Global Innovation Hubs Index 2020

- Research innovation
- Innovation economy
- Innovation ecosystem

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Xu Heping	Research Fellow, Information Research Unit, General Office of the Ministry of Science and Technology
Xuan Zhaohui	Research Fellow, Chinese Academy of Science and Technology for Development

Research team:

Principle Investigator: Chen Ling
Associate Professor, School of Public Policy and Management, Tsinghua University
Director, Center for Industrial Development and Environmental Governance, Tsinghua University
Adjunct Research Fellow, Institute for National Governance and Global Governance, Tsinghua University

Team Members:

Beijing Academy of Science and Technology	Li Fang, Wang Yanhui
School of Public Policy and Management, Tsinghua University	Jiang Lidan, Li Xin, Sun Jun, Kong Wenhao, Wang Xiaofei, Buhe Chulu, Fu Yuhang

Research Support:

Nature Research	David Swinbanks
Digital Science	Daniel W. Hook, Simon J. Porter, Juergen Wastl, Helene Draux

Data Analysis:
Huang Ying, Zhang Lin, Li Ting, Peng Yujie, Zou Fang, Li Yashan, Guo Haotian, Li Chenyang, Li Hongquan, Li Tingting, Liu Yifan, Ren Meitong, Yu Chunru

Content Editor:
Zhou Yingying

Layout & Design:
Lu Yefei, Zhao Xinwu

Project Coordination:
Cen Lichao, Yan Zijun, Bai Jie, Wang Xiaoxia

Executive summary

Global innovation hubs are defined as cities or metropolitan areas that can lead the flow of global innovation elements and influence the efficiency of resource allocation, drawing on their unique advantages in science and technology innovation. In technological and industrial competitions, they emerge as global cities that integrate research innovation, an innovation economy and a supportive ecosystem for innovation.

The global community faces common challenges. Climate change, ecological degradation, infectious diseases and potential risks brought by emerging technologies have challenged the stability of human development. The solution lies in significant breakthroughs and a paradigm shift in science. The fourth industrial revolution, triggered by the development of digital technologies, requires more efficient innovation models. Moreover, the nature of innovation-driven development demands updating, cultivating and reshaping the innovation ecosystem. In meeting these needs, global science and technology innovation hubs play a vital role; they continually produce new knowledge and ideas, drive economic development, and facilitate the evolution of the innovation ecosystem. A worldwide assessment of these global innovation hubs is, therefore, of great relevance.

The Global Innovation Hubs Index (GIHI), developed by the Center for Industrial Development and Environmental Governance at Tsinghua University, with support from Nature Research, aims to set up an index system, based on scientific methods and objective data, to evaluate the innovation capacities and development potentials of global science and technology innovation hubs, providing a reference for policy-makers and practitioners.

The GIHI primarily assesses global innovation hubs in three dimensions: research innovation, innovation economy, and innovation ecosystem.

First, an innovation hub is a centre with extensive research activities and research networks. In the GIHI, the dimension of research innovation examines the scientific and technological resources of its people, research institutions, research infrastructure, and knowledge creation of the city or metropolitan area.

Second, a global innovation hub, with vibrant innovation activities, typically has a booming innovation economy. This dimension includes metrics on the region's technological innovation capacity, high-tech enterprises, emerging industries, and economic growth.

Third, the development of a global innovation hub benefits from a supportive innovation ecosystem. This dimension focuses on the openness and collaboration networks of a region, its support for entrepreneurship, public service infrastructure, and the innovation culture.

Seeking to be scientific, objective, independent and impartial, the GIHI system has its distinct features compared with other index systems in the world for innovation evaluation. It makes use of metrics, such as network centrality to measure the relative potential and influence of a city in a global network. It uses micro-level data with fine granularity to measure a city's research output, patents, foreign investment, high-tech companies, as well as the international flight network. It also adopts metrics constructed by international organizations based on large surveys to measure some system or culture-related factors, like business environment, talent attraction, and entrepreneurship, to add a subjective perspective. Lastly, it focuses on cutting-edge technologies and emerging economic sectors, such as artificial intelligence, information and communication technologies, and biomedicine, to demonstrate the development potential of a city.

Given the tight timeline and limitations for data collection, this is just a beta version, and the ranking provided by this report is preliminary. The indicators and data analysis in the report will be updated and improved in future.

For now, the report selected and assessed 30 cities or metropolitan areas. The results show that:

For the overall GIHI ranking, the top ten cities/metropolitan areas are: San Francisco-San Jose, New York, Boston-Cambridge-Newton, Tokyo, Beijing, London, Seattle-Tacoma-Bellevue, Los Angeles-Long Beach-Anaheim, Baltimore-Washington and Chapel Hill-Durham-Raleigh.

The GIHI top 10 cities/metropolitan areas in research innovation are: New York, Boston-Cambridge-Newton, San Francisco-San Jose, London, Baltimore-Washington, Paris, Chapel Hill-Durham-Raleigh, Beijing, Los Angeles-Long Beach-Anaheim and Tokyo.

The GIHI top 10 cities/metropolitan areas in innovation economy are: San Francisco-San Jose, Tokyo, Beijing, Shenzhen, Shanghai, Tel Aviv, Seoul, Kyoto-Osaka-Kobe, Seattle-Tacoma-Bellevue and Boston-Cambridge-Newton.

The GIHI top 10 cities/metropolitan areas in innovation ecosystem are: San Francisco-San Jose, New York, London, Boston-Cambridge-Newton, Chicago-Naperville-Elgin, Los Angeles-Long Beach-Anaheim, Amsterdam, Singapore, Seattle-Tacoma-Bellevue and Philadelphia.

Further analyses show that:

The global innovation cities have varied development paths and positioning. While few cities, like San Francisco-San Jose and Boston-Cambridge-Newton, have balanced performance in all dimensions, most follow divergent paths in the development of research innovation, innovation economy and ecosystem. It suggests that cities/metropolitan areas have their distinct advantages and their development may be unbalanced.

Big international metropolises and smaller cities with their distinctive features are complementary to each other in the progress of innovation. Big international metropolises, like New York, Tokyo, Beijing and London, enjoy inherent advantages in bringing together innovation resources, creating scientific knowledge and incubating high-tech start-ups, given the clustering effects they have. Yet, some cities/metropolitan areas with smaller populations, like Seattle-Tacoma-Bellevue and Chapel Hill-Durham-Raleigh, have their own distinctive features in innovation-driven development, with specialties in certain technological fields. Each city plays a significant role in its own field, and is exploring its unique path towards innovation development.

Basic research and technological innovation capacities remain important elements that determine a city or metropolitan area's position in the global innovation network. More than half of cities/metropolitan areas in the overall top 10 list, like San Francisco-San Jose, Boston-Cambridge-Newton, New York, Beijing and London, have a concentration of renowned universities and research institutions, with solid bases in scientific research, and therefore, have an edge in innovation capacities, and their positions are difficult to challenge.

Digitalisation has accelerated technological innovation and research translation. The rapid progress of digital economy has highlighted Asian cities' advantages in innovation economy. Asian cities are gaining development momentum in emerging new economies, which are exerting an increasingly significant impact. Seven Asian cities are ranked among the global top 10 list in innovation economy. Chinese cities like Beijing, Shenzhen and Shanghai are establishing their unique strengths by stimulating innovative potentials of digital technology companies; cities/metropolitan areas such as Tokyo, Seoul, Kyoto-Osaka-Kobe and Tel Aviv have also shown the world their distinct culture, tradition and innovation.

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Introduction

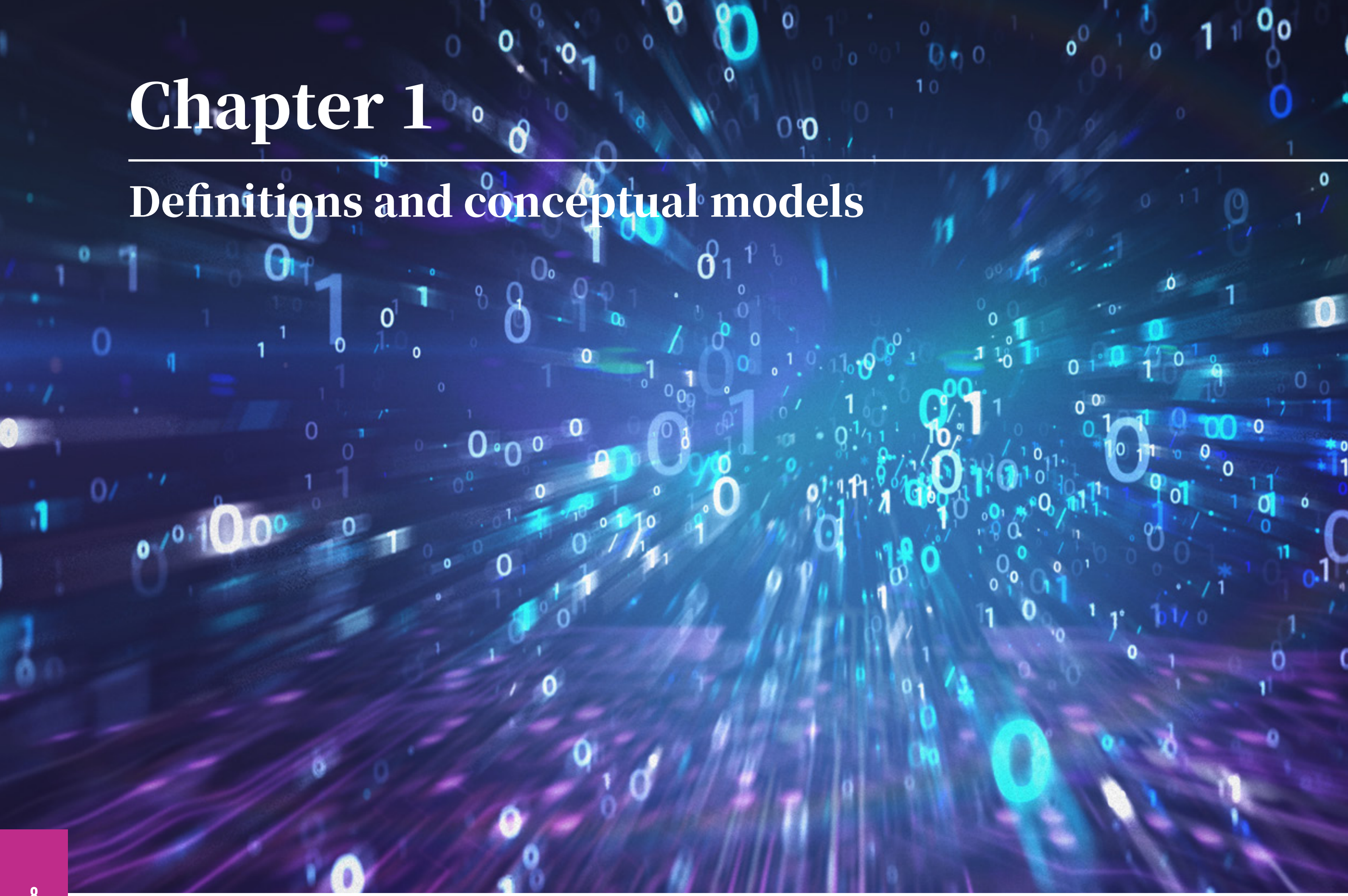
In today's world, a new round of scientific and technological revolution is reshaping the global socioeconomic landscape. With the development of digitalisation, and network and intelligent technologies, countries around the world are looking into science and technology innovation to gain an edge. Innovation hubs, as the key nodes in the global innovation network, have emerged as centres of scientific activity and pivots of innovation economy. Building global innovation hubs has become essential for countries to compete and to keep up with the scientific and technological revolution. The strategic importance of building these hubs can be manifested in the following three aspects:

First, the world is now in a critical period of significant changes. Global climate change, the deterioration of the ecosystem, the outbreaks of infectious diseases and the risks of emerging technologies are all threatening the stability of human development. The solutions to these problems lie in major research breakthroughs in science. Countries, regions, cities and institutions need to leverage science centres and major science facilities, and foster more robust, trusting and symbiotic research collaboration. Global innovation hubs, as an important source of new knowledge and technology, provide the intellectual foundation, material supply and incentives needed for a paradigm shift in scientific research.

Second, the development of digital technology requires more efficient innovation models and advanced economies, allowing for more opportunities for its application. Digital technology provides new growth points and vitality for the economy. Meanwhile, the rapid rise of the digital economy is breaking down geographical boundaries, systemic and cultural barriers, and protection of the status quo. Under the impact of rapid technological upgrades, enterprises and other actors in innovation activities face new challenges from changing market demands and intensifying competition, while the spatial distribution of innovation resources will be more unbalanced. This will give rise to new models of resource allocation and technological innovation. A global innovation hub brings together innovation elements across the world and provides impetus for the development of cutting-edge technologies and emerging industries. Its rise is thus an effective way to respond to these challenges.

Third, innovation-driven development, by nature, demands the cultivation, renewal and reshaping of an innovation ecosystem. Innovation is the most important engine in driving economic growth and employment, and ensuring long-term competitiveness. Yet, it is subject to considerable uncertainty. Basically, innovation activity is the process of continual trial and error, within a framework of openness and cooperation. A more diverse and inclusive innovation support system, such as an open-minded innovation culture, accessible public services, smart governance mechanisms[1], as well as a friendly business environment, provides the ground for sustained innovation.

The continuing evaluation of global innovation centres will undoubtedly facilitate their development, as it objectively tracks the technological revolution, institutional innovation and economic growth in a city over time. It also allows for a forecast of the development of knowledge creation, cutting-edge technologies, and emerging businesses and economies. Through the evaluation, potential technological and social risks may be revealed, and a city's innovation capacity can be enhanced. In light of this, the Global Innovation Hubs Index (GIHI), developed by the Center for Industrial Development and Environmental Governance (CIDEG) at Tsinghua University, in collaboration with Nature Research, aims to provide a framework for assessing the innovation capacity and development potential of global innovation hubs, based on scientific methods and objective data, providing a useful reference for public policy-makers and practitioners.



Chapter 1

Definitions and conceptual models

1.1 Defining a global innovation hub

Global innovation hubs 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, these cities are the main actors in global technological and industrial competition. The most successful emerge as global cities by integrating research innovation, the innovation economy, and a supportive ecosystem for innovation.

First, a global innovation hub is a science centre[2] that emerges as a result of expanding research activities both in depth and geographic breadth. The concentration of research activities promotes knowledge sharing and the exchange of ideas, while sharing infrastructure and thereby reducing risks and costs. Global science centres naturally emerge as research activities and innovation resources continue to aggregate, with their impacts spilling over to surrounding regions as well as globally.

Second, a global innovation hub features thriving innovation activities and a vibrant innovation economy[3,4]. The concentration of industries such as advanced manufacturing and production services creates demands for innovative solutions. As globalization accelerates economic and trade exchanges, those that are at the nodes of the global network are considered global cities[5]. Typical global metropolitans such as New York, London, Tokyo and Paris have been international trade and commercial centres historically, and are also home to headquarters and R&D centres of multinational corporations. Evidently, they direct and drive the global allocation of industrial chains and production resources.

Third, a global innovation hub benefits from a supportive innovation ecosystem. A well-governed, dynamic and evolving innovation ecosystem requires collaboration and the 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 commercialisation capacities, and drives the development of research innovation and the innovation economy for the global network[6].

Therefore, this report primarily assesses the development and innovation capacities of global innovation hubs in three dimensions — research innovation, the innovation economy, and the innovation ecosystem.

1.2 A conceptual model for assessing global innovation hubs

Based on the above definitions, this report highlights three core connotations of a global innovation hub: strong research innovation, a vibrant innovation economy, and a supportive innovation ecosystem. By identifying the key metrics for analysis for the three dimensions, it constructs a conceptual model of the evaluation index system, as shown in Figure 1.

❶ **Research innovation.** Human resources are important capital in science and technology innovation, and thus, the supply of a science and technology workforce is vital for a city's innovation capacity. As important providers of science and technology human resources, research institutions generate fundamental theories essential for technological development, and their overall strength is indicative of a city's research capacity particularly in basic sciences. Scientific infrastructure provides tools and facilities for research activities to take place, and its performance and scale largely decide the output of research. Knowledge creation, whose outcome is primarily research output, refers to the process by which human resources create and disseminate new knowledge and apply it to innovation.

The combination and interaction of science and technology human resources, research institutions and scientific infrastructure generate knowledge, providing the theoretical basis for technological innovation, and boosting technological innovation capacities.

❷ **Innovation economy.** Technological innovation capacity represents the knowledge stock and competitive edge that enterprises have to enable them to keep updating their technologies and respond to market competition. It can be measured by the number of invention patents and the size of patent exports. Innovative enterprises are usually those with independent intellectual property rights, and who gain their competitive edge based on their capacity for technological innovation. Their number and scale reflects a city's ability to innovate and its economic vitality. Typically represented by information technology, new materials, biotechnology and other high technologies, emerging industries are new economic forms that promote the transformation of traditional industrial economies into high-quality, intelligent ones. Their development reflects a city's potential and trends in economic growth, promoting a positive cycle. The level of economic growth also represents how advanced its technological innovation is.

In short, technological innovation capacity is at the core of the survival and development of innovative enterprises, and is the fundamental driving force of industrial development. Innovative enterprises, and particularly their size and market value, also reflect the development status of specific emerging industries. Together, they boost a city's economic development.

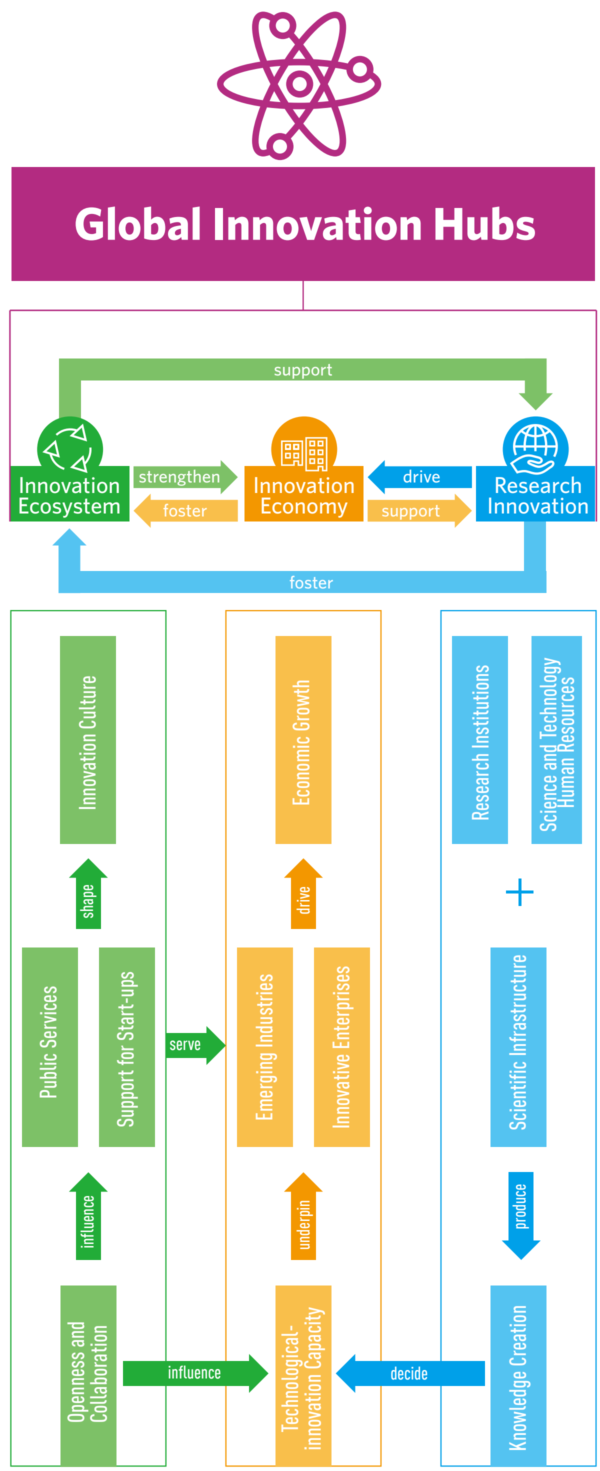
❸ **Innovation ecosystem.** Cities participating in innovation activities typically have an open attitude and embrace collaboration, qualities that are conducive to building a supportive environment for innovation. The depth and breadth of collaboration forms the basis of an innovation ecosystem[7]. Support for start-ups refers to the external support system, including financial and social backing for innovation and entrepreneurial activities, while public services here are the infrastructure and facilities provided by government agencies and service organisations for innovation and entrepreneurial activities. Together, they foster an innovation culture.

The processes of science and technology innovation and its commercialisation are full of uncertainty, and require mutual support among the economic, political and social systems. The degree of openness and collaboration in a city, in large part, determines the readiness of its public service and support systems for start-ups, essential ingredients for the free flow of innovation elements. These supportive systems, along with an innovation culture that is well integrated with society and the market, form a healthy innovation ecosystem.

To sum up, research innovation promotes the development of the innovation economy, which in turn exerts impacts on the input and output of research innovation. The continued development of both helps create an innovation ecosystem, which also promotes the growth of research innovation and innovation economy.

Figure 1

A conceptual model for the GIHI assessment



Chapter 2

The index system and evaluation subjects

2.1 Basic principles for constructing the index system

In this report, the following principles guide the construction of the index system:

(1) Balance the theoretical basis and feasibility. The index system should reflect the internal logic between the evaluated concepts and should be based on sound evaluation methods[8]. The indicators chosen should be able to measure the individual concepts. This way, the index system will be theoretically grounded, internationally comparable and transparent in methodology. The selection of indicators also needs to consider data availability, ensuring their simplicity, clarity and feasibility.

(2) Focus on both the current performance and the future potential. The index system should capture the historically accumulated strengths and existing innovation capacities of global innovation hubs as well as their dynamic development, and the future trends in emerging technologies and frontier fields.

(3) Be independent and stable, while forward-looking. The indicator system should have independent, objective and stable data sources. The indicators selected should be able to capture the dynamic change of global innovation hubs, and allow for regular evaluations and adjustment.

(4) Be inherently logical and consistent. The indicators should be universally applicable to a variety of cities/regions. Repeated measurement of innovation input and output should be avoided[9,10], and the focus should be on assessing innovation capacity and performance.

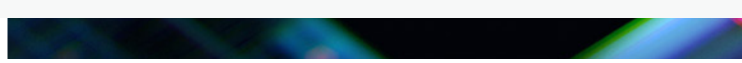
2.2 The index system

The index system is constructed following a three-stage process: qualitative design, quantitative screening, and feedback and testing. At the first stage, city profiles are drawn and their conceptual characteristics are considered to select indicators meeting the above criteria for analysis, following the evaluation logic. Then, data are collected, and their variability across time and cities are analysed, so that indicators with very low variability (that is, the scores do not vary much across cities), and very high or low time sensitivity (that is, change dramatically or do not change over time) are eliminated. After a preliminary assessment, the results are shown to experts for feedback, and are checked by common-sense understanding of the cities. For data or results that are difficult to interpret, the index system is modified accordingly.

Due to data availability limitations and time constraints, compounded by the COVID-19 pandemic this year, the current report is just a beta version. Only a limited number of cities are assessed here; when city-level data are not available, country-level data are used instead; for subjective measures that require data to be collected through survey questionnaires, such as measures on city culture or system, relevant evaluation data already collated by well-recognised international organisations are used instead. As for the weighting of different indicators, because of the lack of expert-opinion surveys, equal weights are applied, where possible, based on the number of indicators.

In future, based on this beta version, the research team will modify and optimise the index system, expand the scope of the assessment and further mine the data for constructing better indicators. The goal is to make GIHI a scientific, credible and widely accepted index system for global innovation hubs.

Based on the conceptual model for global innovation hubs and the principles for constructing the indicators, we have constructed the GIHI evaluation system. Research innovation, the innovation economy and innovation ecosystem constitute level-1 indicators of the GIHI system. The key elements for each dimension constitute level-2 indicators. Weight allocation is as follows: the total weight for level-1 indicators is 100%, made up of 30% for research innovation, 30% for innovation economy and 40% for innovation ecosystem. The linear-weighted-sum method is used to calculate the overall scores. Details of the GIHI system are shown in Table 1 (for detailed explanations and data sources for each indicator, please see Appendix I).



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Chapter 2: The index system and evaluation subjects

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%	Number of R&D personnel (per million people)
				Number of highly cited scientists
				Number of winners of top scientific awards
		A2. Research institutions	30%	Number of top 200 world-class universities
				Number of top 200 world-class research institutions
		A3. Scientific infrastructure	10%	Number of big science facilities
				Number of top 500 supercomputer centres
		A4. Knowledge creation	30%	Percentage of highly cited papers
				Proportion of papers cited in patents, policy reports and clinical trials
B. Innovation economy	30%	B1. Technological innovation capacity	25%	Total number of valid patents (per million people)
				Number of patent cooperation treaty (PCT) patents
		B2. Innovative enterprises	25%	Number of top 100 innovative enterprises
				Valuation of unicorn companies
		B3. Emerging industries	25%	Market value of high-tech manufacturing companies
				Revenue of listed companies in new economy industries
		B4. Economic growth	25%	GDP growth rate
				Labour productivity
C. Innovation ecosystem	40%	C1. Openness and collaboration	25%	Paper co-authorship network centrality
				Patent collaboration network centrality
				Foreign direct investment (FDI)
				Outward foreign direct investment (OFDI)
		C2. Support for start-ups	25%	Venture capital investment
				Private equity
				Ease of business environment
		C3. Public service	25%	Number of data centres (public clouds)
				Broadband connection speed
				Number of international flights (per million people)
		C4. Innovation culture	25%	Talent attraction
				Entrepreneurial spirit
				Degree of internationalisation of culture-related industries
				Number of public libraries and museums (per million people)

The GIHI system has several distinctive features.
First, general measures based on individual actors of innovation, as well as network indicators are incorporated. Following the basic patterns of innovation activities, the GIHI system incorporates general and commonly used indicators based on individual actors in innovation, such as the number of R&D personnel, big science facilities, and the proportion of highly cited papers, as well as network measures, such as paper co-authorship network centrality and patent collaboration network centrality. The former measures a region's innovation capacity and performance, while the latter attempts to capture the region's openness and connection to the world.

Second, direct, micro data are used to maintain fine granularity. To improve the objectivity and accuracy of the index system, GIHI uses micro data where possible, such as the number and valuation of innovative enterprises, the revenue of listed companies in new-economy industries, number of patents and published papers, venture capital investment, foreign direct investment (FDI), outward foreign direct investment (OFDI), the number of international flights and more.

Third, for subjective indicators, data based on large-scale surveys from well-recognised international organisations are used. Some indicators related to culture and systems are subjective, such as entrepreneurial spirit[11], ease of business environment[12] and talent attraction[13]. They normally need to be constructed based on large-scale surveys, which take time. Instead, this report uses data from international organisations such as the World Bank and the World Economic Forum, and where city-level data are not available, country-level data are used as substitutes. This way, we have incorporated subjective indicators while maintaining the authority and fairness of the index system as much as possible.

Fourth, the GIHI system focuses on frontier technologies and emerging-economy sectors. Frontier technologies and the emerging economy are at the core of the fourth industrial revolution, and are the focus of future technological competition. Keeping pace with the times, this report focuses on artificial intelligence (AI) technologies in its examination on patents to better capture a city's technological innovation capacity and potential. In measuring a city's development of emerging industries, the report uses market capitalisation of high-tech manufacturing companies and the revenue of listed companies in new economy industries, focusing specifically on bio-manufacturing, high-tech equipment, and information and communication technology (ICT) for the former, and on ICT and biomedicine[14] for the latter.

Table 2

List of the cities/metropolitan areas evaluated

Number	City (metropolitan area)	Country
1	Beijing	China
2	Shanghai	China
3	Hong Kong	China
4	Shenzhen	China
5	San Francisco – San Jose	USA
6	Baltimore – Washington	USA
7	Boston – Cambridge – Newton	USA
8	New York	USA
9	Los Angeles – Long Beach – Anaheim	USA
10	Seattle – Tacoma – Bellevue	USA
11	Philadelphia	USA
12	Chicago – Naperville – Elgin	USA
13	Chapel Hill – Durham – Raleigh	USA
14	Paris	France
15	Lyon – Grenoble	France
16	Berlin	Germany
17	Munich	Germany
18	Tokyo	Japan
19	Kyoto – Osaka – Kobe	Japan
20	Singapore	Singapore
21	Seoul	Korea
22	Stockholm	Sweden
23	Toronto	Canada
24	London	UK
25	Bangalore	India
26	Tel Aviv	Israel
27	Sydney	Australia
28	Amsterdam	The Netherlands
29	Helsinki	Finland
30	Copenhagen	Denmark

2.3 Subjects of evaluation

In this report, subjects of evaluation are defined as a metropolitan area (MA); that is, a region comprising a densely populated urban core area and relatively sparsely populated peripheral areas that are closely integrated with the core economically and socially[15]. Metropolitan areas usually consist of multiple administrative units, such as cities, towns, suburbs, counties and districts; they may have blurred the geographic boundaries of individual administrative cities. For example, some European metropolitan areas may even cross national boundaries, and commute time and mode are considered in defining their boundaries.

The use of metropolitan areas to define evaluation subjects is based on the following considerations: (1) The definition of MA fits the connotation of innovation hubs. A 'global innovation hub' should have global impact, especially a spill-over effect of the core area on the surrounding areas. However, defining a city simply based on administrative boundaries might artificially cut off the city's socioeconomic connections, and the spill-over influence of the core area might not be well captured. In contrast, using the MA definition helps to more comprehensively and objectively capture the influence. (2) The definition is in line with the transformation pattern of urban spatial systems. The space of leading cities usually evolves over time, from a single-centre city to a multi-centre metropolitan area, a cluster of cities, and then to an integrated city belt[I]. (3) It helps ensure that a consistent calibre is used for evaluation. To ensure statistical consistency for the measurement of indicators, this report generally adopts the Nature Index definition for MAs that is based on official specifications from government offices, or described in legal documents, while taking into account the degree of socioeconomic integration of neighbouring administrative areas.

To ensure objectivity, comprehensiveness and validity of the coverage of evaluation subjects, this report refers to relevant city ranking reports, including the *Nature Index Science Cities*[16], the *Global Urban Competitiveness Report*[17], the Global Innovation Index[18], and the *2019 Global Science and Technology Innovation Center Evaluation*[19] to select candidate cities. Then, overall scores and by-dimension scores are calculated for cities on the list for a pre-assessment, and via a 'city profiling' process by expert panels, the final list of cities is determined (for the process of city selection, see Appendix II). A total of 30 cities/metropolitan areas are evaluated in the GIHI report, as shown in Table 2 (for the areas covered by each metropolitan area, see Appendix III).

These 30 cities/metropolitan areas cover 151 administrative divisions. They account for only about 3.70% [II] of the world's total population, but have gathered the world's top innovation resources and results, and are leading in scientific research, innovation economy and innovation ecosystem. In research innovation, they boast almost 60 world-class universities and about 80 world-class research institutions [III], having attracted 178 winners of the Nobel Prize, Turing Award, Fields Medal and other top science awards. In the innovation economy, the total GDP of these 30 cities/metropolitan areas accounted for about 17.15%[IV] of the world's total in 2018, and 54 of the world's top 100 innovative enterprises[20] and 367 of the world's top 500 unicorn companies (in 2019)[21] are located in these cities. As for the innovation ecosystem, these 30 cities/metropolitan areas are core leaders of economic globalisation, with the amount of OFDI greenfield investments accounting for about 34.48% of the global total in 2019.

Chapter3

Overall scores of global innovation hubs

Considering the variation across indicators, this report uses the Z-score method to normalise the raw data for all the indicators (see Appendix IV for explanation of the data standardisation and score calculation). The standardisation allows data to be rescaled, leading to the scores and ranking shown in Table 3.

The results show that, based on the overall scores, the top-ranked city (metropolitan area) is San Francisco-San Jose by a long way. The other cities/metropolitan areas in the top 10 are New York, Boston-Cambridge-Newton, Tokyo, Beijing, London, Seattle-Tacoma-Bellevue, Los Angeles-Long Beach-Anaheim, Baltimore-Washington and Chapel Hill-Durham-Raleigh.

Capital cities, such as Tokyo, Beijing and London have distinct advantages in innovation. Home to the respective country's or the world's leading innovative companies, and as major science centres, they perform well in measures of current strength and growth. Other cities, though not capitals, also have their own characteristics. San Francisco-San Jose benefits from a balanced development of research innovation, innovation economy and innovation ecosystem; Boston-Cambridge-Newton and New York, given their traditional strengths in scientific and technical manpower, and concentrated research institutions, rank highly in innovation capacities; Seattle-Tacoma-Bellevue, as home to several high-tech companies, has relatively balanced development in innovation economy and innovation ecosystem. Chapel Hill-Durham-Raleigh, known as the 'North Carolina Triangle', houses three prestigious universities, and is a renowned high-tech R&D centre in the United States, as well as a global leader in university-industry collaboration. Though its ranking in innovation economy is not particularly high, it is an indispensable force in global innovation given its successful development of biotechnology.

In terms of urban development patterns, these global innovation hubs exhibit differentiated development paths and special positioning. Except for a few, such as San Francisco-San Jose, the cities demonstrate a clear differentiation in the development of research innovation, innovation economy and innovation ecosystem. For example, Tokyo and Beijing rank high in innovation economy, and have relatively good performance in research innovation, while London and Los Angeles perform well in innovation ecosystem, and New York and Boston are outstanding in research innovation.

By urban population size, the international metropolises and smaller cities each have developed their own complementary characteristics. Those with a population of 10 million or more, such as New York, Los Angeles-Long Beach-Anaheim, Tokyo, Beijing and London, are home to well-known universities and multinational companies, with frequent international exchanges and vibrant economies fully reflecting the agglomeration effect on innovation development of mega cities. Smaller cities/metropolitan areas with a population of a million or more, such as San Francisco-San Jose, Boston-Cambridge-Newton, Chapel Hill-Durham-Raleigh, and Seattle-Tacoma-Bellevue, have developed strengths in their speciality high-tech fields, such as information communication or biotechnology.

Table 3

Overall ranking of the global innovation hubs

City/metropolitan area	Overall		Research innovation		Innovation economy		Innovation ecosystem	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking
San Francisco – San Jose	100.00	1	91.59	3	100.00	1	100.00	1
New York	88.44	2	100.00	1	67.63	11	94.26	2
Boston – Cambridge – Newton	85.57	3	98.49	2	67.91	10	87.73	4
Tokyo	84.75	4	82.99	10	90.92	2	76.37	15
Beijing	84.68	5	85.96	8	86.49	3	77.96	11
London	80.69	6	88.49	4	63.63	18	88.09	3
Seattle – Tacoma – Bellevue	77.61	7	81.80	14	69.47	9	80.04	9
Los Angeles – Long Beach – Anaheim	76.88	8	85.10	9	63.46	19	81.18	6
Baltimore – Washington	76.72	9	87.96	5	63.74	15	77.90	12
Chapel Hill – Durham – Raleigh	76.58	10	87.13	7	64.20	14	77.81	13
Paris	76.43	11	87.80	6	66.78	12	74.20	20
Amsterdam	75.64	12	82.30	11	62.87	22	81.01	7
Chicago – Naperville – Elgin	75.11	13	80.43	15	62.76	23	81.39	5
Singapore	74.36	14	77.80	18	63.66	16	80.86	8
Copenhagen	73.62	15	82.20	12	61.47	27	77.15	14
Seoul	73.46	16	77.75	19	71.29	7	70.84	24
Shanghai	73.44	17	75.36	23	72.28	5	71.95	23
Philadelphia	72.66	18	77.20	21	61.68	26	78.89	10
Munich	72.37	19	77.69	20	63.66	17	75.67	17
Stockholm	72.25	20	81.90	13	63.24	20	72.00	22
Toronto	72.14	21	78.68	17	63.23	21	74.61	18
Hong Kong	71.94	22	76.71	22	64.64	13	74.42	19
Tel Aviv	70.46	23	74.59	24	71.43	6	65.58	27
Berlin	70.15	24	73.20	27	61.77	25	75.74	16
Shenzhen	70.07	25	64.89	29	77.24	4	67.46	26
Sydney	69.75	26	79.82	16	60.00	30	70.48	25
Helsinki	68.83	27	73.83	25	60.76	28	72.69	21
Kyoto – Osaka – Kobe	68.56	28	73.43	26	70.12	8	62.91	29
Lyon – Grenoble	65.00	29	72.69	28	60.59	29	63.71	28
Bangalore	60.00	30	60.00	30	62.43	24	60.00	30

Chapter 3: Overall scores of global innovation hubs

Based on the overall ranking of global innovation hubs and their scores on level-1 indicators, the innovation development patterns of the top 10 cities can be illustrated as in Figure 2.

Figure 2

Development models of the global innovation hubs

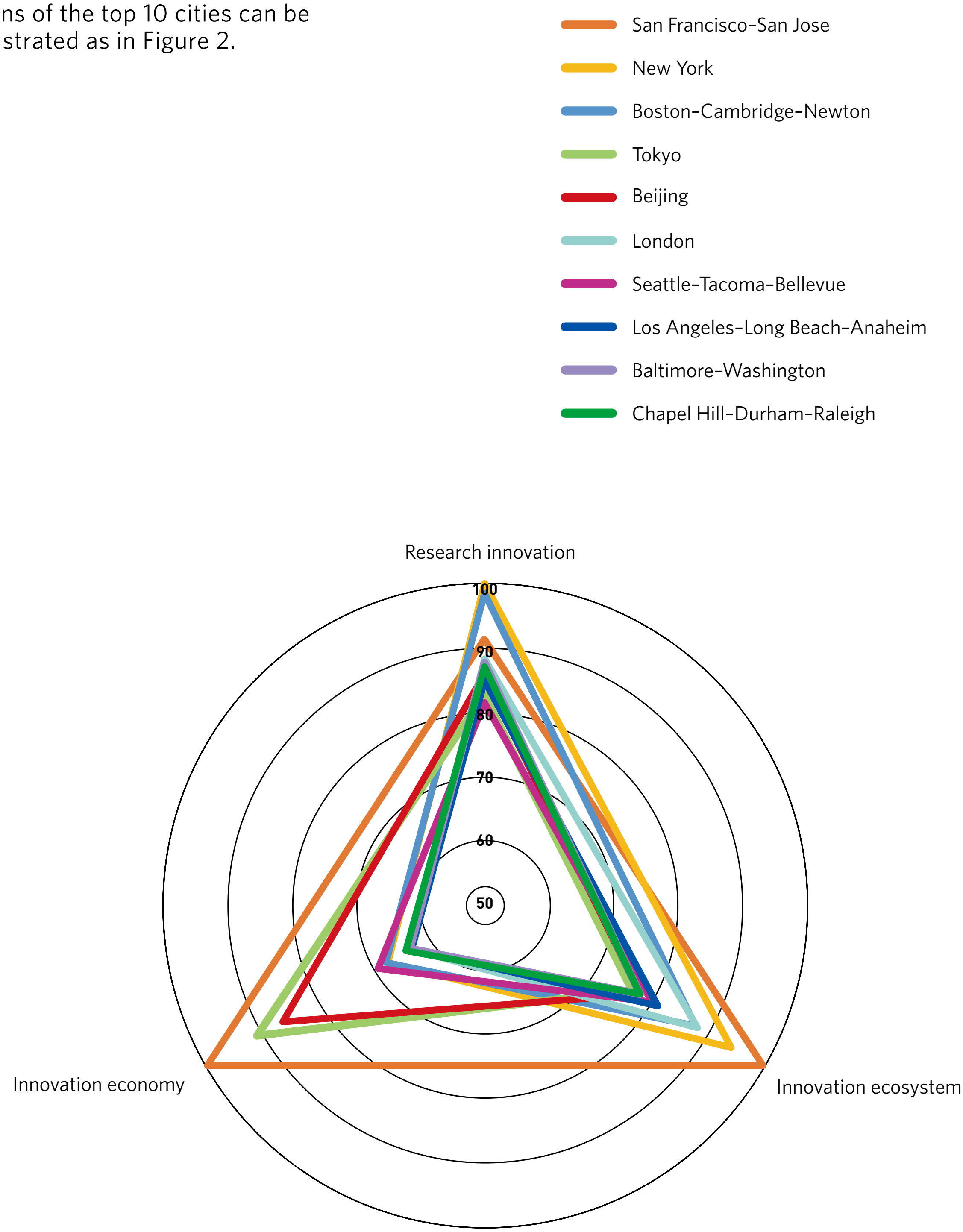
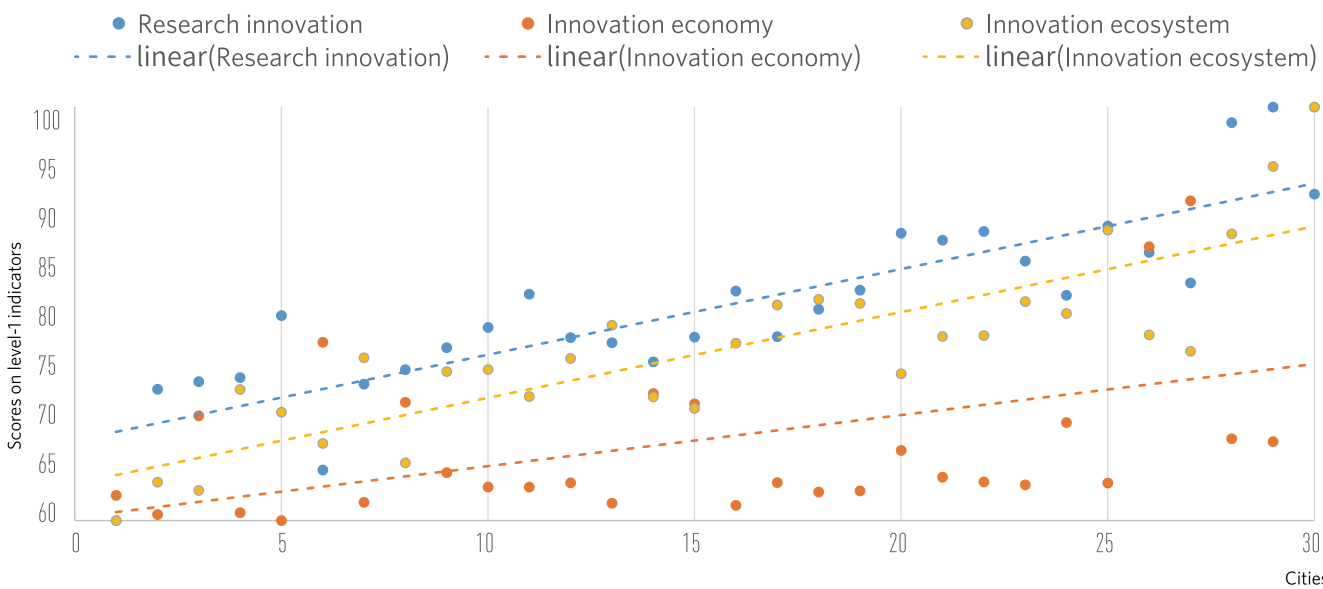


Figure 3

Scatter plot of scores on level-1 indicators of the 30 global innovation hubs



Analysis using Pearson's correlation shows that scores on each of the three level-1 indicators are significantly correlated with the overall scores ($p<0.01$). Specifically, the correlation between the innovation ecosystem and the overall score is the strongest, with a correlation coefficient of 0.877. It is followed by that between research innovation and the overall score, with a correlation coefficient of 0.823. The innovation economy has the weakest correlation with the overall score, at a correlation coefficient of 0.675 (see Figure 3 for the scores on the level-1 indicators of each city). Further analysis of the correlation between scores on the three level-1 indicators shows that the correlation between research innovation and innovation ecosystem is strongest, with a correlation coefficient of 0.815 ($p<0.01$), indicating that good innovation ecosystem can promote the development of research innovation, and vice versa.

Looking at the three level-1 indicators, the top 10 cities/metropolitan areas in research innovation are New York, Boston-Cambridge-Newton, San Francisco-San Jose, London, Baltimore-Washington, Paris, Chapel Hill-Durham-Raleigh, Beijing, Los Angeles-Long Beach-Anaheim and Tokyo. The top three cities have a strong lead over the others, whose scores are relatively close. Basic research, as a major driver of science and technology innovation, is highly recognised around the world as a focus area for countries and cities to improve their innovation capabilities.

In innovation economy, San Francisco takes the lead, followed by Tokyo, with Beijing third. The other cities/metropolitan areas in the top I0 are Shenzhen, Shanghai, Tel Aviv, Seoul, Kyoto-Osaka-Kobe, Seattle-Tacoma-Bellevue, and Boston-Cambridge-Newton. Asia has seven cities ranking among the global top 10. Except for the top three, scores of the other cities/metropolitan areas are in the range of 70-79, showing a trend of polarisation. San Francisco Bay Area, as one of the world's most important high-tech R&D bases, boasts a concentration of the global 500 enterprises. Its unique and strong advantages in innovation resources have made it a leader in innovation. Tokyo has maintained its advantage as a long-established global city of science and technology innovation, leading in the scale and market value of innovative tech companies, and the number of PCT patents. Its recent arrangement in the development of artificial intelligence technologies, leading to the edge in patents in this field, has further strengthened its position in the global innovation network. Meanwhile, Chinese cities such as Beijing and Shenzhen are rising rapidly in innovation economy, with strong performance in PCT patents, unicorn companies and high-tech equipment manufacturing. Israel's Tel Aviv finds a position in the global top 10 in innovation economy, with a clear advantage in its high labour productivity.

For innovation ecosystem, San Francisco-San Jose again takes the top spot, followed by New York and London, while fourth is Boston-Cambridge-Newton. The other cities in the top 10 are Chicago-Naperville-Elgin, Los Angeles-Long Beach-Anaheim, Amsterdam, Singapore, Seattle-Tacoma-Bellevue and Philadelphia.

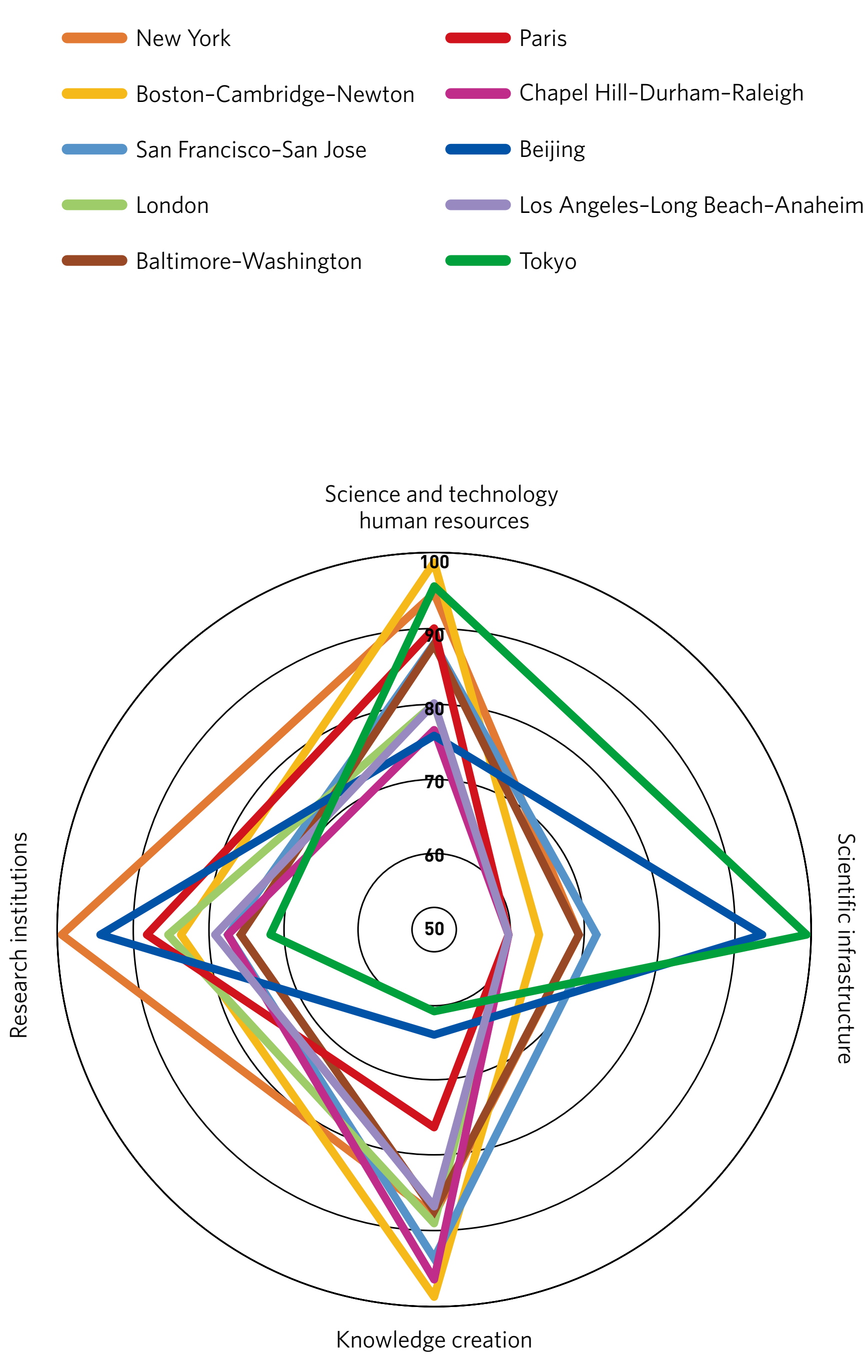
Chapter 4

Research innovation

Scientific research is the building block of innovation. Global innovation hubs are generally leaders in scientific research and the global sources of knowledge dissemination. The GIHI measures 'research innovation' via four level-2 indicators – human resources, research institutions, scientific infrastructure and knowledge creation – along with nine level-3 indicators.
Figure 4 shows the development patterns of the top 10 global innovation hubs in research innovation. Their scores are relatively close in knowledge creation, science and technology human resources, and research institutions. Many cities fall short in scientific infrastructure, with Tokyo and Beijing being the exceptions. Beijing, particularly, shows strong performance in both scientific infrastructure and research institutions.

Figure 4

Development patterns of the top 10 cities/metropolitan areas in research innovation



Chapter 4: Research innovation

4.1 Science and technology human resources

Science talent is important capital for scientific research. The size of the science and technology workforce, along with a good workforce structure featuring a certain number of high-impact researchers, is essential for research output, as well as the sustainability and potential in research. This report uses the numbers of R&D personnel (per million people), highly cited scientists (2000-2018) and winners of the leading scientific awards to measure a city's science and technology workforce stock, as well as its ability to attract the best minds.

Boston–Cambridge–Newton leads the world in the number of top science award winners, having attracted more than 40 laureates of the world's most prestigious science awards, including the Fields Medal, the Turing Award and the Nobel Prize (excluding the Nobel Prizes in Literature and Peace). This has enhanced the metropolitan area's basic research capabilities, and boosted its attraction to other leading research teams. Tokyo, with 9,514 highly cited scientists (based on papers published between 2000 and 2018), ranks first globally in this measure, with a strong lead over Baltimore–Washington and New York, ranked second and third, respectively. Figure 5 shows the numbers of highly cited scientists and premier research institutions for the top 10 cities/metropolitan areas in research innovation.

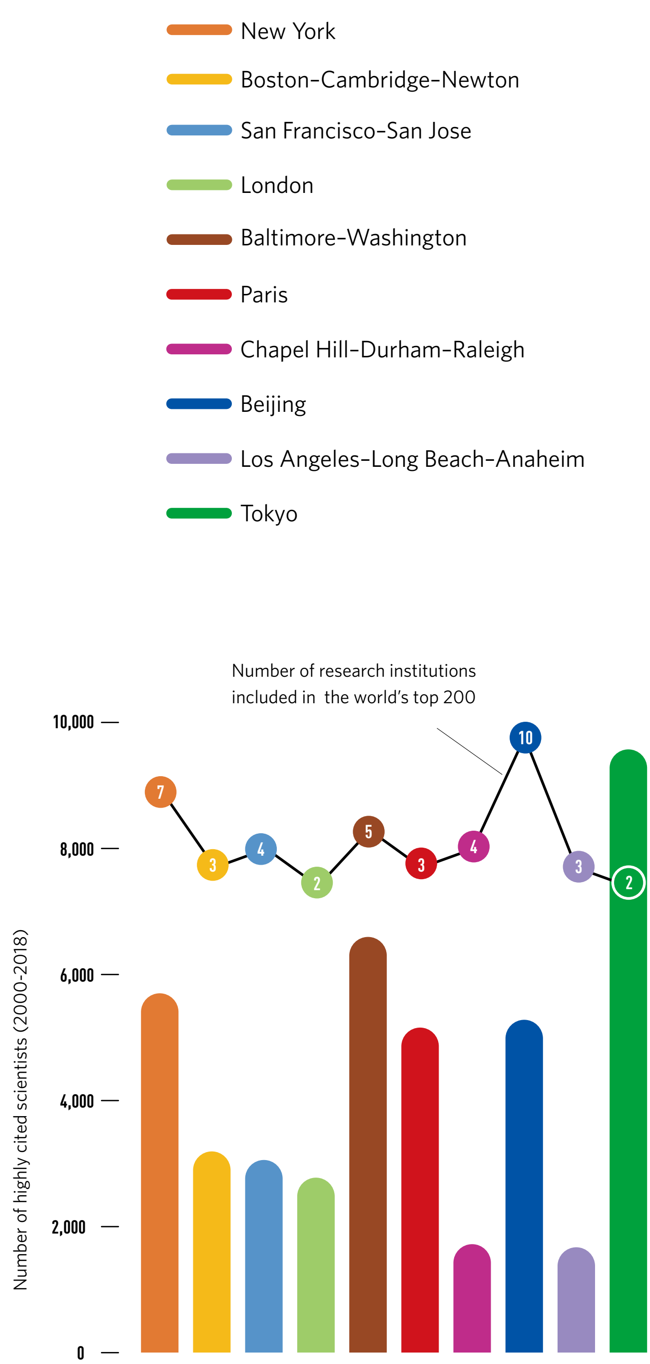
4.2 Research institutions

Research institutions are places where research and development activities are taking place and are well organised. They are major actors in knowledge creation and original innovation, and take much responsibility for conducting major theoretical and key research projects of strategic importance for a city or a country. This report measures the overall strength and research capacities of research institutions in a city by looking at the ARWU top 200 universities and the Nature Index top 200 research institutions. (Though the two indices might overlap, they have different emphases, with the former looking at universities' overall strength, including reputation, while the latter focuses on recent research output.)

Here, New York ranks highest, followed by Beijing, Paris, London, Boston–Cambridge–Newton and Shanghai. Those housing a larger number of prestigious universities are mostly Western cities, including New York, Paris, London and Boston–Cambridge–Newton, while Beijing, New York, Shanghai and Baltimore–Washington have a good concentration of leading research institutions that have performed well in high-quality scientific publications last year.

Figure 5

Numbers of highly cited scientists and of top 200 research institutions for the top 10 cities/metropolitan areas in research innovation



4.3 Scientific infrastructure

Scientific infrastructure provides the technological platforms for researchers to conduct high-quality, cutting-edge scientific research. It is also an important means for cities to attract talented research teams from around the world to carry out key research projects. This report uses the numbers of big science facilities and supercomputers listed in the TOP500, a list that tracks the world's fastest supercomputers, as proxies for the development status of science infrastructure in cities/metropolitan areas.

Tokyo and Beijing are the top two cities, demonstrating obvious advantages in their scientific infrastructure. Tokyo houses KEK, Japan's High Energy Accelerator Research Organisation, which is home to eight of the world's leading big science facilities, such as the Proton Synchrotron Accelerator (PS), the KEK Pulsed Spallation Neutron Source (KENS) and the Photon Factory (PF). This world-renowned cluster of facilities has greatly boosted the technological competence of Tokyo and even that of Japan, contributing significantly to industrial and economic prosperity. Opening major facilities for shared use is also an important mechanism in attracting scientists from around the world. Tokyo is a pioneer in this regard when it opened KENS to scientists from home and abroad in 1980, while its asymmetric positron-electron collider (KEKB), which began operations in 1998, has attracted hundreds of researchers from 53 research institutions in 13 countries to participate in the Belle Collaboration, which leads the Belle experiment on particle physics[V].

Beijing is a growing force in scientific infrastructure. It now houses 12 supercomputing centres, 46 supercomputers in the TOP500 list, and a number of big science facilities, such as the Beijing Electron Positron Collider (BEPC), the Beijing Synchrotron Radiation Facility (BSRF) and the Earth System Numerical Simulator. These key facilities have laid a solid foundation for Beijing to enhance its science and technology innovation capabilities, as it strives to become a global innovation hub.

4.4 Knowledge creation

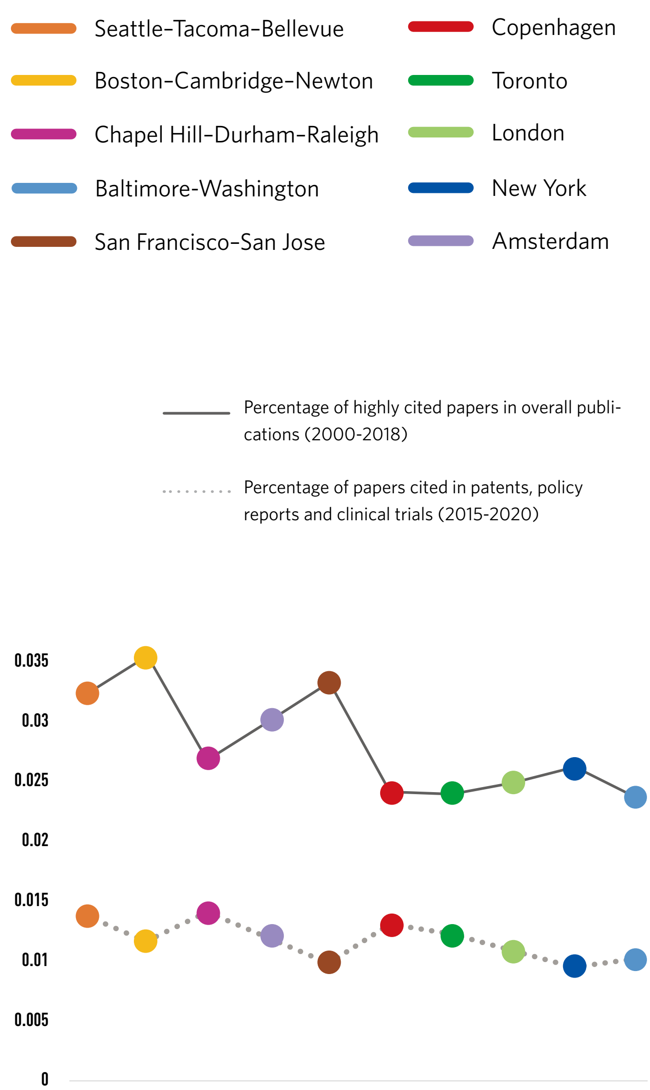
Knowledge creation is an important indicator of research strength, and can be represented in the output of high-quality scientific papers. GIHI uses the percentage of highly cited papers published by a city's researchers to measure the quality and academic impact of its papers. It also uses the percentage of papers cited in policy reports, patents and clinical trials as a proxy for the application potential of research output.

The top three cities/metropolitan areas in knowledge creation are Seattle–Tacoma–Bellevue, Boston–Cambridge–Newton and Chapel Hill–Durham–Raleigh. Looking at the proportion of a city's total publications that are in the top 1% of highly cited papers, Boston–Cambridge–Newton and San Francisco–San Jose lead at 3.52% and 3.30%, respectively. Chapel Hill–Durham–Raleigh and Seattle–Tacoma–Bellevue have the highest percentage of scientific papers cited in policy reports, patents and clinical trials, at 1.39% and 1.37%, respectively.

As shown in Figure 6, Chapel Hill–Durham–Raleigh has the highest percentage of papers cited in patents, policy reports and clinical trials – possibly a result of its market-driven development in knowledge creation and industrial innovation, particularly in biotechnology and clinical medicine. It is home to prestigious universities such as Duke University, the University of North Carolina at Chapel Hill and North Carolina State University, and houses the world-renowned Research Triangle Park.

Figure 6

Percentages of highly cited papers and externally cited papers for the top 10 cities/metropolitan areas in knowledge creation



Chapter 5

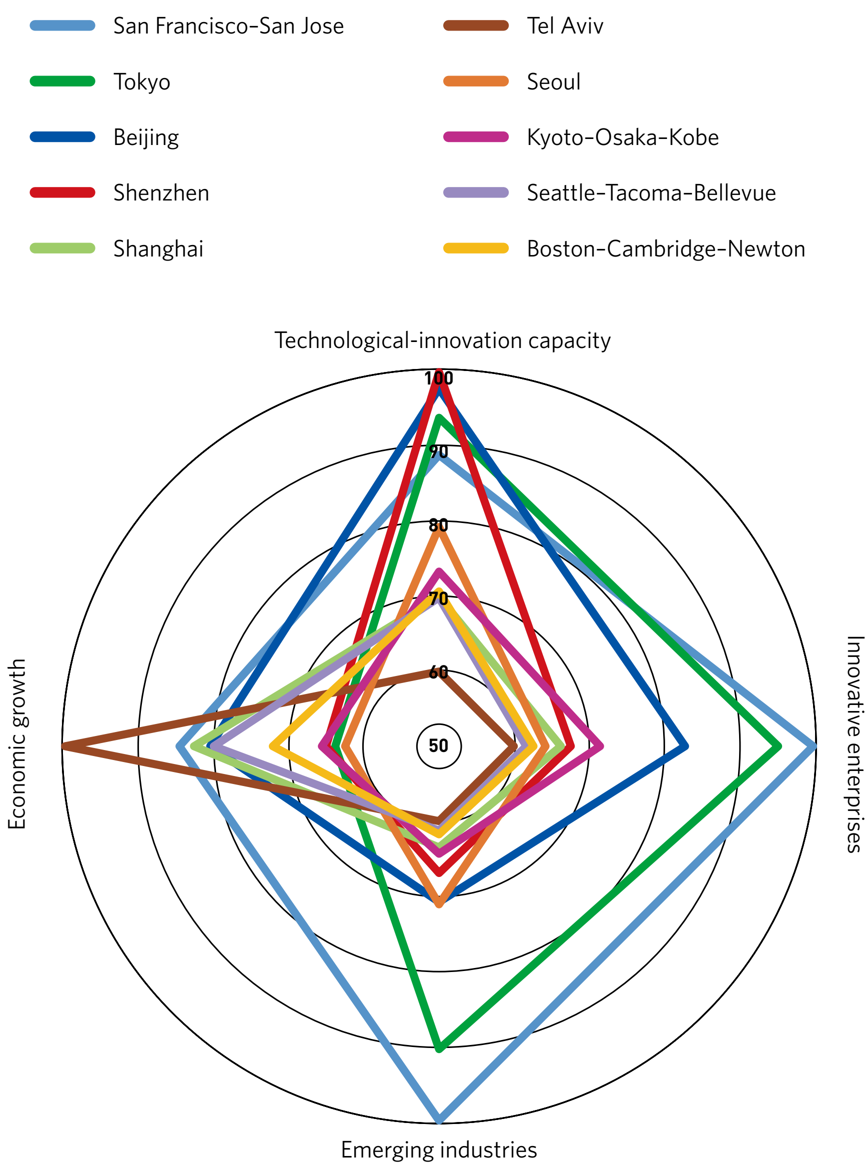
Innovation economy

As a global innovation hub emerges, innovation activities thrive and a vibrant innovation economy is developed. The GIHI examines the innovation economy from four aspects – technological-innovation capacity, innovative enterprises, emerging industries and economic growth – using eight metrics. The top five cities/metropolitan areas in innovation economy are San Francisco–San Jose, Tokyo, Beijing, Shenzhen and Shanghai.

Figure 7 shows the development in the four aspects of the top 10 cities (metropolitan areas) in innovation economy. Evidently, San Francisco–San Jose has a relatively balanced performance in all the four aspects, while others show more uneven development. For instance, in emerging industries, San Francisco–San Jose and Tokyo score above 90, while other cities/metropolitan areas score only in the 60-70 range, meaning there is room for improvement. Shenzhen, Beijing and Tokyo stand out in technological innovation capabilities, with scores above 90; Tel Aviv performs extremely well in labour productivity, but lags in other aspects.

Figure 7

Development patterns of the top 10 cities/metropolitan areas in innovation economy



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Chapter 5: Innovation economy

5.1 Technological-innovation capacity

It is generally believed that stronger intellectual property rights (IPRs) spur innovation and lead to increased technological innovation capacities. This report focuses on AI, an enabling technology in the information age, to measure the numbers of valid patents (from 1970 to 2018) and PCT patents (1970–2019) in this field per million people, and show a city's technological capabilities and the possible impacts of those capabilities on the world .

The top three cities/metropolitan areas here are Shenzhen, Beijing and Tokyo. Known as the window on China's reform and opening up, Shenzhen has attracted a large number of AI-focused high-tech companies, performing well in patenting activities. Looking at the two metrics, respectively, Beijing leads the world with 842 AI-related invention patents (a stock number) per million people, followed by Shenzhen and San Francisco–San Jose, while Tokyo ranks first in the number of PCT patents at 2,877 – again, followed by Shenzhen and San Francisco–San Jose. Figure 8 shows the numbers of valid invention patents and PCT patents for the top 10 cities/metropolitan areas in detail.

Figure 8

Numbers of valid invention patents and PCT patents for the top 10 cities/metropolitan areas in technological innovation capacity

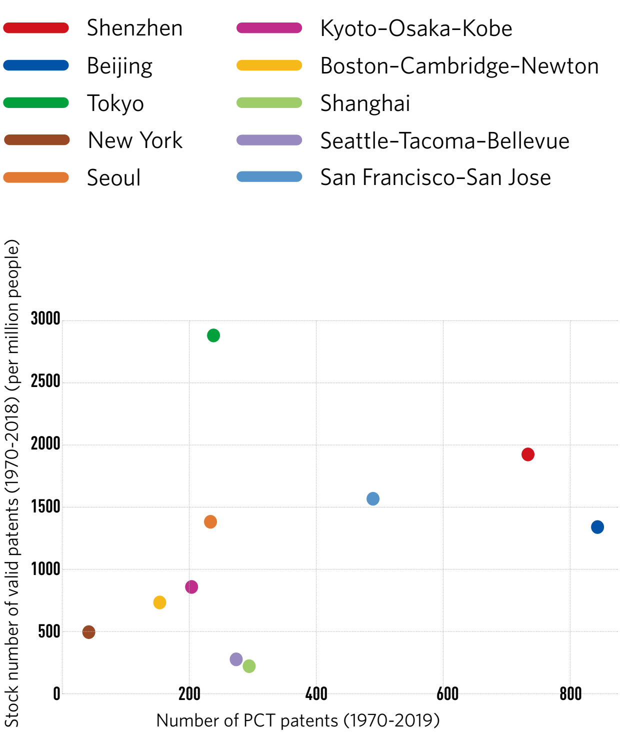
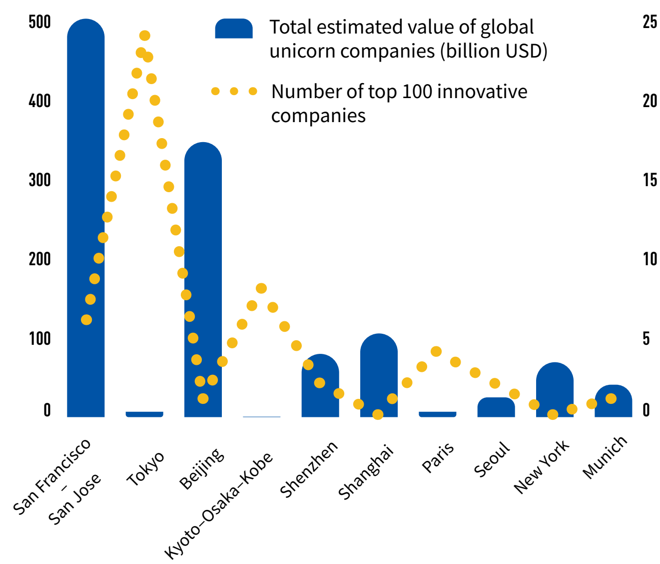


Figure 9

The total estimated value of unicorn companies and the number of top 100 innovative companies



5.2 Innovative enterprises

Innovative companies typically own their intellectual property rights and have their edge in technological innovation capabilities. The presence of unicorn companies, mostly high-tech start-ups, is usually regarded as indicative of the growth of new-economy sectors. Thus, the report uses the number of innovative companies, as listed in the Derwent Top 100 Global Innovators 2018-19, and the estimated total value of the top 500 unicorn companies, to measure the scale of innovative enterprises and innovative economic activities in a city.

The top three cities/metropolitan areas in this category are San Francisco–San Jose, Tokyo and Beijing. Of the top 100 innovative companies, 24 have headquarters in Tokyo, eight in Kyoto-Osaka-Kobe and six in San Francisco–San Jose. According to the Report of 2019 Top 500 Global Unicorn Enterprises Development, jointly released by the Research Center of Chinese Private Enterprises of Renmin University of China and the Beijing Institute of Hidden Unicorn (BIHU), San Francisco–San Jose boasts 103 of the global 500 unicorn companies, and their total corporate valuation is the highest among all the cities assessed. The San Francisco Bay Area, a place with the highest concentration of high-tech companies, has developed a positive interaction between technologies and its market. Beijing, Shanghai, Shenzhen and Seoul rank 2nd to 5th in terms of the estimated total value of their unicorns. The rise of Chinese unicorns is closely linked to the focus on smart-technology industries such as smart transportation, driven by cloud computing and big data technologies. The total estimated value of unicorn companies and the number of top 100 innovative companies for the top 10 cities/metropolitan areas in innovative enterprises are shown in Figure 9.

5.3 Emerging industries

Emerging industries refer primarily to industrial sectors that are characterised by their focus on high technologies, rapid growth, high added value and resource intensification. These include sectors such as biomedicine, electronic information, new materials, new energy and high-end equipment manufacturing. They play an important role in updating the regional economic structure and maintaining the competitiveness of the economy. This report focuses on the sizes of a city's high-tech manufacturing industry and its new-economy industries to measure the development in emerging industries. The former is defined to include the bio-manufacturing, high-tech equipment and information and communication technology (ICT) industries, based on the global industry classification standards (GICS) and using data from the Forbes Global 2000 List on the market value of high-tech manufacturing enterprises. The latter is measured by the 2019 total revenue of listed companies in the new-economy industries, primarily information technology and communication services.

The top three cities/metropolitan areas in emerging industries are San Francisco–San Jose, Tokyo and Seoul, with Beijing ranked fourth. San Francisco–San Jose has the highest concentration of high-tech manufacturing companies, with its companies' total market value 6.4 times that of Tokyo's. As for the total revenue of listed companies in the new-economy sector, Tokyo tops the list, with total revenue in 2019 2.36 times that of San Francisco–San Jose. The market value of high-tech manufacturing companies and the revenue of listed companies engaged in the new-economy sector are shown in Figure 10.

Figure 10

The market value of high-tech manufacturing companies and the revenue of listed companies in the new-economy sector for the top 10 cities/metropolitan areas in emerging industries

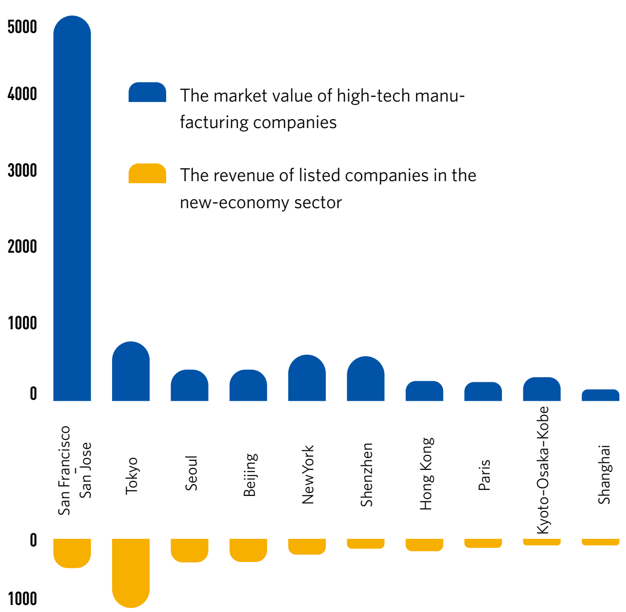
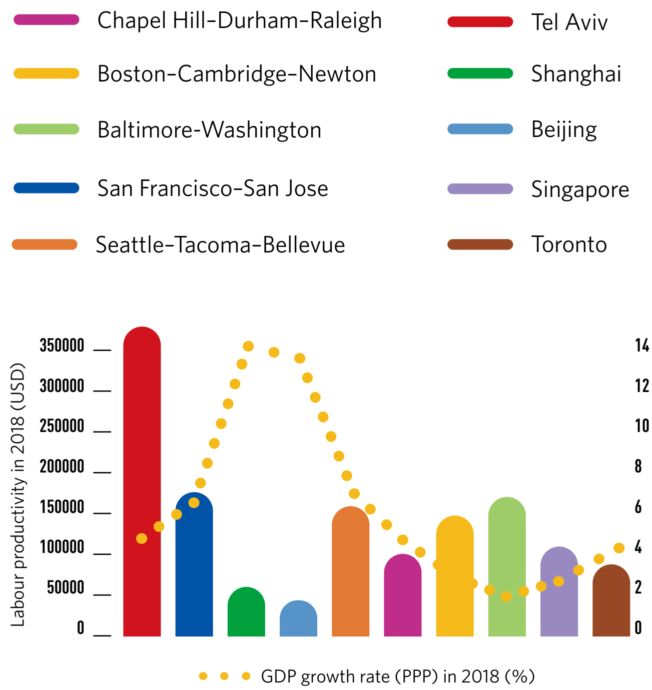


Figure 11

The GDP growth rate and labour productivity (2018) of the top 10 cities/metropolitan areas in economic growth



5.4 Economic growth

Innovation drives high-quality economic development and is essential for improving social productivity and public well-being. This report uses GDP growth rate, adjusted by 2018 purchasing power parity (PPP), to measure the overall economic growth level and living standards. Labour productivity (2018) is used to measure a city's development of social productivity.

The top three cities/metropolitan areas in economic growth are Tel Aviv, San Francisco–San Jose and Shanghai. Specifically, those leading in GDP growth are Shanghai, Beijing and Bangalore, while Tel Aviv leads in labour productivity, way ahead of San Francisco–San Jose and Baltimore–Washington, ranked second and third, respectively. Tel Aviv is the economic and technological centre of Israel and the country's entrepreneurial hotspot, known as the mini Los Angeles and Silicon Wadi. Israel, as a country of immigrants, has a high percentage of international students at its universities, such as Tel Aviv University and Bar-Ilan University. Figure 11 shows the GDP growth rate and labour productivity (2018) of the top 10 cities/metropolitan areas in economic growth.

Chapter 6

Innovation ecosystem

An innovation ecosystem refers to the economic, political and social environments beneficial to the development of science and technology innovation. Global innovation hubs usually have a supportive innovation ecosystem, enabling a healthy flow of innovation subjects and elements. The GIHI examines innovation ecosystem in four aspects – the level of openness and collaboration, support for start-ups, public services and innovation culture – using 14 level-3 indicators.

Figure 12 shows the performance in the four aspects above for the top 10 cities/metropolitan areas in innovation ecosystem. In general, the variation in the scores on public services and innovation culture tends to be small, but there is some divergence in the scores on openness and collaboration and support for start-ups, with most cities/metropolitan areas scoring in the 60-80 range, while a few are further ahead. In support for start-ups, San Francisco–San Jose leads the way, while others are far behind in a lower score range.

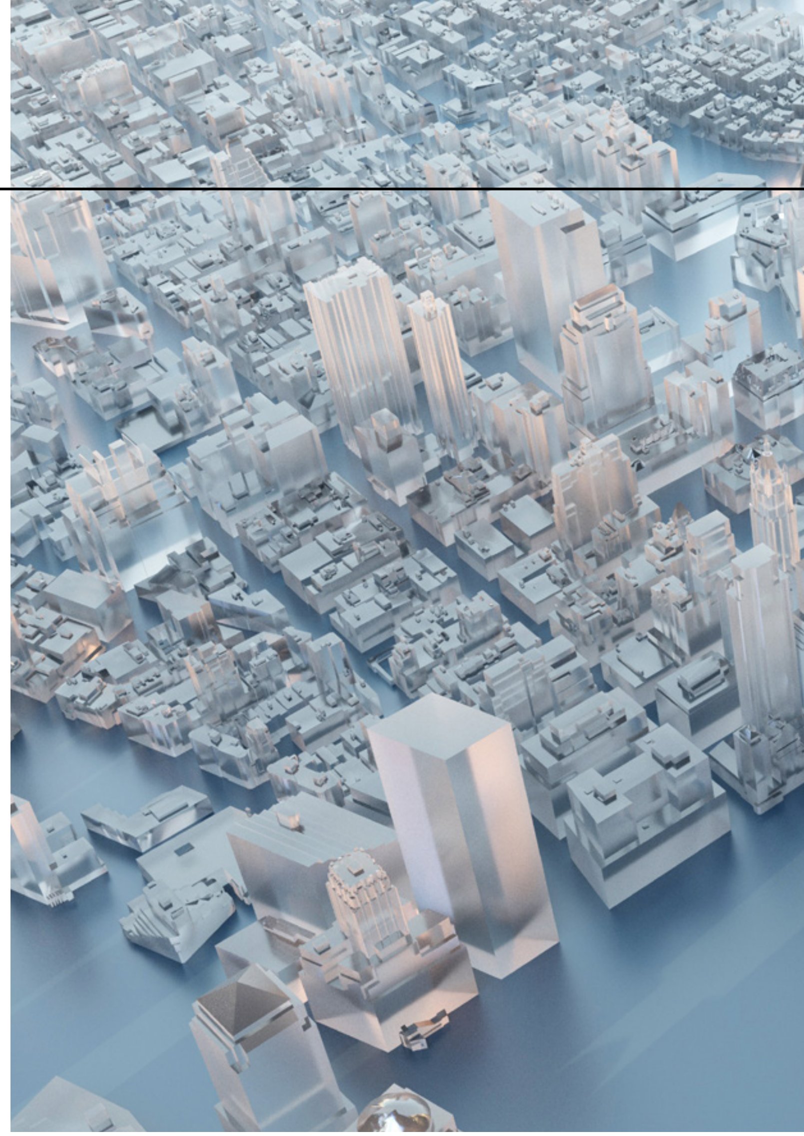
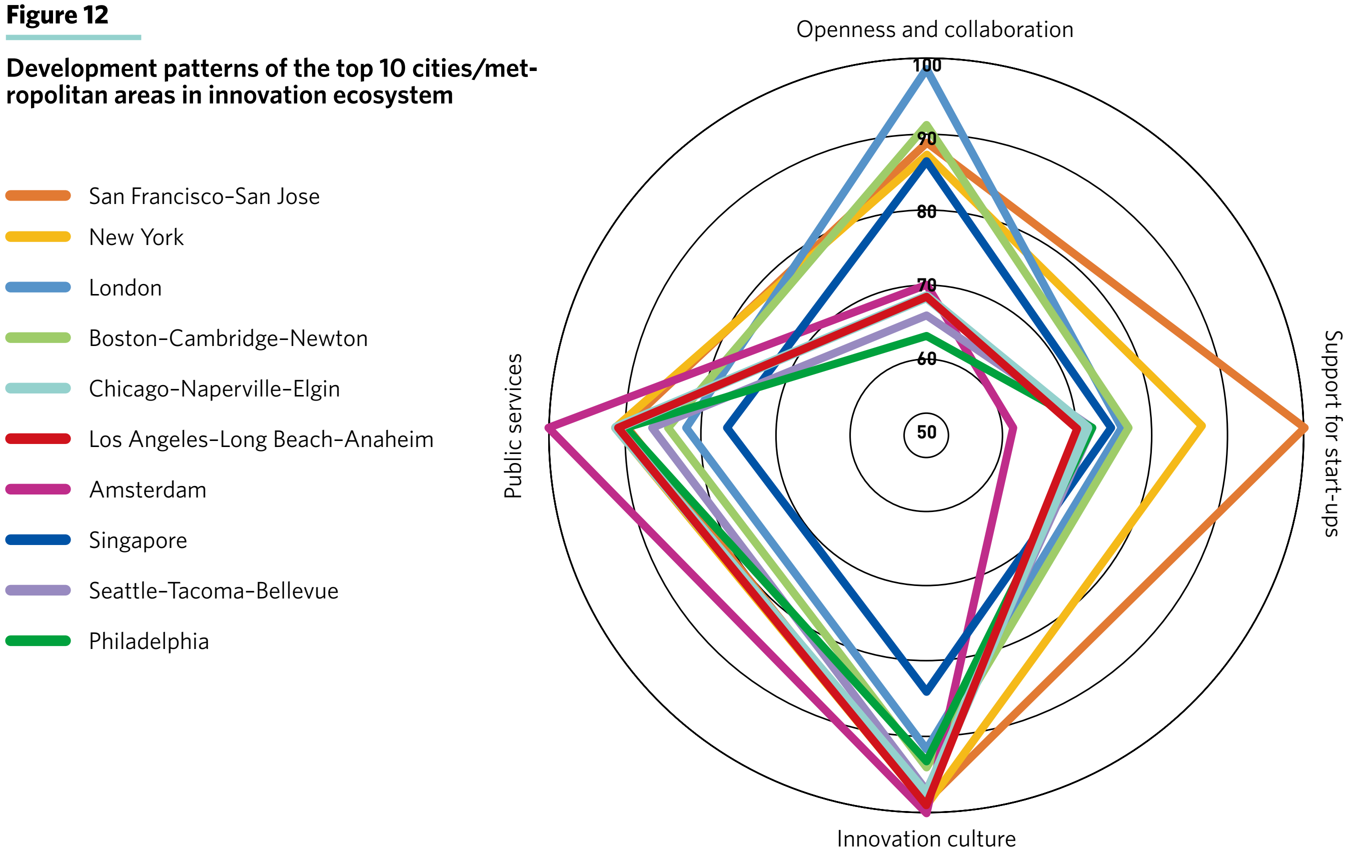


Figure 12

Development patterns of the top 10 cities/metropolitan areas in innovation ecosystem



6.1 Openness and collaboration

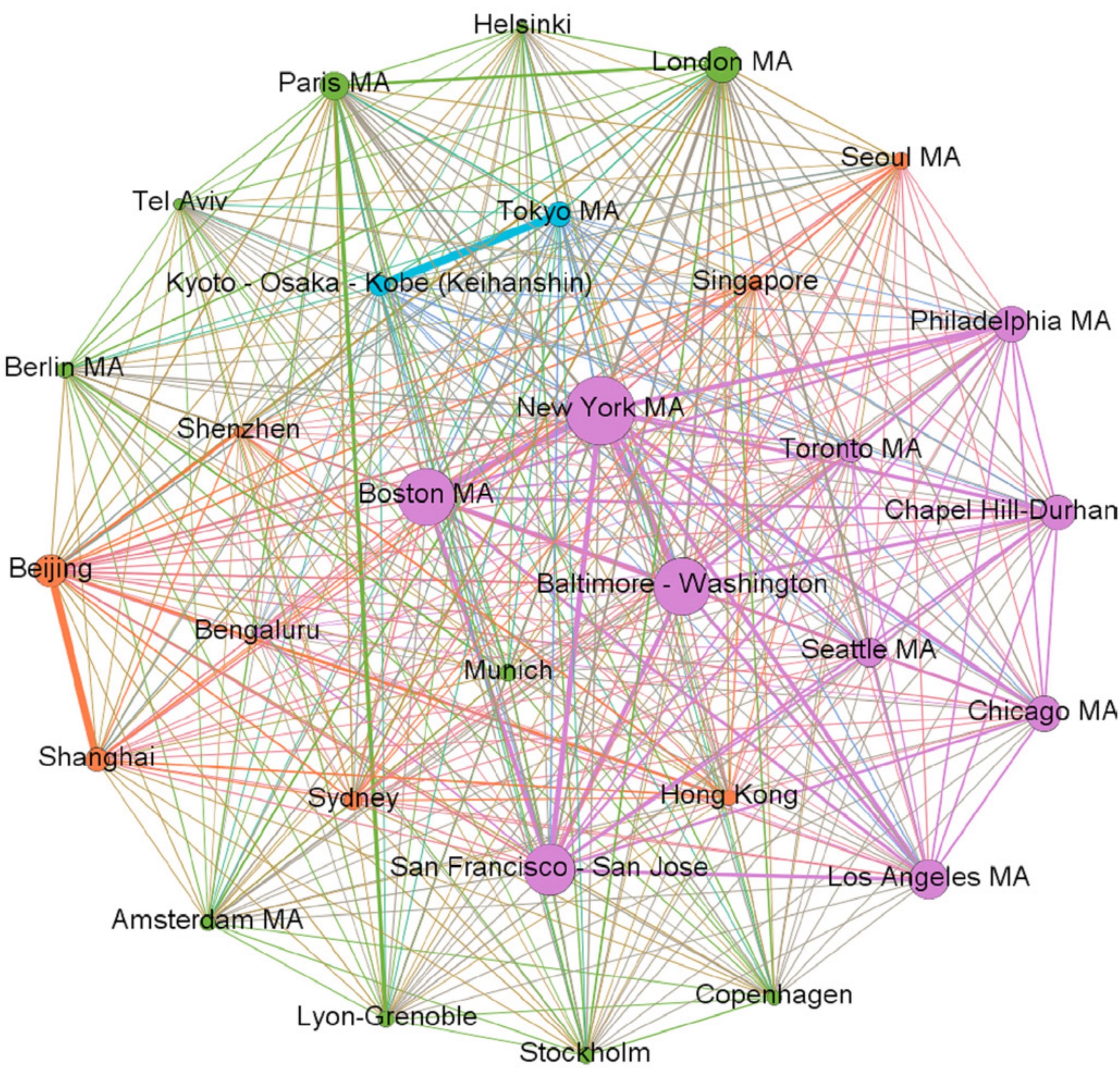
Openness to technologies, and active science and technology collaboration accelerate the process of knowledge creation and dissemination, promoting the accessibility of knowledge and the impact of technology. Openness and collaboration in economic activities are essential for a city's ability to attract global capital and promote the international impact of its economy. This report uses paper co-authorship centrality, patent collaboration network centrality, foreign direct investment (FDI, 2019 data), and outward foreign direct investment (OFDI, 2019 data) to measure a city's degree of openness and collaboration. These measures respectively reflect a city's connection in academic exchange and research collaboration, its position in technical exchange network, the flow of capital in the global city network, and the spill-over effect of its external capital export. Note that FDI differs from indirect investment, such as venture capital investment, in that in FDI the investor acquires more controlling interest in the foreign assets.

Chapter 6: Innovation ecosystem

Tokyo, London, Boston–Cambridge–Newton, Beijing, and San Francisco–San Jose are the top five cities/metropolitan areas in openness and collaboration. Figure 13 shows the paper co-authorship eigenvector centrality based on papers published in 2019. The node size indicates the importance of the city (metropolitan area) in the co-authorship network, and is determined by the number of links it has. The chart shows that Boston–Cambridge–Newton, New York, Baltimore–Washington, and San Francisco–San Jose stand out as major hubs in the paper collaboration network.

Figure 13

Paper co-authorship network (2019)



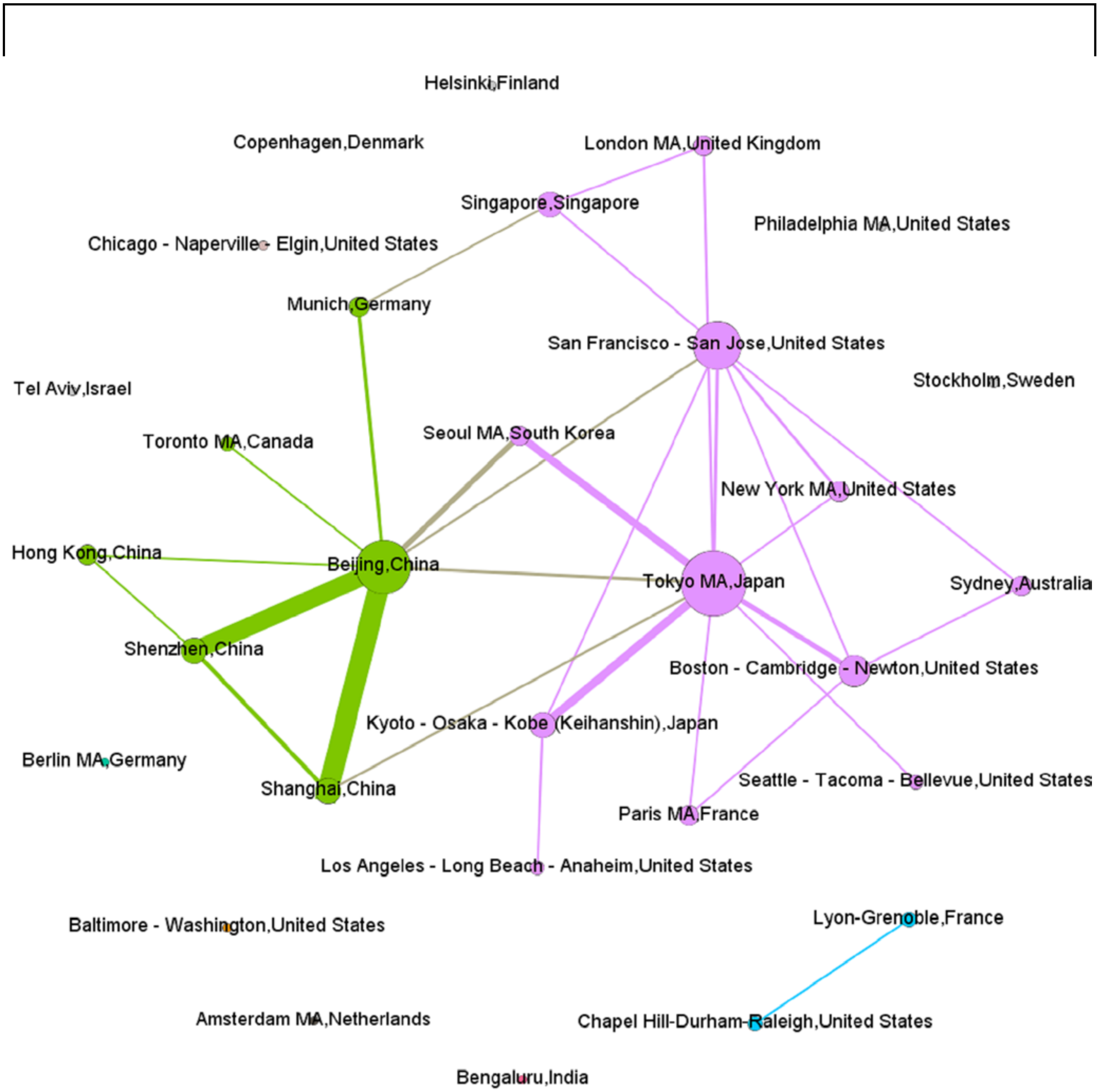


Figure 14 illustrates the AI-related patent collaboration network. Tokyo, Beijing, San Francisco–San Jose and Boston–Cambridge–Newton are active in collaborative patenting activities relevant to AI technologies. In terms of geographic coverage of patent collaboration, Tokyo collaborates with a wider group of cities distributed across the world, while for Beijing, its top collaborators are two other Chinese cities: Shanghai and Shenzhen.

Figure 14

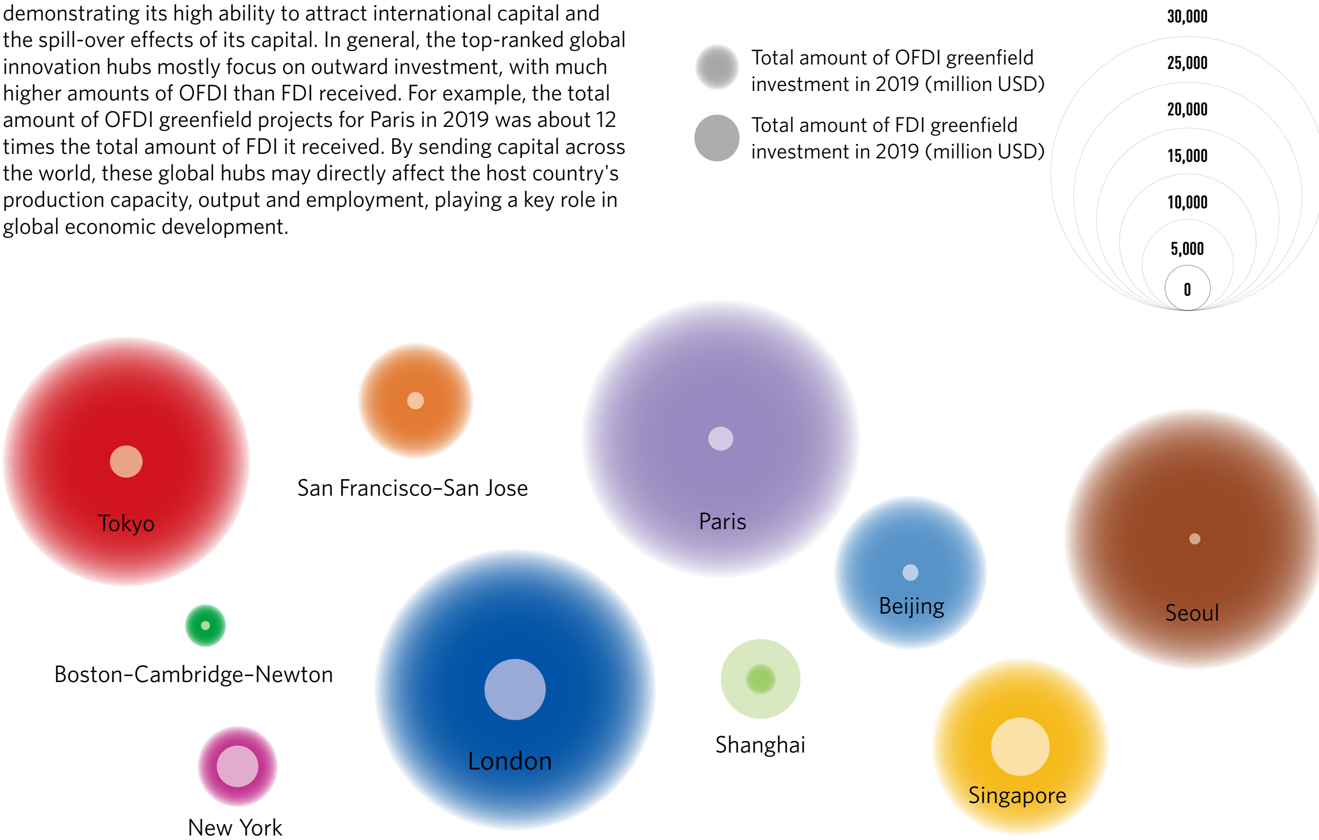
AI-related patent collaboration network (2019)

Chapter 6: Innovation ecosystem

Figure 15 shows the total amounts of FDI and OFDI greenfield investment for the top 10 cities/metropolitan areas in openness and cooperation. In 2019, Shanghai, London and Singapore led in the total amount of FDI received, and in terms of OFDI, the top three were London, Paris and Seoul. As a well-established global financial centre, London is highly ranked in both indicators, demonstrating its high ability to attract international capital and the spill-over effects of its capital. In general, the top-ranked global innovation hubs mostly focus on outward investment, with much higher amounts of OFDI than FDI received. For example, the total amount of OFDI greenfield projects for Paris in 2019 was about 12 times the total amount of FDI it received. By sending capital across the world, these global hubs may directly affect the host country's production capacity, output and employment, playing a key role in global economic development.

Figure 15

Total amounts of FDI and OFDI greenfield investment in 2019 for the top 10 cities/metropolitan areas in openness and collaboration



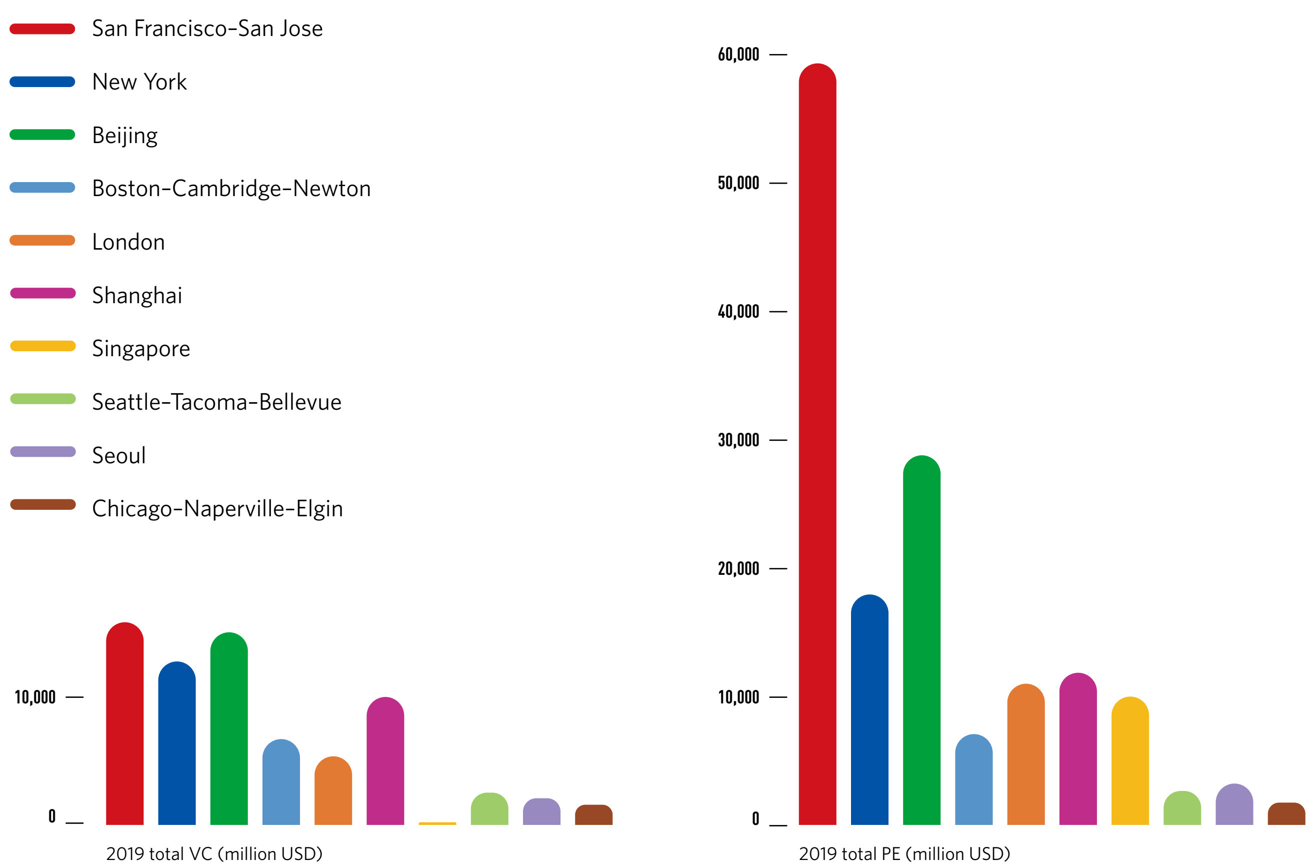
6.2 Support for start-ups

Encouragement of entrepreneurship and support for start-ups are essential for promoting the translation of innovation results and driving technological revolution and industrial development. This report evaluates the level of support to start-ups by measuring the amounts of venture capital (VC) investment and private equity (PE) investment, along with the ease of doing business. Investing in start-ups provides the needed capital support to the innovative companies, while enabling the investors to acquire some shares in the company. Such investing, measured here by the amount of VC investment, offers important financial guarantees in promoting the transformation of innovation results. PE refers to the growth capital received during the pre-IPO period of a proposed public company. Places with active investment activities are more likely to have a higher level of technological and business model innovations. The ease of doing business, on the other hand, reflects the external environment of business activities and the ease of market access and exit for market participants.

San Francisco-San Jose, New York, Beijing, Boston-Cambridge-Newton, and London are the leading performers in support for start-ups. Figure 16 shows the total amounts of VC and PE received by the top 10 cities. The total amount of VC investment in 2019 of San Francisco-San Jose was three times that of New York, demonstrating the San Francisco Bay Area's position as an ideal incubator for start-ups, given its well-established ecosystem and its open environment for investment and entrepreneurship. Beijing ranks third in support for start-ups, with the second-highest amounts of both VC and PE investment in 2019, while Shanghai's start-ups have attracted the fourth-highest VC and PE investment in the same period. Their performance demonstrates the vigour of the thriving start-up and high-capital activity environment in China.

Figure 16

2019 total VC and PE investment for the top 10 cities/ metropolitan areas in support for start-ups



6.3 Public services

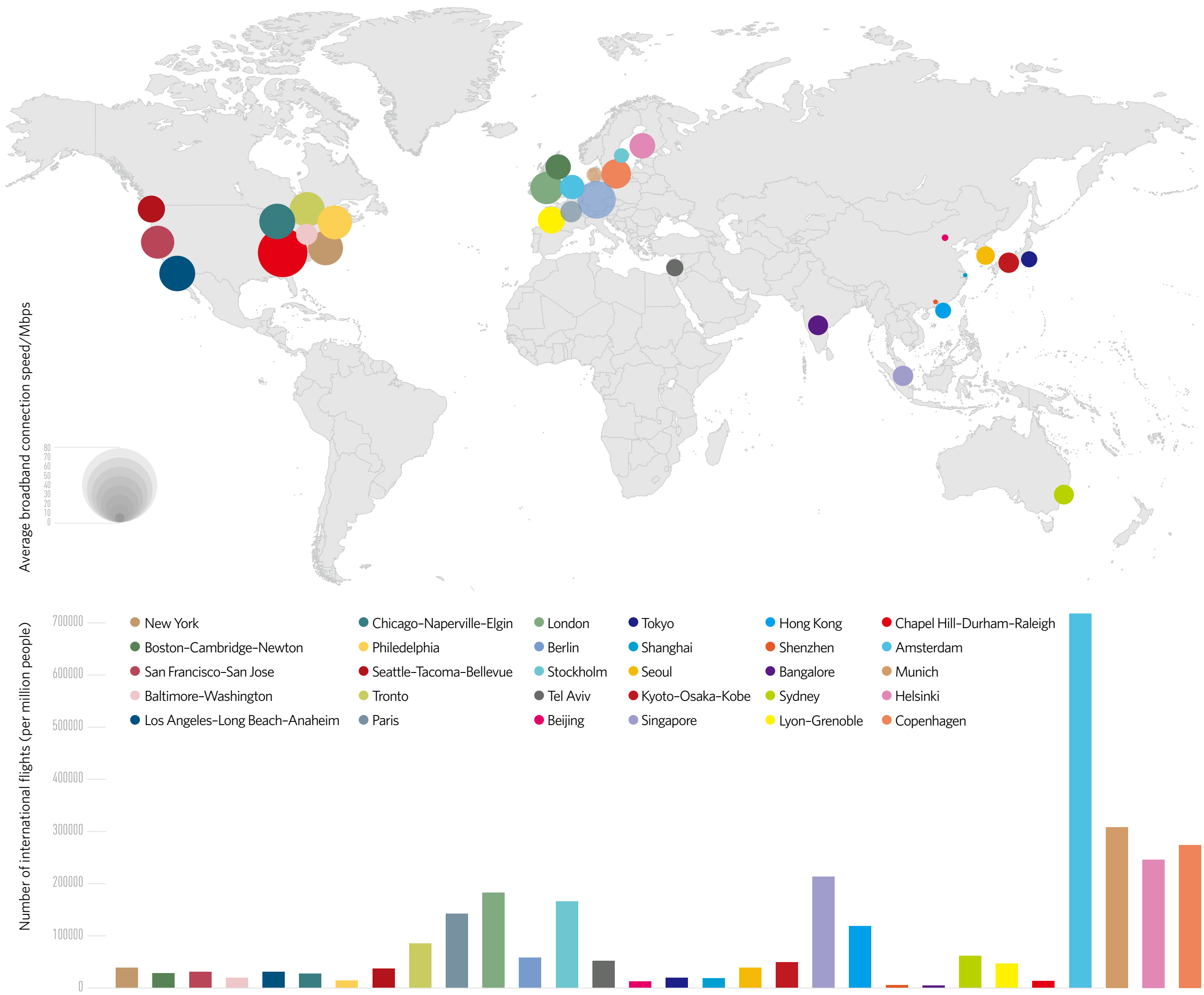
Urban public services are the infrastructure and facilities provided by cities to support innovation and entrepreneurship. In the knowledge economy, the exchange and creation of ideas depends on the development of communication technologies and transportation, while face-to-face, direct communications remain important for forming partnerships based on tacit consensus. Therefore, communication and transportation are indispensable tools for supporting innovative activities. The GIHI uses the number of international flights (per million people) to measure the frequency of collaboration and exchanges across national borders. The speed of broadband connections – an indicator for the efficiency of cross-regional data exchange and access – along with the number of data centres (public clouds) – which are information facilities that support innovation – are used to represent the maturity of a city's network infrastructure.

The top-ranked city in public services is Amsterdam, followed by Chapel Hill–Durham–Raleigh, New York, Chicago–Naperville–Elgin and Los Angeles–Long Beach–Anaheim. Amsterdam, with a well-developed air transportation system, shows a clear advantage in the number of international flights. Chapel Hill–Durham–Raleigh leads in the number of hosted data centres, and in average broadband connection speed. Note that, given the lack of city-level data, national-level data are used for the number of data centres (public clouds); by this metric, the United States has the largest market size for hosted data centres, followed by Germany, France, the Netherlands, Canada, Australia, China and Japan. The top 10 cities with the fastest broadband connection speed are all in the US or Europe.

Chapter 6: Innovation ecosystem

Figure 17

Number of international flights and broadband connection speed



6.4 Innovation culture

Innovation culture is a key predictor of the wealth of society produced by innovation activities. Such a culture creates the conditions for innovation, enhancing a city's competitiveness and sustaining its long-term prosperity. This report measures innovation culture by talent attraction, entrepreneurial spirit, degree of internationalisation of culture-related industries, and the number of public museums and libraries (per million people). Talent attraction reflects people's recognition of a city's innovation culture. The entrepreneurial spirit is a driving force behind technological innovation and a source of economic growth. The degree of internationalisation of culture-related industries, measured by the number of headquarters of multinational companies in advertising, convention/exhibition, law, consulting, insurance and accounting businesses, based on the Globalization and World Cities (GaWC) rating data, demonstrates the openness of a city's innovation culture. The number of public museums and libraries as cultural places that may draw innovators, meanwhile, reflects a city's public cultural environment.

Amsterdam, with the most public museums and libraries, stands out in this rating on city culture. It is followed by New York, which scores highly on talent attraction and entrepreneurial spirit. Los Angeles–Long Beach–Anaheim and San Francisco–San Jose are tied for third place.

Chapter 7

Summary and outlook into future

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The GIHI is constructed based on three dimensions of innovation: research innovation, the innovation economy and innovation ecosystem. Using objective data, this report gives a preliminary ranking of selected cities, based on the GIHI, in the hope of exploring the forces, key elements and conditions for innovation revolution. By showing the necessary preparation cities need to make to fully participate in the process of economic globalisation, the core competitiveness they need to work on, and their development directions and prospects, the report expects to help inspire global science and technology enterprises. It also hopes to spur government agencies to pursue innovation, and cultivate an innovation system that supports high-end production sharing of global industries. We hope the GIHI 2020 can act as a guide for science and technology policy-makers and innovation practitioners to promote innovation and economic development.

The main findings are:

First, cities/metropolitan areas have varied development patterns and unique positioning in innovation development. The majority of the cities assessed here have uneven development in research innovation, innovation economy and innovation ecosystem. Some show clear advantages in certain aspects of innovation, while also having room for improvement in other aspects.

Second, research innovation plays a key role in determining a city's position in the global innovation network. Evidently, cities housing prestigious universities or research institutions, or with accumulated research strengths, dominate the higher ranks in the GIHI.

Third, the geographical distribution of global innovation hubs is quietly changing. Asian cities are on the rise, and their rapid development in digital economy and new-economy sectors has enhanced their standing in the innovation economy. As for European and American cities, they stand out in the supportive innovation ecosystem, performing exceptionally well in the attractiveness of public services and in fostering innovation culture.

Constructing a global, city-level index system for assessing innovation capacities is challenging. This report builds the GIHI evaluation model based on the concept, connotation and characteristics of global innovation hubs, and takes into account a variety of factors – including tradition and future prospects, science and technology, and economy, performance and environment – to select the indicators for measurement. It also draws on survey results from well-recognised third-party organisations, such as the World Economic Forum and the World Bank, to reduce subjectivity, while ensuring a solid theoretical foundation and broad indicator coverage for the index system.

Due to capability and time constraints, compounded by the impact of the COVID-19 pandemic, the 2020 GIHI assessment system has its shortcomings. We will improve future reports and are aiming for regular publication to track the dynamic evolution of the global innovation network and identify patterns of change, making it a credible reference for global innovators, innovation evaluators and policy makers.

References

1. Kraay, A., Kaufmann, D., & Mastruzzi, M. (2010). The worldwide governance indicators: methodology and analytical issues. The World Bank.
2. Csomos, G., & Toth, G. (2016). Exploring the position of cities in global corporate research and development: a bibliometric analysis by two different geographical approaches. Journal of Informetrics, 10(2), 516-532.
3. Sassen, S. (1991). The Global City. Princeton, NJ: Princeton University Press.
4. Parnreiter, C. (2010). Global cities in Global Commodity Chains: exploring the role of Mexico City in the geography of global economic governance. Global Networks, 10(1), 35–53.
5. Sassen, S. (2001). The global city: New York, London, Tokyo. Princeton, NJ: Princeton University Press.
6. Derudder, B., & Taylor, P. J. (2017). Central flow theory: comparative connectivities in the world-city network. Regional Studies, 52(8), 1029–1040.
7. Valley, J. V. S. (2020). 2020 Silicon Valley Index. Joint Venture Silicon Valley.
8. OECD/Eurostat (2018), Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation,4th Edition, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg.
9. Hollanders, H., Nordine, E. S., Merkelbach, I., & Khalilova, A. (2020). European Innovation Scoreboard 2020. European Commission.
10. 詹·法格伯格，戴维·莫利，理查德·纳尔逊．(2009). 牛津创新手册．知识产权出版社．
11. Schwab, K.(2019). The Global Competitiveness Report 2019. World Economic Forum.
12. World Bank. 2020. Doing Business 2020. Washington,DC: World Bank. License: Creative Commons Attribution CCBY 3.0 IGO.
13. Bris, B., & Cabolis, C. (2020). The IMD World Talent Ranking 2019. IMD World Competitiveness Center.
14. 薛澜，陈玲，王刚波，等．中美产业创新能力比较：基于对 IC 产业的专家调查 [J]. 科研管理，2016, V37(004):1-8.
15. United Nations Department of Economic. (2016). The World's Cities in 2016. UN.
16. Nature.(2018).Nature Index Nature Index Science Cities 2018.Nature.
17. 倪鹏飞，马尔科·卡米亚，王海波．(2018). 全球城市竞争力报告 (2017-2018)．社会科学文献出版社．
18. Cornell University, INSEAD, and WIPO (2019). The Global Innovation Index 2019: Creating Healthy Lives—The Future of Medical Innovation, Ithaca, Fontainebleau, and Geneva.
19. 上海市信息中心．(2017) .2017 全球科技创新中心评估报告．上海市信息中心．
20. 科睿唯安．(2019). 德温特 2018-2019 年度全球百强创新机构．德温特，科睿唯安．
21. 中国人民大学中国民营企业研究中心，北京隐形独角兽信息科技院 (BIHU) .2019 全球独角兽企业 500 强发展报告．中国人民大学中国民营企业研究中心，北京隐形独角兽信息科技院 (BIHU)．

Ⅰ Note Refer to the Global Urban Competitiveness Report (2019-2020) The World: 300 years of transformation into city jointly published by the Chinese Academy of Social Sciences (the National Academy of Economic Strategy) and UN-Habitat, http:// gucp.cssn.cn/zjwl/hzhb/201911/t20191118_5044016.shtml

Ⅱ Note According to the World Bank, the world's total population in 2018 was estimated at 7.594 billion, https://datacatalog.worldbank.org/

Ⅲ Note The world's leading universities and research institutions are based on the top 200 Academic Ranking of World Universities (ARWU) and the Nature Index 2020 top 200 research institutions for publications, respectively.

Ⅳ Note According to IMF, the world's total GDP in 2018 was worth $84.74 trillion.

Ⅴ Note Refer to the sharing service platform of CAS large research infrastructures, http://lssf.cas.cn/lssf/kpyd/zsk/kyjd/201006/t20100616_4513343.html

Appendix

Appendix I:
GIHI indicator definitions and data sources

A. Research innovation

1) Number of research and development personnel (per million people)
Definition: the number of research and development (R&D) personnel per million people in the country in which the city is assessed in 2017 or 2018.

Data source: World Development Indicators from the World Bank (https://datacatalog.worldbank.org/dataset/world-development-indicators).

2) Number of highly cited scientists
Definition: the number of highly cited scientists the city has had between 2000 and 2018, with a highly cited scientist being a researcher who has published at least one paper in the top 1% citation range in his or her field in three out of five years, the same below.

Data sources: Digital Science-Dimensions

3) Number of winners of top scientific awards
Definition: the top scientific awards refer to the Nobel Prize (excluding the Nobel Prize for Literature and the Peace Prize), 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 most recent workplace or institution by using "biography" and "institution" in Wikipedia, and then summed up.

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).

4) Top 200 world-class universities
Definition: This study uses the number of top 200 universities in the ARWU World University Rankings as an indicator of a city's top universities. Academic Ranking of World Universities (ARWU), released by the Center for World-Class Universities (CWCU) of the Graduate School of Education of Shanghai Jiaotong University (formerly the Institute of Higher Education), ranks the world's universities based on objective indicators such as the quality of education, quality of faculty, research output, and performance per faculty, etc. The ARWU list is one of the four most authoritative university rankings in the world, with more than 1,800 universities ranked annually, and publishes the top 1,000 universities in the world.

Data sources: Academic Ranking of World Universities (http://www.shanghairanking.com/ARWU2019.html).

5) Top 200 world-class research institutions
Definition: the number of top 200 scientific institutions in the world in terms of scientific publications according to Nature Index 2019.

Data sources: Nature Index.

6) Number of large scientific facilities
Definition: the large scientific facilities counted in this report include two major categories: the first is dedicated research installations, i.e., research installations built for major science and technology goals in specific disciplinary fields; the second is public experimental platforms, i.e., large public experimental installations with strong support capabilities for basic, applied basic 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 organised by Tsinghua University.

7) Number of top 500 supercomputer centres
Definition: A supercomputer is a computer consisting of hundreds, thousands or more processors (machines) that can process large and complex tasks that cannot be done with ordinary PCs and servers. This study assesses the level of development of IT science facilities in each city by measuring the number of world's top 500 computers and counting the supercomputers located in the same institution as one supercomputer centre.

Data sources: Global Top 500 Supercomputers in November 2019 (https://www.top500.org/list/2019/11/)

8) 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 2018.

Data sources: Digital Science-Dimensions

9) Proportion of papers cited in patents, policy reports and clinical trials

Definition: the proportion of scientific papers published by the city in 2015-2019 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

1) Patent-related indicators: stock of active patents (per million people) and number of PCT patents
Definition: this study takes five fields, including machine learning, computer vision, natural language processing, expert systems and robotics, as the main fields of artificial intelligence, and formulates keywords for artificial intelligence patent search through multiple rounds of discussions between experts in the artificial intelligence industry and patent search experts. 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, the patent publication year of this report was between 1970 and 2019. By removing duplicate data and other patent data pre-processing, 281,585 patents for AI applications are obtained, including 87,514 for machine learning, 56,948 for computer vision, 63,616 for natural language processing, 48,614 for expert systems, and 31,136 for robotics, according to which a preliminary exploration of the innovation capabilities of AI in major city clusters around the world is conducted.

There are two main categories of valid patents: 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 the

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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".

The patent priority country/region field is used to characterize the origin of the technology to count the number of patent applications in each city cluster. The patent family field is used to characterize the international layout of patented technology to count the export of patented technology from each city.

Data sources: Derwent Innovation patent database.

2) Number of top 100 innovative enterprises
Definition: the number of headquarters of Derwent Top 100 Global Innovators 2018-2019 in a city

Data Sources: Derwent Top 100 Global Innovators 2018-2019 report

3) Valuation of unicorn enterprises
Definition: unicorn is the term used to refer to the startups that are valued at $1 billion or more, have existed for a relatively short period of time (typically within a decade) and have not been listed. This report uses unicorn enterprise valuation data from the Global Unicorn Top 500 Report 2019 jointly published by the Research Center of China's Private Enterprises of Renmin University and Beijing Institute of Hidden Unicorn (BIHU).

Data Source: Unicorn List of Renmin University of China

4) 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 2020 Forbes Global 2000 list by city (metropolitan area). 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 "chemical" "biopharmaceutical" and "health care equipment and services" enterprises. The electronic information enterprises include companies engaged in IT software and services, semiconductor, technical hardware and equipment and communication services sectors. High-end manufacturing companies include those engaged in aerospace & defense, materials and transportation business.

Data sources: Forbes China (https://www.forbeschina.com/lists/1735)

5) 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, and in line with the direction of industrial development. 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 2019 operating incomes of the listed companies in new economy industries of the cities.

6) GDP growth
Definition: This study uses GDP growth in 2018 (using 2015 as the real GDP base) for each city after evaluating the level of purchasing power.

Data sources: (1) GDP-PPP from OECD and statistics offices of countries and cities; (2) PPP index from the World Bank.

7) Labor productivity
Definition: It is the output per unit of labor, calculated as gross regional product (GRP) divided by the number of laborers. The GDP used in this study is the GDP-PPP data for 2018 (based on 2015).

Data sources: (1) some city data were directly from OECD

Definition of the new economy industries (based on GICS classification)

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

statistics; (2) some were calculated based on labor force data when no data was directly available. For example, labor force data for Chinese cities are from the China Urban Statistics Yearbook 2019; those of Hong Kong, Singapore and Boston-Cambridge-Newton are from Trading Economics and the U.S. Economic Census Bureau, and Tel Aviv data are from the Tel Aviv government website; (3) for Moscow and Bangalore, due to missing data, their countries' data were used instead.

C. Innovation ecosystem

1) 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 2019 inter-city paper publication collaboration matrix of 30 evaluated cities (metropolitan areas). The importance of a node in the eigenvector centrality depends on both the number of neighboring nodes (i.e., the degree of the node) and the importance of the neighboring nodes, which provides a more accurate representation of the node's position in the network. The eigenvector centrality calculates the centrality of a node based on the centrality of neighboring nodes, and the eigenvector centrality of node i is $Ax = \lambda x$, where A is the adjacency matrix of a graph G with the eigenvalue λ. For information about the calculation of the eigenvector centrality, see the following link: https://networkx.github.io/documentation/stable/reference/algorithms/generated/networkx.algorithms.centrality. eigenvector_centrality_numpy.html?highlight=eigenvector_centrality_numpy

Data sources: Digital Science-Dimensions

2) Patent cooperation network centrality

Definition: patent cooperation is the joint filing of patent applications by two or more researchers or organizations. In this study, the patent cooperation network centrality refers to the number of cities a city cooperates with in filing patent applications, which is calculated as shown below.

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

Data sources: Derwent Innovation patent database.

3) Foreign Direct Investment (FDI) and Outward Foreign Direct Investment (OFDI)

Definition: this study measures a city's attraction to foreign investment by its foreign direct investment (FDI) in greenfield projects (2019) and its global presence by its OFDI in greenfield projects (2019).

Data sources: fDi markets, an online database of cross-border greenfield investments (https://www.fdimarkets.com/).

4) Venture capital investment

Definition: This study measures the venture capital activity by measuring the amount of venture capital investment received in 2019, defined as the total financing amount in Pre-Seed, 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/)

5) Private equity

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 2019. PE investment is calculated as the total of nine rounds of financing from Series C, D, E, F, G, H, I, J and K.

Data sources: CB Insights (https://www.cbinsights.com/).

6) Ease of Doing Business

Definition: The World Bank's Doing Business report combines data on 10 areas of business regulation, including "starting a business, obtaining construction permits, getting electricity, registering property, getting credit, protecting minority investors, paying taxes, trading across borders, enforcing contracts and going bankrupt" to formulate an ease of doing business score to reveal where an economy stands in relation to best regulatory practices, with higher scores indicating a more business-friendly environment. This study measures the ease of doing business of each city with the ease of doing business scores of the economy the city belongs to in the World Bank's Doing Business 2020 report. Some cities are part of the sample cities of the report, thus their city-level data are available and adopted.

Data sources: World Bank (https://www.doingbusiness.org/).

7) Number of data centres (public cloud)

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 country where the city is located is used as an indicator of the city's digital economy development.

Data sources: Cloudscene (https://cloudscene.com/)

8) 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 July 17, 2020.

9) Number of international flights (per million people)

Definition: in this report, the number of international flights (per million people) means the number of all direct flights originating and terminating in the city in the year 2019.

Data source: OAG, the world's leading provider of aviation intelligence (https://www.oag.com/).

10) Talent Attraction

This report uses the IMD World Talent Ranking's attractiveness index as one of the indicators of a city's innovation competitiveness. WTR's assessment of attractiveness is based on 11 indicators, including the cost of living, the number of highly skilled people and brain drain.

Data sources: IMD World Competitiveness Center, The IMD World Talent Ranking 2019.(https://www.imd.org/research-knowledge/reports/imd-world-talent-ranking-2019/)

Appendix

11) Entrepreneurship
Definition: this study cites "Entrepreneurial culture" from the WEF (World Economic Forum) Global Competitiveness Index 4.0 as one of the indicators of regional entrepreneurial culture. The indicators include: (1) Attitudes towards entrepreneurial risk, (2) Willingness to delegate authority, (3) Growth of innovative companies, (4) Companies embracing disruptive ideas.

Data sources: World Economic Forum (http://reports.weforum.org/global-competitiveness-report-2019/downloads/).

12) Degree of internationalization of the culture-related industries
Definition: it is measured by the GaWC's categorization of world cities. The GaWC (Globalization and World Cities) examines cities worldwide to narrow them down to a roster of world cities, then ranks these based on their connectivity through five sectors: finance, advertising, law, accountancy and management consultancy. It classifies world cities into Alpha, Beta, Gamma and Sufficiency tiers, namely the first-tier, second-tier, third-tier and fourth-tier world cities, in order to measure a city's position and integration in the global high-end manufacturing and production services network. Based on the 2020 roster, this report assigns 12-1 points to 12 categories of world cities (Alpha++, Alpha+, Alpha, Alpha-, Beta+, Beta, Beta-, Gamma+, Gamma, Gamma-, High Sufficiency and Sufficiency), respectively. For the cities that are not included in the roster, a point of 0 is assigned.

Data sources: The World According to GaWC 2020 (https://www.lboro.ac.uk/gawc/world2020t.html)

13) 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 2019 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 II: The city selection process

First, the top 100 science cities were selected based on the Nature Index 2018 Science Cities; then the Global Urban Competitiveness Report 2017-2018 of the Chinese Academy of Social Sciences (CASS) and the Global Scientific and Technological Innovation Centres Evaluation Report 2017 of the Shanghai Information Center were cross-referenced to select the first 137 candidate cities, with the cities that have a population less than 1 million removed.

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 use five indicators, namely total GDP, GDP growth rate, number of top science and technology award winners, total number of scientific papers and number of leading innovation enterprises (top 500 unicorn enterprises, top 50 innovation enterprises, and top 100 digital economy enterprises). Considering the overall ranking of core indicators and the ranking of individual indicators, we select the cities that rank in the top 30 for any three indicators, and then select the cities that rank in the top 10 for a single indicator.

Scheme 2: Hierarchical Ranking. It examines the performance of cities in terms of economic growth, scientific research and the innovation economy. Firstly, the total GDP, GDP per capita and GDP growth rate are selected to represent the scale, quality and trend of the economy; any city that makes it to the top 10 by two indicators is selected; Secondly, the total number of scientific papers, Nature Index and the number of top science and technology award winners are selected to represent the scale, quality and top human resources of science and technology innovation, respectively; any city that makes it to the top 10 by two indicators is selected. For indicators like the numbers of top 500 unicorn enterprises, top 50 innovation enterprises and top 100 digital economy enterprises, any city that makes it to the top places by two indicators is selected.

A primary list of 39 cities were selected by comparing the two schemes above, and 23 innovation experts and entrepreneurs were invited to conduct a questionnaire survey in order to obtain a list of innovation hubs that were in line with the experts' intuition and general consensus. It was a city profile-based questionnaire, in which experts were invited to select the cities he/she thought were the global centres of scientific and technological innovation, and then to describe the characteristics of these cities in a pictorial way to form a final list of 30 cities (metropolitan areas), covering 153 administrative cities.

Appendix III: 30 evaluated cities (metropolitan areas)

No.	City (metropolitan area)	Administrative division	Country
1	New York MA	New York City	USA
		Staten Island	USA
		Paterson	USA
		Bridgeport	USA
		Edison	USA
		New Haven	USA
		Stamford	USA
		Brooklyn	USA
		The Bronx	USA
		Queens	USA
		Newark	USA
		Jersey City	USA
2	Boston - Cambridge - Newton	Lowell	USA
		Cambridge	USA
		Boston	USA
3	San Francisco - San Jose	Berkeley	USA
		Concord	USA
		Antioch	USA
		San Jose	USA
		Fremont	USA
		Richmond	USA
		Santa Rosa	USA
		Oakland	USA
		Hayward	USA
		San Mateo	USA
		Vallejo	USA
		Santa Clara	USA
		San Francisco	USA
		Sunnyvale	USA
4	Baltimore - Washington	Baltimore	USA
		Washington, D.C.	USA
		Arlington	USA
		Alexandria	USA

No.	City (metropolitan area)	Administrative division	Country
5	Los Angeles - Long Beach - Anaheim	Torrance	USA
		Santa Ana	USA
		Rancho Cucamonga	USA
		Pomona	USA
		Pasadena	USA
		Orange	USA
		Los Angeles	USA
		Long Beach	USA
		Huntington Beach	USA
		Glendale	USA
		Fullerton	USA
		El Monte	USA
		Downey	USA
		Costa Mesa	USA
		Anaheim	USA
6	Chicago - Naperville - Elgin	Naperville	USA
		Chicago	USA
		Aurora	USA
7	Philadelphia MA	Philadelphia	USA
8	Seattle - Tacoma - Bellevue	Tacoma	USA
		Seattle	USA
		Renton	USA
		Kent	USA
		Everett	USA
		Bellevue	USA
9	Toronto MA	Toronto	Canada
		Oshawa	Canada
		Vaughan	Canada
		Richmond Hill	Canada
		Burlington	Canada
		Markham	Canada
		Brampton	Canada
		Mississauga	Canada
		Oakville	Canada
10	Paris MA	Paris	France
		Cergy	France
		Pontoise	France
		Saint-Quentin-en-Yvelines	France
		Boulogne-Billancourt	France
11	London MA	London	UK
		Watford	UK
		Croydon	UK
		Enfield Town	UK
12	Berlin MA	Berlin	Germany
		Potsdam	Germany
13	Stockholm	Stockholm	Sweden
14	Tel Aviv	Tel Aviv	Israel
15	Beijing	Beijing	China

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No.	City (metropolitan area)	Administrative division	Country
16	Tokyo MA	Tokyo	Japan
		Asaka	Japan
		Zama	Japan
		Kamakura	Japan
		Chigasaki	Japan
		Ōme	Japan
		Hino	Japan
		Atsugi	Japan
		Fujisawa	Japan
		Noda	Japan
		Yokosuka	Japan
		Ichihara	Japan
		Kashiwa	Japan
		Chiba	Japan
		Sōka	Japan
		Saitama	Japan
		Koshigaya	Japan
		Abiko	Japan
		Ageoshimo	Japan
		Tokorozawa	Japan
		Kawasaki	Japan
		Matsudo	Japan
		Narita	Japan
		Higashimurayama	Japan
		Musashino	Japan
		Sayama	Japan
		Yokohama	Japan
		Nagareyama	Japan
		Kawagoe	Japan
		Sakura	Japan
		Chōfu	Japan
		Machida	Japan
		Kawaguchi	Japan
		Isehara	Japan
		Kisarazu	Japan
		Hiratsuka	Japan
		Hachiōji	Japan
		Honchō	Japan
17	Shanghai	Shanghai	China
18	Seoul MA	Seoul	Korea
		Osan	Korea
		Seongnam-si	Korea
		Guri-si	Korea
		Goyang-si	Korea
		Ansan-si	Korea
		Suwon	Korea
		Incheon	Korea
		Hwaseong-si	Korea
		Bucheon-si	Korea
		Uijeongbu-si	Korea
		Anyang-si	Korea
		Hanam	Korea
19	Kyoto - Osaka - Kobe	Kyoto	Japan
		Osaka	Japan
		Kobe	Japan
20	Singapore	Singapore	Singapore
21	Hong Kong	Hong Kong	China
22	Shenzhen	Shenzhen	China
23	Bengaluru	Bengaluru	India
24	Sydney	Sydney	Australia

No.	City (metropolitan area)	Administrative division	Country
25	Lyon-Grenoble	Lyon	France
		Grenoble	France
26	Chapel Hill-Durham-Raleigh	Chapel Hill	USA
		Durham	USA
		Raleigh	USA
27	Amsterdam MA	Amsterdam	The Netherlands
28	Munich	Munich	Germany
29	Helsinki	Helsinki	Finland
30	Copenhagen	Copenhagen	Denmark

Appendix IV: Data standardization and calculation formulae

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

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

y_{ij}^{s} is the standardized value of the Z-score for the i-th level-3 indicator for city j. x_{ij} is the raw data for the i-th level-3 indicator for city j. $\overline{x_i}$ is the mean of the raw data for the i-th level-3 indicator for all cities, and Std($_{xi}$) 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-scores for each of the three levels of indicators are linearly weighted by the indicator weights to calculate the z-scores 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 a1 indicator for city j. X_{aj} is the z-score for the a1 indicator for city j. X_{min} is the minimum the z-score for the a1 indicator for city j. X_{max} is the maximum the z-score for the a1 indicator for city j.

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-scores of the 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_{ij}^{s} is the GIHI Z-score for the sum of city j's level 3 indicators. 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.

清华大学产业发展与环境治理研究中心

Center for Industrial Development and Environmental Governance, Tsinghua University

nature research custom media

Phone:
+86 (0)10 62772497

Email:
cideg@tsinghua.edu.cn

Website:
www.cideg.tsinghua.edu.cn

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