers cited by patents, policies, and clinical trials reach 2.83%, which is nearly 1% higher than the global average of 1.88%. Therefore, excellent performance in knowledge creation and the concentration of leading talents has helped the United States become a scientific powerhouse. Against the backdrop of a new round of revolutions in science, technology, and industry, it is important for GIHs to focus on cutting-edge technologies, to be driven by the market, to gather top science talents, and to improve the capability of knowledge creation.

**4. In innovation economy, the global digital economy is booming. China, Japan, the United States, and South Korea enjoy respective advantages in enabling technologies, and Chinese innovative enterprises are particularly active.**

The digital economy is booming despite the COVID-19 pandemic. The pandemic quashed many economic and social activities for a significant time, resulting in a reduced flow of talents and dramatic reductions in international flights, venture capital, and private equity, which has imposed great challenges on enterprises. Gross operating revenue declined by 2.25% in 2020 from the previous year, but the industries of information technology and software services have managed to maintain a growth rate of 7% and 6.5% in spite of the pandemic. A growth spurt has been seen in the pharmaceutical and chemical industries, data services, and in digital industries such as digital healthcare and telecommuting.

China, United States, Japan, and South Korea all have their respective strengths in enabling technologies in AI and IC . Comparisons of the number of valid patents between these countries have found that China stands out in innovation in AI technology. Seven Chinese cities/metropolitan areas, except for Shanghai and Suzhou, have a larger number of valid patents in AI than in IC. Cities/metropolitan areas in the United States, Japan, South Korea lead in IC technology innovation and boast more patents in IC than in AI, with half of the major manufacturers of semiconductor chips being located in Tokyo MA, San Francisco-San Jose, and Seoul MA.

In innovative enterprises and emerging industries, Chinese cities are gaining momentum in the new-economy sectors. The number of Chinese cities in the top 2,500 R&D investors indicates their active performances. Beijing, the Greater Bay Area, and Shanghai enter the top 10 in innovative enterprises, with 23 unicorn companies being drawn from Hangzhou, surpassing the sum of those (19 in total) in cities/metropolitan areas such as Tokyo MA, Paris MA and Munich. This shows that Chinese cities have a stronger advantage in emerging digital areas as AI, and are rising rapidly.

**5. Innovation ecosystem lays a vital foundation for GIHs' sustainable competitiveness.**

Scientific and technological innovation is fraught with uncertainties. A healthy innovation ecosystem provides external conditions required for the full flow of innovation subjects and elements, and is also crucial to providing new impetus for future science and technology and maintaining sustainable competitiveness. The top 20 cities/metropolitan areas in overall ranking also score highly in innovation ecosystem, especially UK/European cities like London MA, Paris MA, Munich and Amsterdam MA, whose citizens have higher levels of education on average, more professional inflows, and better public services.

In openness and collaboration, the international cooperation network continues to expand. Asian cities play an increasingly important role in the global collaboration networks of patents and papers.

With increasing applications for digital technologies and a growing demand for e-governance platforms, the broadband connection speed has become an essential factor in building innovation ecosystem in the digital era. The demand for broadband connections has soared during the pandemic, making it an area of particular importance. In 2020, Asian cities/metropolitan areas made a great leap on this indicator, with Chinese cities, such as Beijing and Shanghai, tripling their average broadband connection speed from 2019.

GIHI2021 is based on three dimensions: research innovation, the innovation economy, and the innovation ecosystem. The selection of measurements takes into account a variety of factors, including tradition and future prospects, science and technology, economy, performance, and environment. The goal is to identify important factors that affect the performance of GIHs, and the critical forces 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-making units across the world to read the report and make suggestions or comments.

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# Appendix

**Appendix I: Adjustments to the GIHI Indicators**

We have made some adjustments to the index system based on feedback gathered from both the media and the general public after the release of GIHI2020. These changes will help us adapt to new trends and advice from experts, as well as taking into account such factors as stability and authority of the index system, and availability and compatibility of index data. Based on the research, three level-1 indicators known as research innovation, innovation economy, and innovation ecosystem and 12 level-2 indicators remain unchanged; 14 of the original 31 level-3 indicators are optimized. Meanwhile, 'E-governance level' is added as a level-3 indicator to better capture the development of GIHs. The specific descriptions are as follows:

| GIHI2020 | Adjustment | GIHI2021 | Descriptions |
|---|---|---|---|
| 01. Number of R&D personnel (per million people) | Indicator replacement | 01. Number of active researchers (per million people) | GIHI2020 used country-level data from the World Development Indicators 2018 of the World Bank, which fails to accurately reflect the size of the science and technology workforce at the city level, and is yet to be updated. The indicator is replaced with the number of active researchers (per million people) this year, which offers city-level data. |
| 02. Number of highly cited scientists | Statistical method | 02. Proportion of highly cited scientists | Proportion of highly cited scientists could reflect the number and competence of scientists. |
| 03. Number of winners of top scientific awards | Statistical method | 03.Number of winners of top scientific awards | The indicator only included cities where winners work full-time last year, whereas cities where winners work part-time are also included this year to reflect the flow of talents. |
| 07. Number of top 500 supercomputer centres | Statistical method | 07. Number of top 500 supercomputers | Last year, multiple supercomputers located in the same institute were counted as one supercomputer centre. This year, the indicator measures the number of supercomputers. |
| 10. Total number of valid patents (per million people) | Statistical connotation | 10. Total number of valid patents (per million people) | The scope of the indicator has been expanded to include integrated circuit (IC) manufacturing instead of just artificial intelligence (AI) as in GIHI2020. |
| 11. Number of patent cooperation treaty (PCT) patents | Statistical connotation | 11. Number of patent cooperation treaty (PCT) patents | The scope of the indicator has been expanded to include IC manufacturing instead of just AI last year. |
| 12. Number of top 100 innovative enterprises | Indicator replacement | 12.Number of the top 2,500 companies in R&D investment | GIHI2020 used city-level data from the Derwent Top 100 Global Innovators published by Clarivate last year, which has a limited coverage and is less accurate and comprehensive due to the majority weighting being on the number of patents. The indicator was replaced with the number of the top 2,500 companies in R&D investment, which expands the coverage and could better measure the innovation activities of enterprises. |
| 13. Valuation of unicorn companies | Data source and statistical method | 13. Number of unicorn enterprises | GIHI2020 used data from the Global Unicorn Top 500 Report 2019 published by Renmin University, which hasn't been updated this year. Given the instability of the valuation of unicorn companies that tend to fluctuate with the market, GIHI2021 have replaced this indicator with the number of unicorn enterprises. |
| 19. Patent collaboration network centrality | Statistical connotation | 19.Patent collaboration network centrality | The scope of the indicator has been expanded to include IC manufacturing instead of just AI as in GIHI2020. |
| 24. Ease of business environment | Indicator replacement | 24. Number of registered lawyers (per million people) | The indicator used the country-level data from the World Bank's *Doing Business* report last year, which hasn't been updated for 2020. The indicator has been replaced with the number of registered lawyers (per million people) to gather city-level data. |
| 25. Number of data centres (public clouds) | Statistical connotation | 25. Number of data centres (public clouds) | The indicator used last year to measure the number of national-level data centres has been replaced with the number of city-level data centres for higher accuracy. |
| | Newly-added indicator | 28. E-governance level | The indicator of E-governance level has been added to reflect the city's digital governance. |
| 28. Talent attraction | Indicator replacement | 29. Professional talent inflow | The indicator used the country-level data from the IMD World Talent Ranking last year, which was unable to reflect a city's attraction to talents. This year, we've used data from the LinkedIn platform to examine the flow of talents. |
| 29. Entrepreneurial spirit | Indicator replacement | 30. Residents' average years of schooling | The indicator used country-level data of 'Entrepreneurial culture' from the WEF (World Economic Forum) Global Competitiveness Index last year, which was not available in the 2020 report. It has been replaced with the residents' average years of schooling to gather city-level data. |
| 30. Degree of internationalization of culture-related industries | Indicator replacement | 31. Number of international conferences | Last year, the indicator examined a city's performance on manufacturing industries. This year, it has been replaced with the number of international conferences to better represent a city's cultural attraction and international exchanges. |

## Appendix II: GIHI indicator definitions and data sources

### A. Research innovation

**01. Number of active researchers (per million people)**

Definition: the number of researchers with publications between 2016 and 2020, per million people, in the assessed city. If a researcher had more than one publication during this period, they will be counted only once.
Data sources: Digital Science - Dimensions

**02. Proportion of highly cited scientists**

Definition: the proportion of highly cited scientists out of the number of active researchers in the assessed city between 2015 and 2019, 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, they 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 the winner works 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 July 6, 2021.

**04. Top 200 world-class universities**

Definition: This study uses the number of top 200 universities in the ARWU World University Rankings 2020 as an indicator of a city's top universities.
Data sources: Academic Ranking of World Universities 2020 (https://www.shanghairanking.cn/rankings/arwu/2020)

**05. Top 200 world-class research institutions**

Definition: the number of top 200 scientific institutions in scientific publications according to the Nature Index 2020. 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. Therefore, 208 scientific institutions are included. 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, i.e., research installations built for major science and technology goals in specific disciplinary fields; and public experimental platforms, i.e., 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: planning of large scientific facilities of different countries, the official websites of the main management agencies of the facilities and relevant research literature among other sources. Finally, the data were confirmed and supplemented by experts from various faculties and 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 computers.
Data source: Global Top 500 Supercomputers in November 2020 (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 2019. 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 2016 and 2020 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. Stock of active 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 newly added field of integrated circuits (ICs). The strategies for patent search have been established through multiple rounds of discussions with experts in AI and IC, 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 1956-2020 for AI and 1965-2020 for IC, respectively. By removing duplicate data, 249,701 patents for AI applications and 522,097 patents for IC 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, 137,488 patents in AI and 242,766 patents in IC have been obtained to analyze 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 (1965-2020) and AI (1956-2020). 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 top 2,500 companies in R&D investment**

Definition: the top 2,500 companies in R&D investment in 2019 used in this study were published by the EU Industrial R&D Investment Scoreboard. Published annually by the Joint Research Centre and DG for Research and Innovation of European Commission since 2004, the Scoreboard collects and studies economic and financial data of companies that invest largest sums into R&D worldwide, exploring the investment scale and features of various companies, industries and economies.
Data sources: The 2020 EU industrial R&D investment scoreboard

**13. Number of unicorn enterprises**

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 (by CB Insights) and 2020 Hurun Global Unicorn List. By removing duplicated companies, 924 start-ups are left. After making corrections on the information about cities where 34 companies are located, a total of 788 companies 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 May 16th, 2021; 2020 Hurun Global Unicorn List (https://www.hurun.net/en-us/rank/hsrankdetails?num=WE53FEER)

**14. Market capitalization of high-tech manufacturing enterprises**

Definition: This study evaluates innovative companies by calculating the market capitalization of high-tech manufacturing companies in the 2021 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 indexes: 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 chemicals, drugs and biotechnology, and health care equipment and services enterprises. The electronic information enterprises include companies engaged in IT software and services, semiconductors, technology hardware and equipment, and telecommunications services sectors. High-end manufacturing companies include those engaged in aerospace and defence, materials and transportation business.
Data sources: Forbes China (https://www.forbeschina.com/lists/1762)

**15. Operating income 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 2020 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 Telecommunications services | 501010 | Diversified information services |
| | | 501020 | Radio telecommunication services |
| 35 Health care | 3510 Health care equipment and services | 351010 | Health care equipment and supplies |
| | | 351020 | Health care providers and services |
| | | 351030 | Health care technology |
| | 3520 Pharmaceuticals, Biotechnology and Life Sciences | 352010 | Biotechnology |
| | | 352020 | Pharmaceuticals |
| | | 352030 | Life science tools and services |

Data sources: Osiris, a library of publicly listed companies worldwide

**16. GDP growth rate**
Definition: this study uses GDP growth rate in 2019 (using 2015 as the real GDP base) for each city after evaluating the level of purchasing power. Due to unavailable information from 2019, data from 2018 is used for Munich, Dublin, Copenhagen, Seoul MA, Tokyo MA, Kyoto-Osaka-Kobe, Nagoya MA, and São Paulo, and 2017 data is used for Toronto MA.
Data sources: (1) GDP data are from OECD and statistics offices of countries and cities; (2) Purchasing power parities [PPP conversion factor, GDP (LCU per international $)] 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 working age population. The GDP uses in this study is the GDP-PPP data for 2019 (based on 2015). The size of workforce refers to the population aged from 15 to 64 in each city. When no data was directly available, some were calculated based on demographic structure of the country and state/province that the city is located and the total population of the city. For example, labour force data for Jakarta and Bangkok were calculated from the demographic structure of Indonesia and Thailand; those of Bengaluru, Central National Capital Region Delhi, Mumbai MA and São Paulo were from demographic structure of Karnataka state, Delhi, Maharashtra state and São Paulo. As data from 2019 is unavailable for the following cities/MAs, 2018 data has been used for Munich, Dublin, Copenhagen, Seoul MA, Tokyo MA, Kyoto-Osaka-Kobe, Nagoya MA, and São Paulo and 2017 data has been used for Toronto MA.
Data source: workforce data are from department 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 2020 intercity paper publication collaboration matrix of 50 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 $\lambda$. 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 cooperation network centrality**
Definition: patent cooperation 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, to examine the patent cooperation network centrality of cities, and to reflect the range of cooperation of each GIH. It is calculated as shown below:

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

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 (2020). 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, which indicates the spill-over 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 2020, 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 2020. 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 2019. 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 country, state, or province where the city belongs. For Madrid, Copenhagen, Kyoto-Osaka-Kobe, Tel Aviv, Bangkok, Dubai, Abu Dhabi, Jakarta, the country-level data are used instead; for Bengaluru, Central National Capital Region Delhi, we use Karnataka and Delhi data instead.
Data source: lawyer associations of countries and cities; ministries of justice of countries.



Appendix

**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 as an indicator of the city's digital economy development.
Data sources: Cloudscene (https://cloudscene.com/), data as of June 17th, 2021

**26. Broadband connection speed**
Definition: the maximum theoretical rate that can be achieved by a network broadband technology, typically including upload and download rates (Mbps). This study uses the average upload and download rates.
Data sources: https://testmy.net/list, with speed measured on May 22th, 2021.

**27. Number of international flights (per million people)**
Definition: the number of all direct flights originating and terminating in the city in 2020.
Data sources: Official Aviation Guide (OAG), provider of aviation intelligence (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 a list 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**
Definition: In this study, the professional talent inflow into the assessed city, as recorded on LinkedIn, is used to measure the attraction of the city/metropolitan areas to talents. For Dublin, Seoul MA, Dubai and Abu Dhabi, due to missing data at the city level, the indicator is estimated using the proportion of citizens in the country and the talent inflow into that country.
Data sources: LinkedIn Talent Insights (https://business.linkedin.com/talent-solutions/talent-insights). Based on integrated information submitted by LinkedIn members voluntarily, the accuracy of data is not committed by LinkedIn. Data as of July 20th, 2021.

**30. Residents' average years of schooling**
Definition: the average years of schooling for population aged over 25 in assessed city. The average years of schooling in 2019 from the Subnational Human Development Index (HDI) published by the United Nations Development Programme (UNDP) are used to measure a city's education quality and human resource.
Data sources: Subnational HDI, UNDP

**31. Number of international conferences**
Definition: number of international conferences held from 2017 to 2019 in the assessed city. Relevant data were collected from annual reports of national conferences and associations. The types of conferences include those organized by medical sector, research institutes, trade organization, professionals and social organizations. About 23,000 conferences are included for each year. To be counted, the conference must: 1) be organized regularly (one-off events are not counted); 2) be held in different countries, and; 3) attended by at least 50 participants.
Data sources: International Congress and Convention Association, ICCA (https://www.iccaworld.org/)

**32. 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 2020 was 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.

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

$y_{ij}^{s}$ 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.

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=32, indicating the number of level-3 indicators; i=1 means starting from the first level-3 indicator.

### Appendix IV: The GIH selection process

In this report, cities/metropolitan areas were selected via the following steps: select the top 100 science cities in the Nature Index 2020 Science Cities, then cross-reference those cities with the Global Urban Competitiveness Report 2020-2021 by the Chinese Academy of Social Sciences, the 2020 Global Cities Index by Kearney, the Global Power City Index by the Mori Memorial Foundation, and the WIPO Global Innovation Index, and select 137 candidate cities, after excluding cities that have a population of less than 1 million.

As a precautionary measure, two schemes were used for secondary selection and cross-referencing for the 137 candidate cities to form a primary list. The two schemes are as follows:

Scheme 1: Balanced Ranking. We used 12 key indicators, namely the number of winners of top scientific awards, number of top 200 world-class universities, number of top 500 supercomputer centres, number of Derwent Top 100 Global Innovators, number of 2500 companies in EU Industrial R&D Investment Scoreboard, FDI, OFDI, Venture capital investment (VC), Private equity (PE), Nature Index, total GDP and GDP growth. By collecting and cleaning 12 groups of data of 137 candidate cities, we selected the cities that rank in the top 45 for any five indicators, which resulted in a shortlist of 44 cities.

Scheme 2: Ranking by Categories. First, the total GDP, GDP per capita and GDP growth rate are selected to represent the economic performance; Second, Nature Index, the number of top science and technology award winners and number of top 200 world-class universities are selected to represent scientific research performance; third, FDI, OFDI, VC and PE are selected to represent a city's ability to attract capital and the spill-over effects from that capital. Any city that made it to the top 20 on two indicators from one category was selected, which resulted in a shortlist of 36 cities.

Comparing the two schemes, 30 duplicated cities were removed from the shortlists. The final list consists of 50 cities/metropolitan areas, covering 225 administrative cities, from 22 countries in 5 continents.





### Appendix V: 50 evaluated cities/metropolitan areas

| No. | City/metropolitan area | Administrative division | Country |
|---|---|---|---|
| 1 | 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 |
| 2 | Boston MA | Lowell | United States |
| | | Cambridge | United States |
| | | Boston | United States |
| 3 | San Francisco - San Jose | Berkeley | United States |
| | | Concord | United States |
| | | Antioch | United States |
| | | San Jose | United States |
| | | Fremont | United States |
| | | Richmond | United States |
| | | Santa Rosa | United States |
| | | Oakland | United States |
| | | Hayward | United States |
| | | San Mateo | United States |
| | | Vallejo | United States |
| | | Santa Clara | United States |
| | | San Francisco | United States |
| | | Sunnyvale | United States |
| 4 | Baltimore – Washington | Baltimore | United States |
| | | Washington, D.C. | United States |
| | | Arlington | United States |
| | | Alexandria | United States |
| 5 | 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 |
| 6 | Chicago - Naperville - Elgin | Naperville | United States |
| | | Chicago | United States |
| | | Aurora | United States |
| 7 | San Diego MA | Vista | United States |
| | | San Diego | United States |
| | | Escondido | United States |
| | | El Cajon | United States |
| | | Chula Vista | United States |
| | | Carlsbad | United States |

# Appendix

| | | | |
|---|---|---|---|
| 8 | Houston MA | Houston | United States |
| | | Pearland | United States |
| | | Pasadena | United States |
| 9 | Atlanta MA | Sandy Springs | United States |
| | | Atlanta | United States |
| | | Athens | United States |
| 10 | Seattle - Tacoma - Bellevue | Tacoma | United States |
| | | Seattle | United States |
| | | Renton | United States |
| | | Kent | United States |
| | | Everett | United States |
| | | Bellevue | United States |
| 11 | Austin | Austin | United States |
| 12 | 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 |
| 13 | Pittsburgh | Pittsburgh | United States |
| 14 | Phoenix MA | Phoenix | United States |
| | | Mesa | United States |
| | | Chandler | United States |
| | | Gilbert | United States |
| | | Glendale | United States |
| | | Scottsdale | United States |
| | | Tempe | United States |
| 15 | Chapel Hill-Durham-Raleigh | Chapel Hill | United States |
| | | Durham | United States |
| | | Raleigh | United States |
| 16 | Toronto MA | Toronto | Canada |
| | | Oshawa | Canada |
| | | Vaughan | Canada |
| | | Richmond Hill | Canada |
| | | Burlington | Canada |
| | | Markham | Canada |
| | | Brampton | Canada |
| | | Mississauga | Canada |
| | | Oakville | Canada |
| 17 | Paris MA | Paris | France |
| | | Cergy | France |
| | | Pontoise | France |
| | | Saint-Quentin-en-Yvelines | France |
| | | Boulogne-Billancourt | France |
| 18 | London MA | London | UK |
| | | Watford | UK |
| | | Croydon | UK |
| | | Enfield Town | UK |
| 19 | Berlin MA | Berlin | Germany |
| | | Potsdam | Germany |
| 20 | Munich | Munich | Germany |
| 21 | Madrid | Madrid | Spain |
| 22 | Stockholm | Stockholm | The Netherlands |



Appendix

| | | | |
|---|---|---|---|
| 23 | Amsterdam MA | Amsterdam | The Netherlands |
| | | Hoofddorp | The Netherlands |
| | | Haarlem | The Netherlands |
| | | Almere Stad | The Netherlands |
| 24 | Dublin | Dublin | Ireland |
| 25 | Copenhagen | Copenhagen | Denmark |
| 26 | Beijing | Beijing | China |
| 27 | 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 |
| 28 | Shanghai | Shanghai | China |
| 29 | Wuhan | Wuhan | China |
| 30 | Hefei | Hefei | China |
| 31 | Hangzhou | Hangzhou | China |
| 32 | Suzhou | Suzhou | China |
| 33 | Chengdu | Chengdu | China |
| 34 | Nanjing | Nanjing | China |
| 35 | Tokyo MA | Tokyo | Japan |
| | | Asaka | Japan |
| | | Zama | Japan |
| | | Kamakura | Japan |
| | | Chigasaki | Japan |
| | | Ôme | 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 |

# Appendix

| | | | |
|---|---|---|---|
| 35 | Tokyo MA | Isehara | Japan |
| | | Kisarazu | Japan |
| | | Hiratsuka | Japan |
| | | Hachiōji | Japan |
| | | Honchō | Japan |
| 36 | Kyoto - Osaka - Kobe | Kyoto | Japan |
| | | Osaka | Japan |
| | | Kobe | Japan |
| 37 | 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 |
| 38 | Bengaluru | Bengaluru | India |
| 39 | Central National Capital Region Delhi MA | Delhi | India |
| | | Faridabad | India |
| | | Ghāziābād | India |
| | | New Delhi | India |
| | | Noida | India |
| | | Greater Noida | India |
| | | Gurgaon | India |
| 40 | Mumbai MA | Mumbai | India |
| | | Navi Mumbai | India |
| 41 | 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 |
| 42 | Singapore | Singapore | Singapore |
| 43 | Tel Aviv | Tel Aviv | Israel |
| 44 | Istanbul | Istanbul | Turkey |
| 45 | Bangkok | Bangkok | Thailand |
| 46 | Dubai | Dubai | United Arab Emirates |
| 47 | Abu Dhabi | Abu Dhabi | United Arab Emirates |
| 48 | Jakarta | Jakarta | Indonesia |
| 49 | São Paulo | São Paulo | Brazil |
| 50 | Sydney | Sydney | Australia |

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

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