ELSEVIER

Data and Insights on International Science, Technology, and Innovation—Comparative Research Report of 20 Global Cities (2016–2020)

上海市研发公共服务平台管理中心
THE ADMINISTRATIVE CENTER OF SHANGHAI R&D PUBLIC SERVICE PLATFORMS
（上海市科技人才发展中心）
SHANGHAI S&T TALENTS DEVELOPMENT CENTER
（上海市外国人来华工作服务中心）
SHANGHAI SERVICE CENTER FOR FOREIGNERS WORKING IN CHINA

Analytical Services

Executive summary

European and North American cities are still the superpowers of scientific research, with a high scholarly impact, but Asian cities are catching up as strong contenders, not only by volume but also for impact.

This report, prepared by Elsevier in collaboration with the Administrative Center of Shanghai R&D Public Service Platforms, presents some key science, technology, and innovation indicators for 20 global cities. It is based on an earlier local report launched by the Center, which focused on the 2014–2018 period. To reflect the latest patterns and trends, Elsevier updated all the bibliometric analysis using data from 2016–2020 [1] and used an updated methodology for the definition of cities. The analysis of patenting activities, which was conducted by the Center, was not updated.

A visual summary of some of the key findings is presented on the first page of each chapter. A quantitative summary of some of the key findings of the report is presented below.

As the available workforce is an important driver for scientific development, the report looked at the number, trends, and productivity of researchers in each city. The number of researchers has been growing in all the 20 cities studied. Beijing, Shanghai, and London had the highest numbers of researchers, and Shenzhen saw the greatest growth in this area. In terms of researcher productivity, measured according to the average number of publications per researcher, Hong Kong and Moscow were leading. Hong Kong also ranked first in the number of top 1% highly cited publications per researcher, followed by San Francisco, Boston, and Singapore.

Apart from the stock of scientific talent, the mobility of research talent was also evaluated. The transitory researcher group was the largest researcher mobility group for all 20 cities and is potentially the driver of a more collaborative scientific community. In addition, in 12 of the 20 global cities, transitory researchers had the highest field-weighted citation impact (FWCI) of all mobility-type groups, showing the positive effect of cooperation on scientific research impact. Seoul, Shenzhen, San Francisco, and Osaka have been attracting talent, having the highest "inflow" researcher shares among the 20 cities. In contrast, Tokyo, Paris, and Seoul had the highest "outflow" researcher shares. The traditional research hubs, such as San Francisco, Boston, London, and New York, as well as the emerging city of Shenzhen, had the highest FWCIs for their sedentary researcher group, indicating that these cities were able to retain high-impact talent.

To measure the competitiveness of scientific research from each city in this study, the volume and academic impact of scholarly output were evaluated. Among the 20 global cities, Beijing, Shanghai, London, Boston, and New York were the leading cities based on the total number of publications; Shenzhen, Moscow, and Shanghai led in terms of the growth rate of their scholarly output. However, the output of San Francisco, Boston, Amsterdam, and other traditional European and American science and technology hubs still had a higher scholarly impact than most Asian cities, as measured by the FWCI. Asian cities are quickly catching up in this regard though: among the seven cities with an FWCI increase from 2016 to 2020, five were from Asia.

[1] Exceptions to this are the periods for researcher mobility, which covers 1996–2020, and for patenting activity presented in Chapter 3, which covers the 2014–2018 period.

There was also a difference in research focus for each city, as measured by the city's share of publications in a particular subject compared to the world average. North American cities focused more on Life Sciences and Health Sciences—for example, Biochemistry, Genetics and Molecular Biology, and Medicine. Asian cities (such as Chinese cities and Singapore) concentrated on Physical Sciences (e.g., Materials Science, Engineering, and Computer Science), and European cities appeared to have diverse concentration areas, ranging from Life Sciences and Health Sciences (e.g., Medicine, neuroscience) to Social Sciences (Economics, Econometrics and Finance). The exception for Europe was Moscow, which showed strength in Earth and Planetary Sciences and Physics and Astronomy.

The share of top 1% highly cited publications is one of the proxy indicators used to evaluate research excellence, as is the share of papers published in the world-leading journals *Cell, Nature*, or *Science* (or "CNS publications"). Among the comparators, San Francisco and Boston had the largest share of top 1% highly cited publications and the largest share of CNS publications, which fully aligned with their FWCI rankings. Except for Singapore and Hong Kong, most Asian cities ranked relatively lower for their share of excellent output; however, we did find that Chinese cities recorded notable growth in their number of excellent publications. Shenzhen ranked first among the 20 global cities presented here based on the compound annual growth rate (CAGR) of its number of CNS publications, with a growth rate of 67.4%. It also ranked first based on the CAGR of the number of top 1% highly cited publications, with a growth rate of 29.3%.

Patents are used as a proxy for technological innovation competitiveness. Tokyo, Beijing, Shenzhen, and Shanghai led in terms of the number of patent applications; Tokyo and Shenzhen were also ahead of other cities for Patent Cooperation Treaty (PCT) patent applications; Hong Kong and Shanghai held the top two rankings for the growth rate of PCT patent applications for the 2014–2018 period. These findings reflect that Japanese and Chinese cities have been very active in patent applications.

Cross-sector collaboration between academic and corporate entities is a bridge linking the industry and research communities. The cities with the highest percentage of research publications resulting from academic–corporate collaboration were San Francisco, Osaka, Boston, and Tokyo, with 11.3%, 9.4%, 9.3%, and 9.2%, respectively. Except for Moscow, all European cities ranked in the top half by the proportion of academic–corporate co-publications among the comparable cities, suggesting possible intentional efforts to increase this collaboration type in these cities. Except for Shenzhen, all Chinese cities ranked at the bottom half for their proportion of academic–corporate collaborated publications. However, Beijing and Hong Kong showed growth on this measure over the study period.

A proxy indicator for the translation of academic research into economic value is patent citations of scholarly output. Boston, San Francisco, and Singapore led in terms of the share of publications cited by patents.

The full report provides further details on the data for and insights into the research and innovation landscape for the 20 global cities. We hope that the report will spur further discussion on how science and technology contribute to the innovativeness of cities, by focusing on their strengths and identifying areas of potential development.

Contents

Introduction

This report presents an overview of the innovation capability of 20 cities around the world. Insights are based on academic and industry outputs.

Scientific and technological (S&T) innovation plays a strong role in dictating the future of society. Therefore, monitoring the state of S&T innovation is of interest to many stakeholders, including the public, researchers, and government policymakers.

The Chinese government has declared that S&T innovation is a core principle driving China's overall development and national strength. Shanghai, as one of the largest economic centers in China, has also launched a regional policy to implement the national strategy and aims to build itself into a leading global S&T innovation center. As part of this implementation, Shanghai set a target for 2023 of having several world-class research institutions and innovation platforms driving enterprise and highly influential original research. Shanghai has achieved much toward its goal of S&T development. It invested 4.16% of its GDP in research and development (R&D) in 2018, which represents a 16.20% increase over the level of investment made five years ago (3.58%). [2] The number of patents for inventions reached 47.5 per 10,000 people in 2018, which is double the figure of five years prior. During the period 2014–2018, Shanghai participated in 11 of China's 50 major scientific advances.

To gain perspective on Shanghai's innovation capability, the Administrative Center of Shanghai R&D Public Service Platforms partnered with Elsevier to benchmark Shanghai against 19 cities worldwide that are known for outstanding innovation. [3]

Research is the foundation for S&T innovation; concurrently, enterprises are the key engine to transfer knowledge powered by innovation into an application. In this report, we provide a comprehensive analysis of the 20 selected global cities' technological innovation competitiveness from the perspective of research and enterprises. To do this, we used the indicators listed beginning on page 7. To assess research strength, we focused on researcher productivity, research output performance, researcher mobility, and researcher collaborations. To assess enterprises, we focused on innovative companies, the number of patents, and academic–corporate collaboration.

This report aims to provide insights for decision-makers so they can better understand the innovation strengths and weaknesses of Shanghai and other cities as they work to build themselves into global innovation hubs. All the analyses presented are based on data such as bibliometric data and patent data and aim to provide solid decision-making support for the construction of innovation centers.

[2] Data source: http://tjj.sh.gov.cn/tjnj/nj19.htm?d1=2019tjnj/C2001.htm

[3] While this report differs from the earlier report published in Chinese due to an updated methodology for the definition of cities and for the period it covers, it is fundamentally based on that report. For this reason, this report may still focus on Shanghai and Chinese comparators.

The global cities

This report selected the top five cities from each of the below seven lists, then ranked them according to the number of times each city appeared in the rankings, excluding some smaller cities. The result was a total of 20 sample cities, which are referred to as "20 global cities" throughout this report.

- 2thinknow, Innovation Cities Global Index [4]
- Savills, Savills Tech Cities index [5]
- A.T. Kearney, Global Cities Index [6]
- Mori Building, Global Power City Index (GPCI) 2017 [7]
- Shanghai Science Research Institution, Springer Nature, 2018 Global Survey of the "Ideal City" for Scientists
- The Chinese Academy of Social Sciences (Financial and Economics Institute) and UN-HABITAT, the Global Urban Competitiveness Report 2018–2019
- World Intellectual Property Organization, Global Innovation Index [8]

The final cities selected were Shanghai, Beijing, Shenzhen, Hong Kong, Tokyo, Osaka, Seoul, and Singapore from Asia; New York, Boston, Chicago, Los Angeles, San Francisco, and Toronto from North America; and Berlin, London, Paris, Stockholm, Moscow, and Amsterdam from Europe.

As the statistical methods used for defining cities differ across countries or regions, and because in some regions, adjacent cities or areas have close social, economic, and especially academic connections and form a metropolitan hub, it was decided to define the cities as metropolitan areas. We referred to the US census definition of Metropolitan Statistical Areas [9] for US cities, the functional urban areas definition of EU Local Administrative Units [10] for European cities, and national census definitions [11] [12] for other cities.

Further information on the cities is presented in Appendix D.

[4] https://2thinknow.com/information/innovation-programs/innovation-cities/
[5] https://www.savills.co.uk/tech-cities/index.html
[6] https://www.atkearney.com/global-cities/2017
[7] http://mori-m-foundation.or.jp/english/ius2/gpci2/2017.shtml
[8] https://www.wipo.int/publications/en/series/index.jsp?id=129
[9] https://www.census.gov/geographies/reference-files/time-series/demo/metro-micro/delineation-files.html
[10] https://ec.europa.eu/eurostat/web/nuts/local-administrative-units
[11] https://www.e-stat.go.jp/en/stat-search/files?page=1&query=metropolitan%20area&layout=dataset&toukei=00200521&file_type=0&survey=metropolitan%20area&metadata=1&data=1
[12] https://www12.statcan.gc.ca/census-recensement/2011/dp-pd/prof/details/page.cfm?Lang=E&Geo1=CMA&Code1=535&Geo2=PR&Code2=35&Data=Count&SearchText=Toronto&SearchType=Begins&SearchPR=01&B1=All&GeoLevel=PR&GeoCode=535&TABID=1

Methodology and indicators

Methodology

Bibliometric analysis

A given city's research output is defined as the number of publications indexed in Scopus that are published by authors with affiliations belonging to that city or metropolitan area.

Publication types and counting method

Throughout this report, analyses include all publication types that are indexed in Scopus to present a complete view of scholarly output.

All analyses make use of the whole counting method rather than fractional counting. For example, if a paper has been co-authored by one author from Beijing and one author from New York, then that paper is included in the publication counts of both cities.

Researchers

In this report, a researcher from a city is defined as an author having at least one publication affiliated to the city or metropolitan area in Scopus during the period 2016–2020. Individual researchers were identified and counted based on their unique Scopus author IDs.

Scholarly impact

To estimate the scholarly impact of publications, we use the field-weighted citation impact (FWCI) indicator. The FWCI is a measure of citations received by publications, normalized to account for differences in referencing practices and citation behaviors across fields, publication types, and publication age. An FWCI of more than 1.00 indicates that the entity's publications have been cited more than would be expected based on the global average for similar publications—for example, a score of 2.11 is 111% higher than the world average.

Research excellence

We use the number and proportion of publications that belong to the top 1% highly cited publications globally as well as the number and proportion of publications published in *Cell, Nature*, or *Science* to gain insight into research excellence.

International collaboration

We also analyze international collaboration by assessing the affiliations of co-authors on publications. A publication with at least one author listing an affiliation in a given country and at least one author listing an affiliation in another country counts as an internationally collaborated publication.

Innovative companies

The number of innovative companies for a given city is the count of the companies with headquarters located in the city that appear on three highly recognized company ranking lists. [13]

Patenting activities

Patent applications

Patent applications are defined as the number of patent applications from the China National Intellectual Property Administration, the European Patent Office, the Japan Patent Office, the South Korean Intellectual Property Office, and the United States Patent and Trademark Office. The count includes applications for plant patents, utility patents, and design patents. In this report, the number of patent applications for a given city are defined as the count of patent applications with application addresses located in the city and with a filing year between 2014 and 2018. The same logic applies to the collaborated patent applications and PCT patent applications indicators described below.

Collaborated patent applications

Collaborated patent applications are defined as patents applied for by two or more applicants. The data source is the same as the total patent applications, above.

PCT patents applications

The Patent Cooperation Treaty (PCT) is an international treaty with more than 150 Contracting States. [14] The PCT makes it possible to seek patent protection for an invention in a large number of countries simultaneously by filing a single "international" patent application instead of filing several separate national or regional patent applications. The PCT is used by the world's major corporations, research institutions, and universities when they seek international patent protection. It is also used by small and medium-sized enterprises and individual inventors. The PCT patent applications are generated from the World Intellectual Property Organization (WIPO).

A more detailed description of the indicators can be found in Appendix C.

[13] The three lists are as follows:

- Boston Consulting Group. (2019). *The Most Innovative Companies 2019: The Rise of AI, Platforms, and Ecosystems.*
- Forbes. (2018). *The World's Most Innovative Companies 2018.*
- European Union. (2018). *The 2018 EU Industrial R&D Investment Scoreboard.*

[14] The list of those States can be found on the WIPO website at www.wipo.int/pct/en/pct_contracting_states.html.

Indicators used in each chapter

Chapter	Indicators	Sub-indicators
Academic research	Researchers	No. of researchers
		CAGR of researchers
		Proportion of researchers by sectors
		No. of publications per researcher
	Scholarly output and impact	No. of publications
		CAGR of publications
		Relative output share per subject
		Field-weighted citation impact
	Excellent scholarly output	No. of top 1% highly cited publications
		Top 1% highly cited publications share (%)
		CAGR of top 1% highly cited publications
		No. of publications in *Cell, Nature*, or *Science*
		Cell, Nature, or *Science* publications share (%)
		CAGR of publications in *Cell, Nature*, or *Science*
Mobility and collaboration	Researcher mobility	Sedentary researchers share (%)
		Inflow researchers share (%)
		Outflow researchers share (%)
		Transitory researchers share (%)
	International collaboration	No. of international collaborated publications
		International collaborated publications share (%)
		CAGR of international collaborated publications
Innovative companies and patenting activity	Innovative companies	No. of companies on the three highly recognized company ranking lists
		Integrated score for highly innovative companies
	Patent applications	No. of patent applications
		CAGR of patent applications
	PCT patent	No. of PCT applications
		CAGR of PCT applications
	Collaborated patent	No. of collaborated patent applications
		Collaborated patent applications share (%)
Research to commercialization	Academic–corporate collaboration	No. of publications resulting from academic–corporate collaboration
		Academic–corporate collaborated publications share (%)
		CAGR of academic–corporate collaborated publications
	Knowledge transfer	Citing–patents count
		Share of publications cited by patents
		Relative share of publications cited by patents

Chapter 1

Academic research: A fundamental pillar of innovation

Key findings

20/20

cities in this report saw their researcher population grow.

Shenzhen

had the highest CAGR for number of researchers (34.1%).

Beijing, Shanghai, London, Boston, and New York

were the top five cities based on total scholarly output and total researchers.

San Francisco, Boston, Amsterdam, and Hong Kong

were the only cities with FWCIs of or over 2.0.

Hong Kong

had the highest number of publications per researcher among the 20 global cities (1.9).

San Francisco and Boston

were the top two cities by share of top 1% highly cited publications and share of CNS publications.

Boston and New York

were the top two cities by the count of publications in *Cell*, *Nature*, or *Science* (CNS publications).

Shenzhen

had the highest CAGR for the top 1% highly cited publications (29.3%) and for CNS publications (67.4%).

1.1 Researcher

The researcher population grew in all of the 20 global cities, with Shenzhen seeing the fastest growth in number of researchers.

Researchers are the powerhouse of S&T innovation. In this report, a researcher from a given city is defined as an author having at least one publication indexed by Scopus and with an author address from the city for the period 2016–2020. Individual researchers were identified and counted based on their unique Scopus author IDs. Although the author ID has limitations in capturing data on all researchers from a city, it does provide a proxy method for counting those among a city's researchers who have published scholarly output in the study period.

Number of researchers

As shown in FIGURE 1-1, Beijing, Shanghai, and London were the top 3 cities in terms of their absolute count of researchers.[15] This may be due to a deliberate concentration of funding, institutions, and facilities in these cities. As we know, many research institutions, including universities, are based in these cities. According to Scopus, there were 555 research institutions in Beijing, accounting for approximately 18% of all Chinese research institutions, which may explain the city's obvious lead here. Additionally, of the top 10 research institutions in China (based on scholarly output in the period 2016–2020), 4 were in Beijing and 3 were in Shanghai. Like Beijing, London hosts many of its nation's high-profile research institutions.

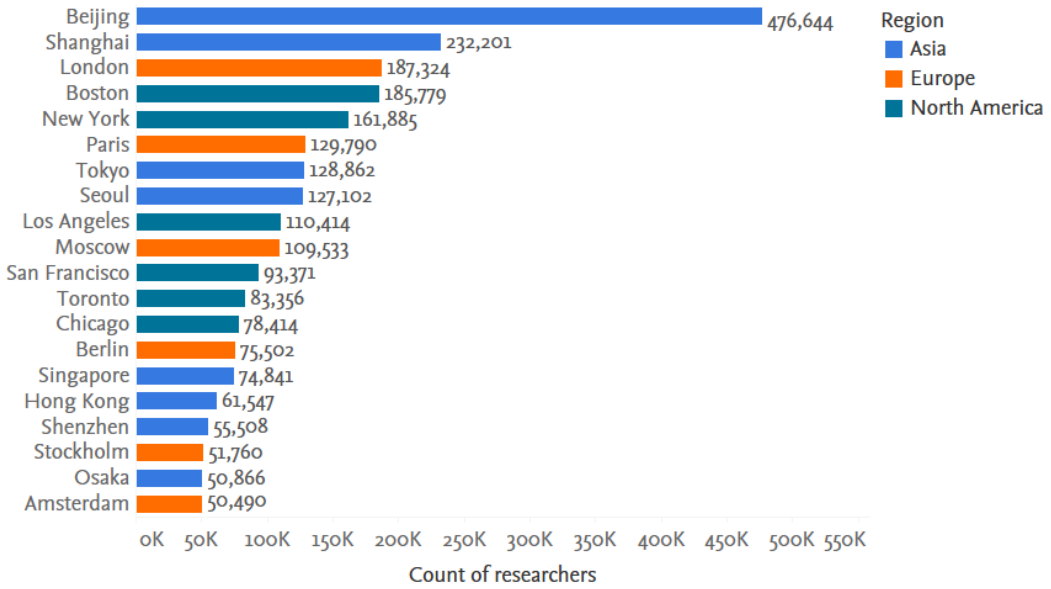


Figure 1-1 Number of researchers from the 20 global cities (2016–2020).
Source: Scopus

[15] In this report, "researchers" refers to those having at least one publication indexed by Scopus during the period 2016–2020.

Growth in number of researchers

Between 2016 and 2020, Shenzhen led in terms of the compound annual growth rate (CAGR) of number of researchers (34.1%), followed by two other Chinese cities, Shanghai and Beijing (FIGURE 1-2). That Chinese cities recorded the largest growth in the number of researchers reflects China's increased efforts to cultivate, support, and introduce talent year after year. Moscow also had relatively high growth in the number of researchers, ranking fourth among all 20 cities and first among all European cities studied here.

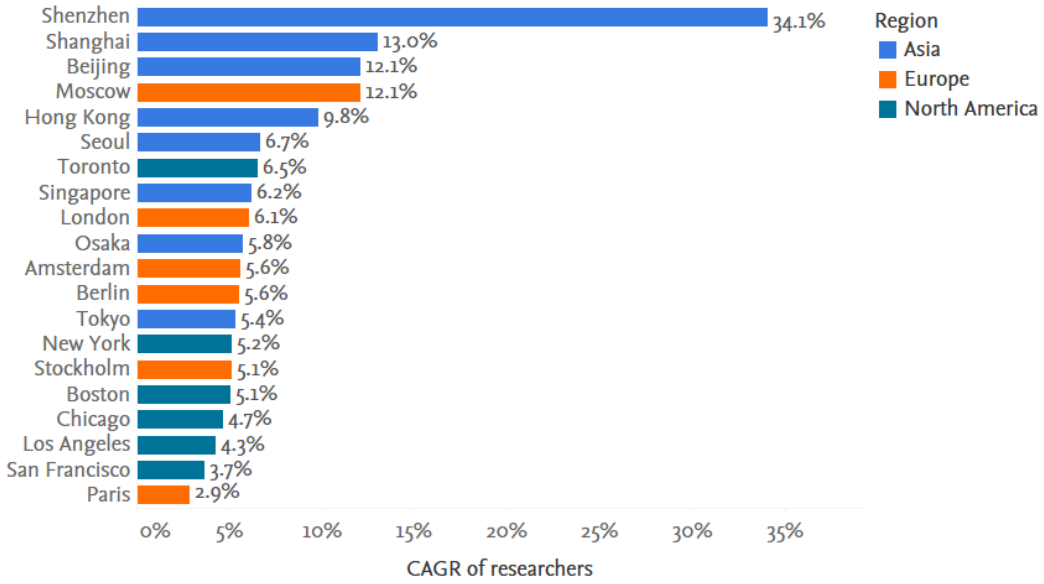


FIGURE 1-2 CAGR of researchers from the 20 global cities (2016–2020).
Source: Scopus

FIGURE 1-3 showed the yearly trend of the number of researchers between 2016 and 2020. As shown here, all of the 20 cities saw growth in their researcher population. This included those cities with the highest counts of researchers (Beijing, Shanghai, and London).

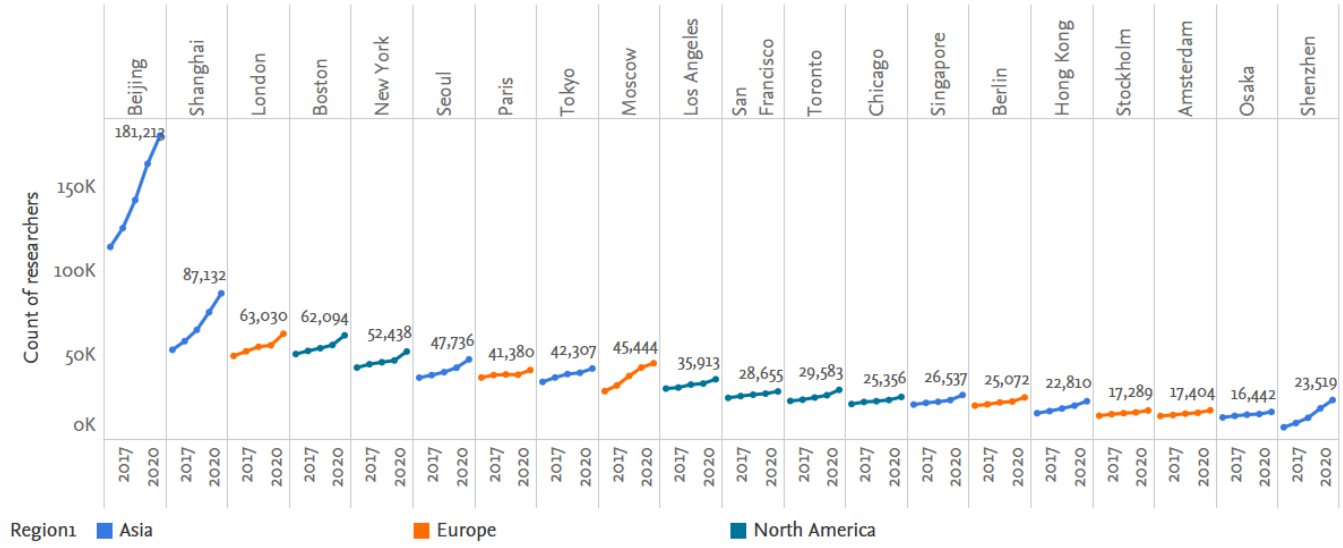


FIGURE 1-3 Trend of researchers from the 20 global cities (2016–2020) (The marked label is the value in 2020).
Source: Scopus

Researchers per sector

The researchers counted in this report can be divided into five sectors[16] according to their type of affiliation: higher education, government, corporate, medical, and others. One researcher might come from multiple sectors. FIGURE 1-4 shows the proportion of sectors for researchers in the 20 cities in the period of 2016–2020. For all 20 cities, over 80% of the researchers were from higher education institutions (e.g., universities). Paris and Moscow had higher proportions of researchers from the government sector than other cities, which may be because of the French National Centre for Scientific Research in Paris and the Russian Academy of Science in Moscow. San Francisco had the highest proportion of researchers from the corporate sector, reflecting a large number of technology companies in the area, such as Google and Apple. Paris also had a large proportion of researchers from the medical sector, possibly given the contribution by research-oriented hospitals in the city, such as Assistance Publique – Hôpitaux de Paris.

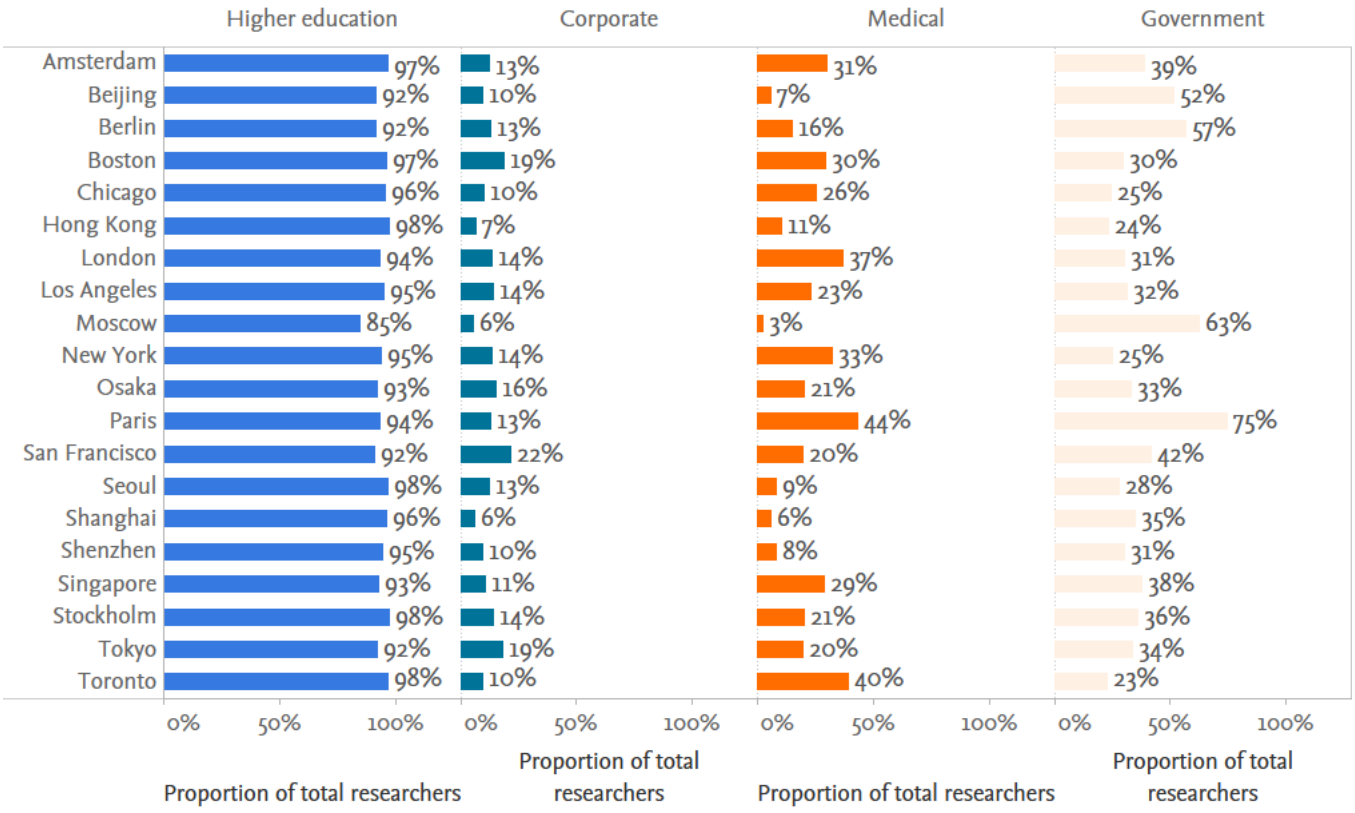


FIGURE 1-4 Proportion of researchers by sector for the 20 global cities (2016–2020).
Source: Scopus

Productivity: per researcher performance

High total counts of outputs can result from resource concentration. Therefore, we also examined the output per researcher to show the productivity of researchers from the 20 global cities. As shown in FIGURE 1-5, Hong Kong and Moscow led in terms of the number of publications per researcher, while most other cities were quite close to each other in productivity performance (around 1.3 to 1.6 publications per

[16] We determine the sector that researchers work in based on the affiliation listed on publications. If a researcher has at least one publication from a sector, we designate that researcher to be from that sector (refer to the types of institutions that conduct research). In this report, the main sectors are corporate, higher education, government, and medical.

researcher). For productivity in terms of highly cited papers, Hong Kong, San Francisco, Boston, and Singapore led in the number of top 1% highly cited publications per researcher.

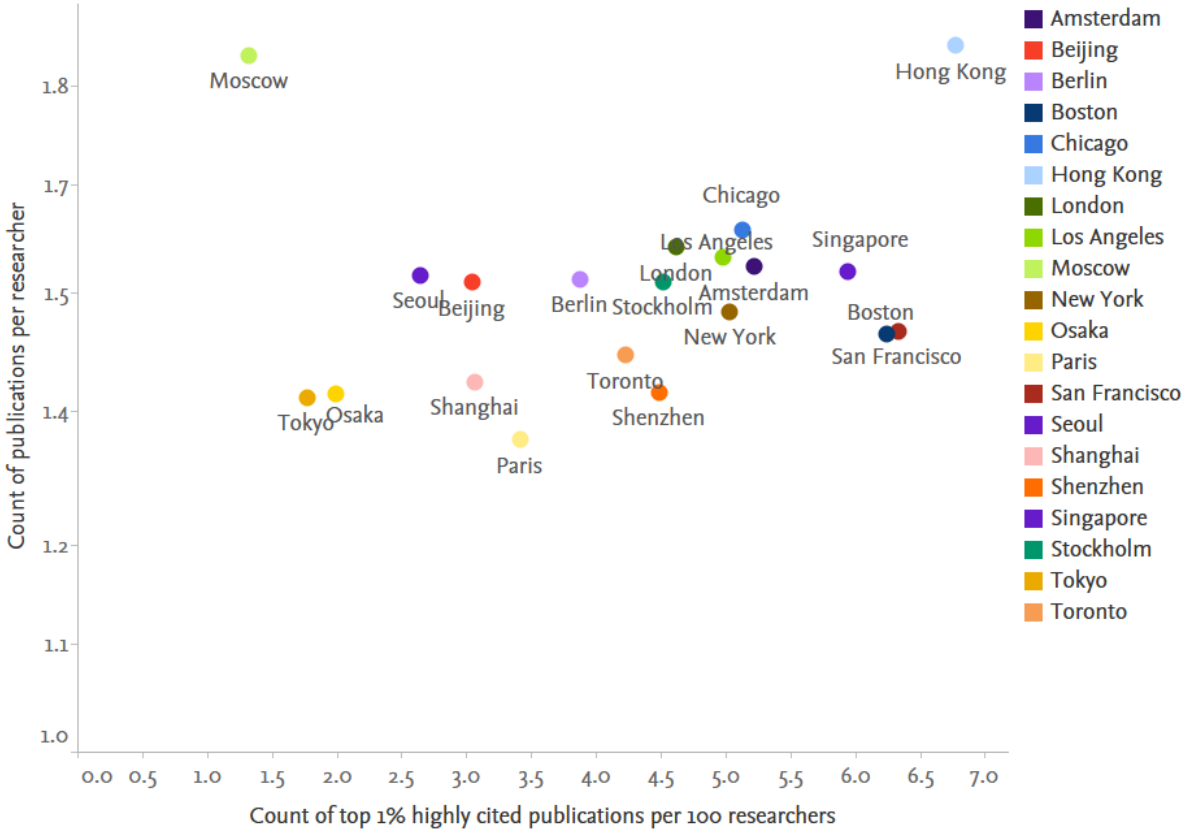


FIGURE 1-5 Number of publications per researcher and number of top 1% highly cited publications per 100 researchers for the 20 global cities (2016–2020).
Source: Scopus

1.2 Scholarly output

Scholarly outputs from Chinese cities have been increasing rapidly, with four Chinese cities (Shenzhen, Shanghai, Beijing, Hong Kong) among the top five for CAGR of publications.

Scholarly output, such as scientific articles published in journals, conference proceedings, or even books, can be used to measure the competitiveness of researchers. In this section, we look at the scholarly output published by researchers from institutions located in the 20 global cities.

Scholarly output and growth rate

The top five cities based on the total publication count from 2016 to 2020 were Beijing, Shanghai, London, Boston, and New York. Beijing was far ahead of the other cities, with 721,777 publications, which is more than double the total publications of the second city, Shanghai (FIGURE 1-6).

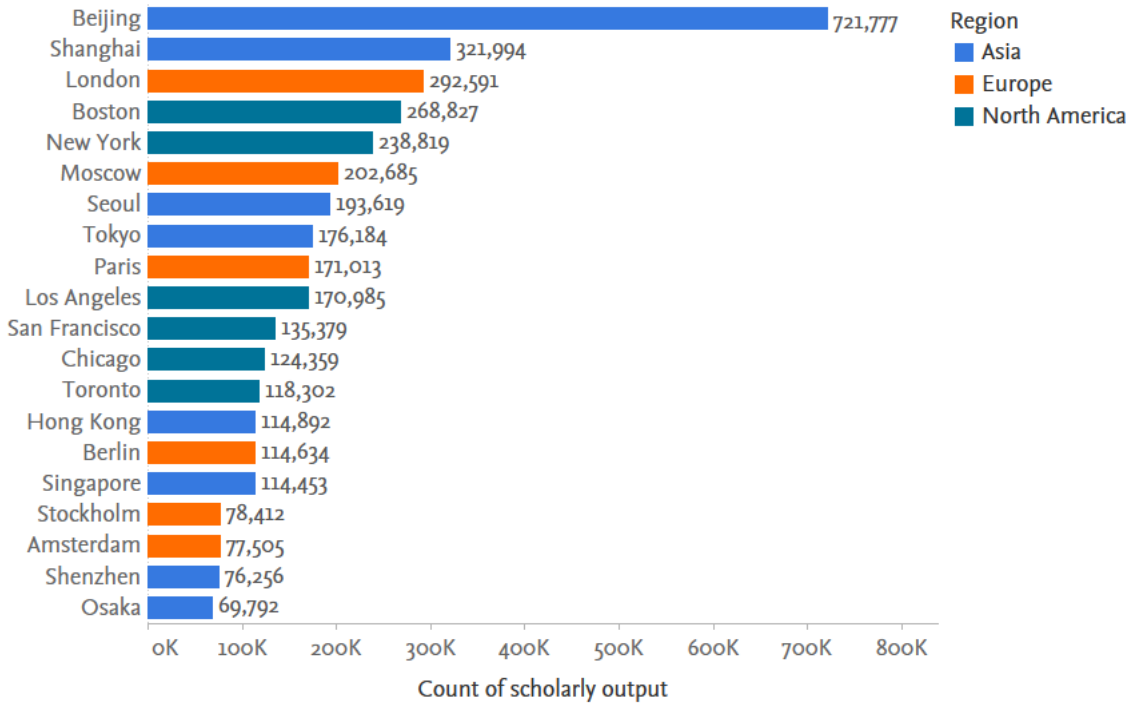


FIGURE 1-6 Count of scholarly output for the 20 global cities (2016–2020).
Source: Scopus

Among the 20 cities studied, all had positive growth in scholarly output. We also found that, for all 20 cities, the trends for scholarly output were, overall, aligned with trends in researcher numbers, suggesting that investment in researchers led to output growth. Shenzhen, Moscow, and Shanghai ranked in the top three by CAGR of publications, with 31.5%, 11.3%, and 10.5%, respectively (FIGURE 1-7).

For all the 20 cities studied here, the CAGR of publications was lower than the CAGR of researchers. This means that in the 20 global cities, the growth in the number of researchers was faster than the output growth. This situation could be due to the growing collaborations among researchers, as we observed from Scopus that the average number of contributors to a paper has increased over the past few years.

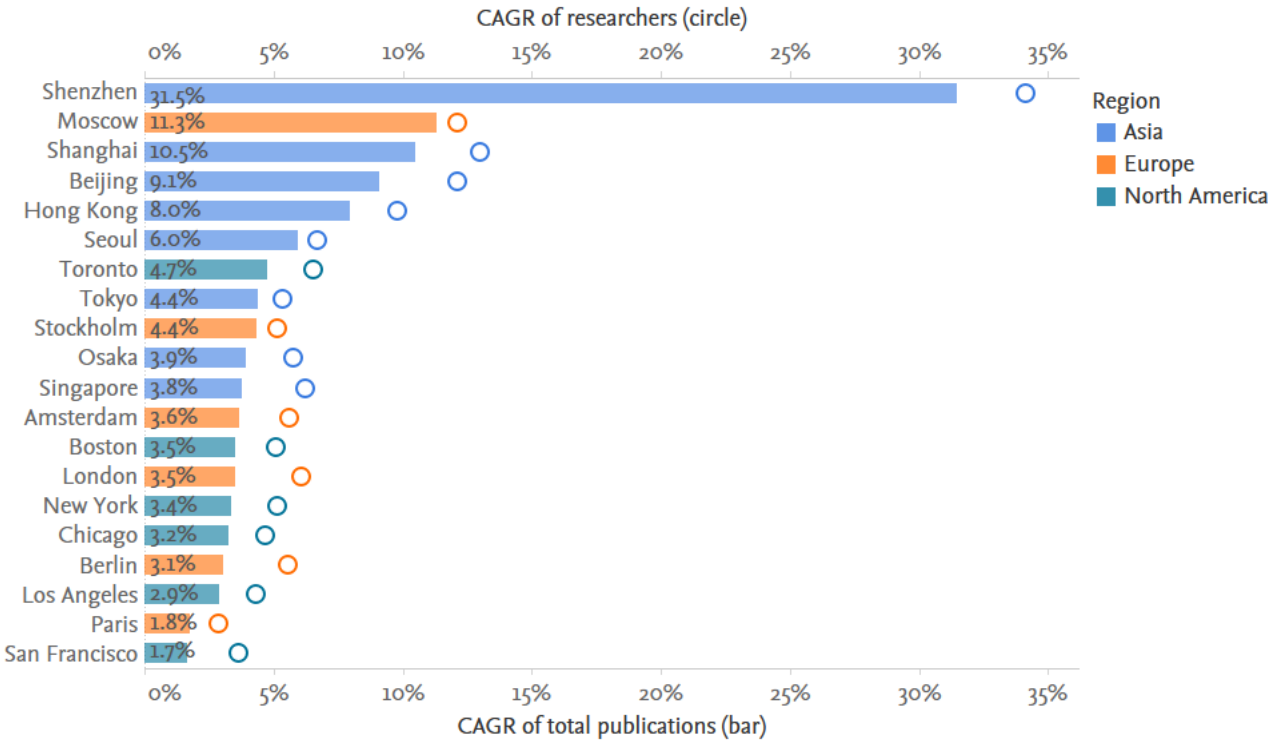


FIGURE 1-7 CAGR of scholarly output and CAGR of researchers for the 20 global cities (2016–2020) (Label is the CAGR of total publications). Source: Scopus

Subject focus

To provide insight into the subject areas that represent areas of strength in each city, we examined the publication output in each subject area, using the formula below, which measures relative output share represented by a subject.

Relative output share of subject X[17] =

$$\frac{\textit{the total publications in subject X from the city} \,/\, \textit{the total publications from the city}}{\textit{the total publications in subject X globally} \,/\, \textit{the total publications globally}}$$

[17] The formula is based on the indicator of revealed comparative advantage index (RCA).

If the "relative output share" is over 1.0 in a subject, it means the city is comparatively focused on this subject.

In Scopus, titles are classified under one of the 27 subjects of the All Science Journal Classification, which are further divided into 334 subcategories. In this report, we have used the same subject classifications to do the benchmark analysis.

As shown in FIGURE 1-8, each city generally had its subject focus. Among them, North American cities had dominant advantages in Health Sciences and Life Sciences—for example, NEUROSCIENCE, MEDICINE, and BIOCHEMISTRY, GENETICS & MOLECULAR BIOLOGY. Moscow had a clear focus on PHYSICS & ASTRONOMY and EARTH AND PLANETARY SCIENCES. Chinese cities and Singapore had a concentration in Physical Sciences, such as ENGINEERING, MATERIALS SCIENCE, and COMPUTER SCIENCE, and the share of relative output of Chinese cities in most areas of Health Sciences and Social Sciences was low. European cities (except Moscow) had strength in MEDICINE, NEUROSCIENCE, IMMUNOLOGY AND MICROBIOLOGY, and ECONOMICS, ECONOMETRICS AND FINANCE. Japanese and Korean cities showed subject focus on Health Sciences and Life Sciences, such as MEDICINE, DENTISTRY, and BIOCHEMISTRY, GENETICS & MOLECULAR BIOLOGY.

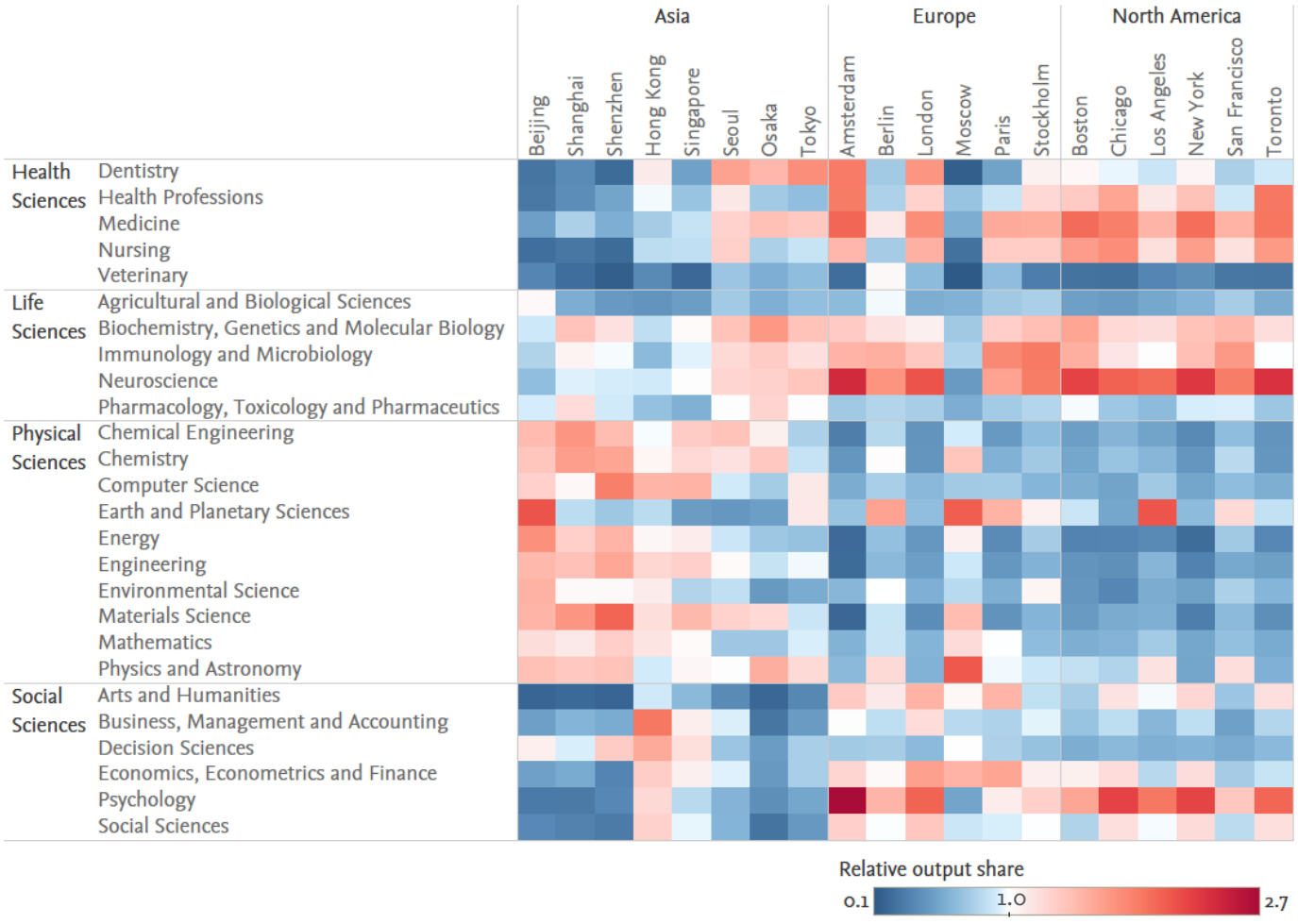


FIGURE 1-8 Relative output share by subject for the 20 global cities (2016–2020) (Values above 1.0 are shown in red, below 1 in blue, at 1 is white).
Source: Scopus

1.3 Field-weighted citation impact

The cities with historically prestigious higher education systems retained their scientific advantage, with higher scholarly impact and more recognized excellence in output compared to most Asian cities. However, Asian cities were on the rise in terms of both volume and impact.

Field-weighted citation impact

To examine scholarly impact, we use one of the most sophisticated indicators in the modern bibliometrics toolkit, the Field-Weighted Citation Impact (FWCI). It provides a normalized measure of citation count. More details about this indicator can be found in the methodology.

As shown in FIGURE 1-9, San Francisco, Boston, Amsterdam, and Hong Kong were the top four cities for this measure, with FWCIs of or over 2.0. Most Asian cities had high research output, but their FWCI scores lagged behind those of North American and European cities. Except for Hong Kong, Singapore, and Shenzhen, most Asian cities had FWCIs ranging from 1.1 to 1.2.

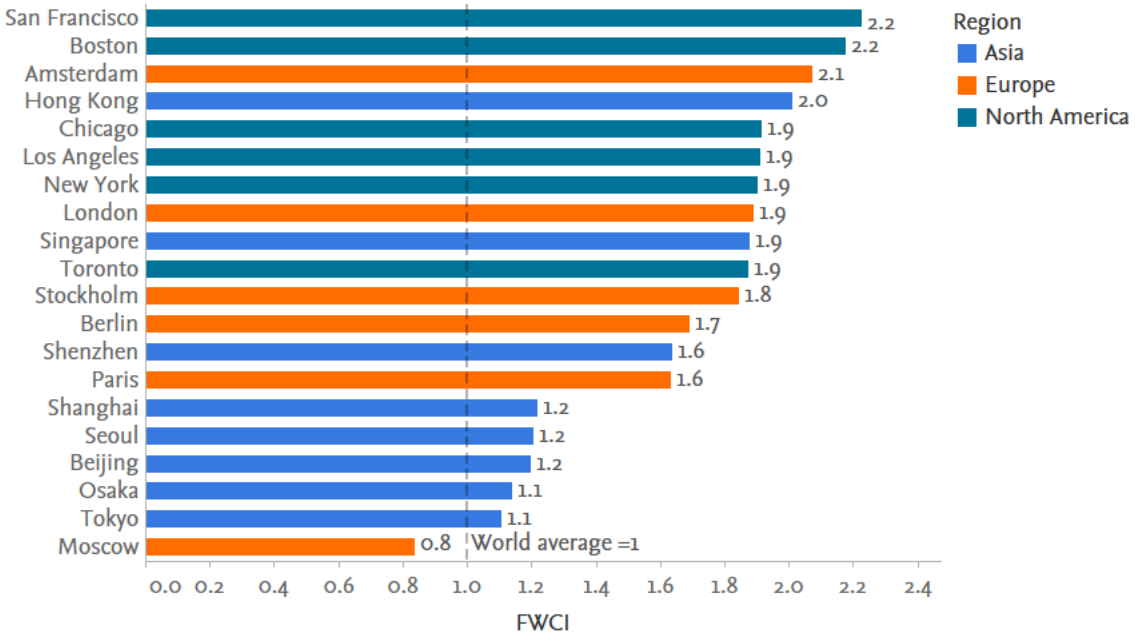


FIGURE 1-9 FWCI of the 20 global cities (2016–2020).
Source: Scopus

Trends suggest that the FWCIs of several Asian cities are increasing, however. For example, all the Chinese cities studied had a higher FWCI in 2020 than their FWCI in 2016 (FIGURE 1-10). Hong Kong achieved a remarkable increase in its 2020 FWCI, which could have been driven by the high number of citations received by their COVID-19 research output[18].

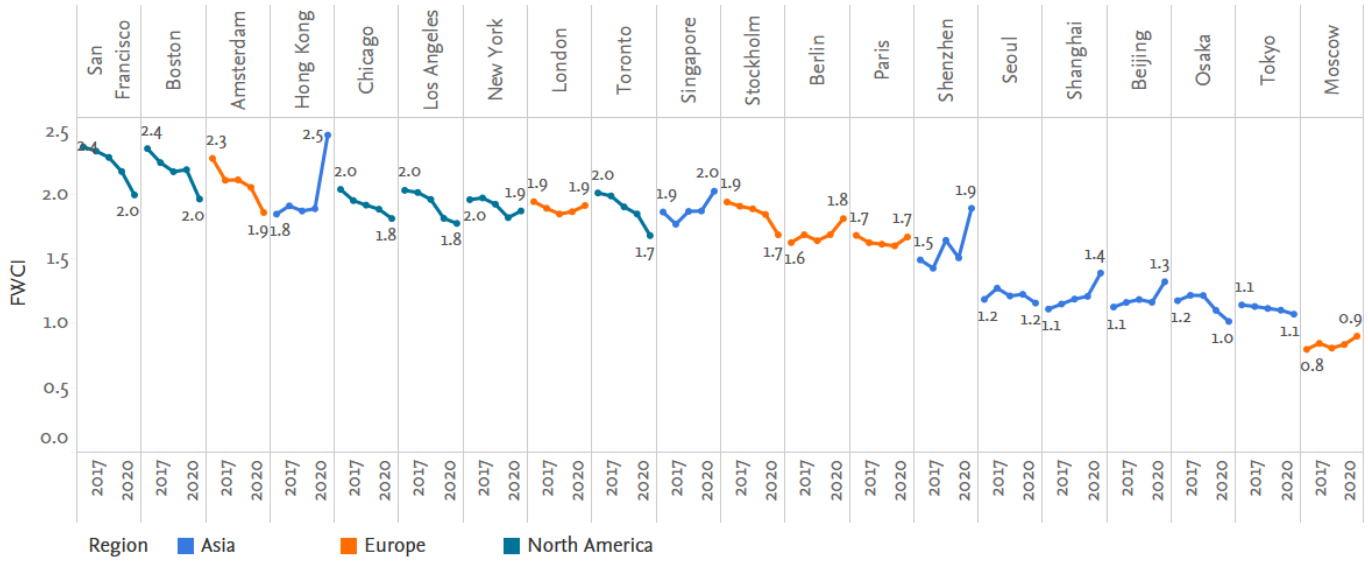


FIGURE 1-10 Yearly FWCI of the 20 global cities (2016–2020) (Label is the value in 2016 and 2020).
Source: Scopus

[18] Based on Scopus, Hong Kong's top 10 cited publications in 2020 all received more than 1,000 citations (the world average citations per publication was 1.9 in 2020). Nine of these publications were on COVID-19 research.

1.4 Research excellence

Chinese cities had the highest growth of excellent output among the comparators, with Shenzhen having the highest CAGR of top 1% highly cited publications (29.3%) and the highest CAGR of CNS publications (67.4%) among the 20 global cities.

Top 1% highly cited publications

The top 1% highly cited publications are those among the top 1% based on citations of all articles published and cited in a given period, which can be presented as the most influential output worldwide. Scores for the number or share of highly cited publications for a given entity are treated as indicative of the excellence of the entity's research.

As shown in FIGURE 1-11, Beijing, Boston, and London ranked in the top three in terms of count of the top 1% highly cited publications. San Francisco, Boston, and Singapore were the top three cities based on the share of the top 1% highly cited publications, and their FWCIs were ranked first, second, and ninth respectively (FIGURE 1-9). We compared the two indicators for the 20 global cities and found the share of the top 1% highly cited publications was positively correlated with the FWCI.

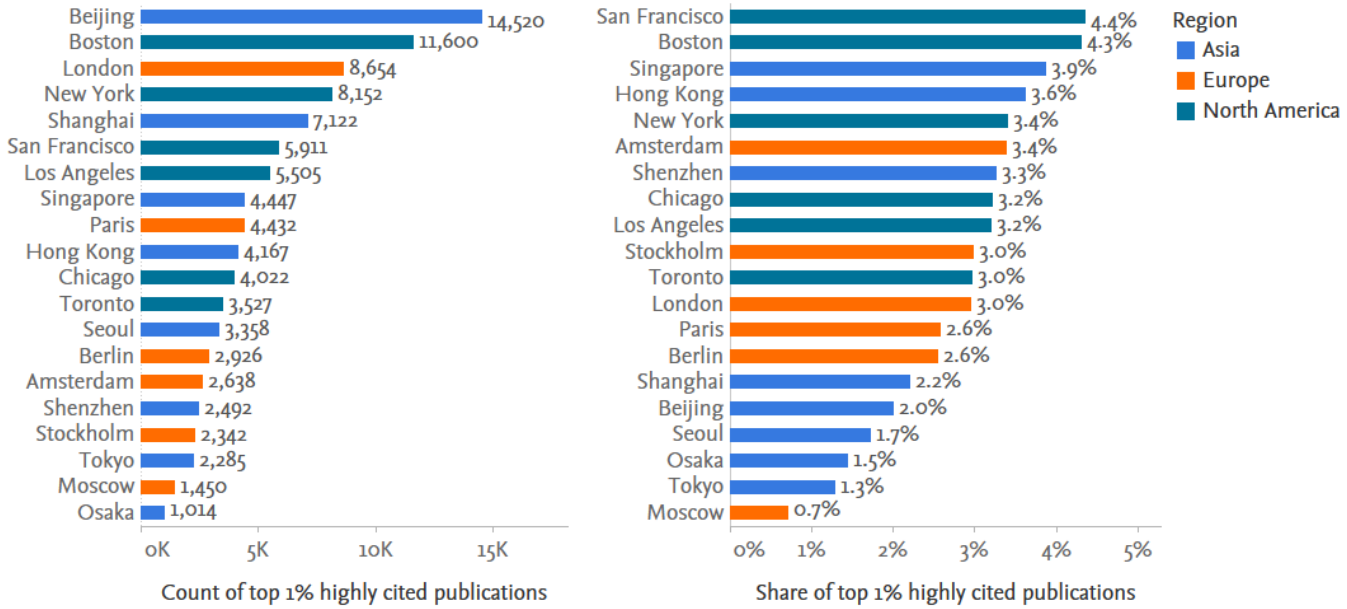


FIGURE 1-11 Share and count of top 1% highly cited publications for the 20 global cities (2016–2020).
Source: Scopus

Although the proportion of highly cited publications in most Asian cities is low, the growth rate is impressive. Based on the annual growth rate for these publications, Chinese cities held the top three rankings (FIGURE 1-12), with Shenzhen at a CAGR of 29.3%, far ahead of those of other cities. Shanghai and Hong Kong followed with CAGRs of 15.0% and 13.7% respectively.

In comparing the total publication growth rate with that of the top 1% highly cited publications, we found that Seoul and Hong Kong had CAGRs for their top 1% highly cited publications that were 1.7 times the growth rate of their total publications (FIGURE 1-12). A similar trend was observed for Shanghai, which also had faster growth in highly cited publications than the growth rate of its total publications. This shows that these Asian cities have been catching up to other cities in terms of excellent output.

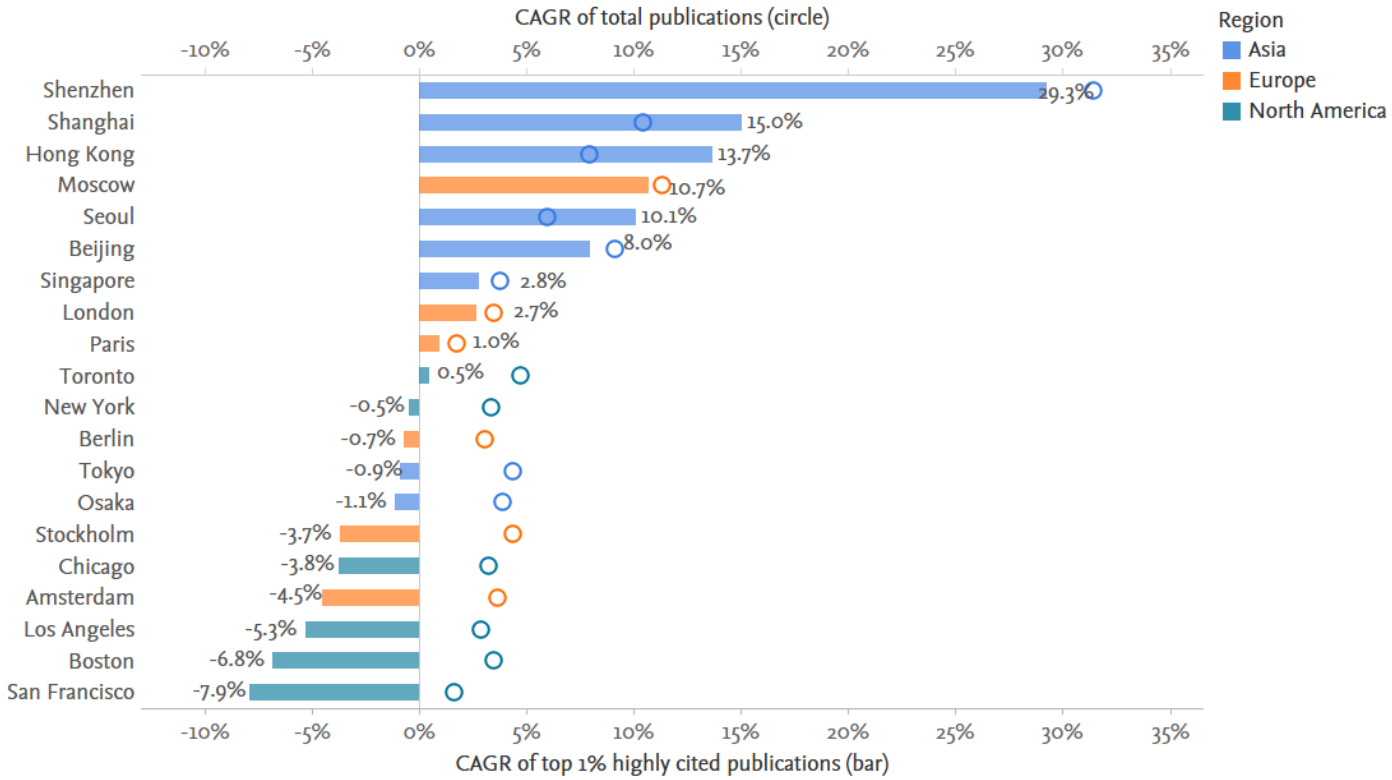


FIGURE 1-12 CAGR of total publications and CAGR of top 1% highly cited publications for the 20 global cities (2016–2020) (Label is the CAGR of top 1% highly cited publications).
Source: Scopus

Publications in *Cell*, *Nature*, or *Science*

"CNS publications" refers to articles published in the most widely influential journals—*Cell, Nature*, or *Science*—which can be used as a proxy to represent a city's best research output in basic research.

In terms of total CNS publications published between 2016 and 2020, Boston was significantly ahead of other cities, with New York and San Francisco following in the second and third places, respectively. Additionally, San Francisco was the only city with a CNS publications share over 1% (FIGURE 1-13). All Asian cities ranked in the second half of the group in terms of CNS publications share.

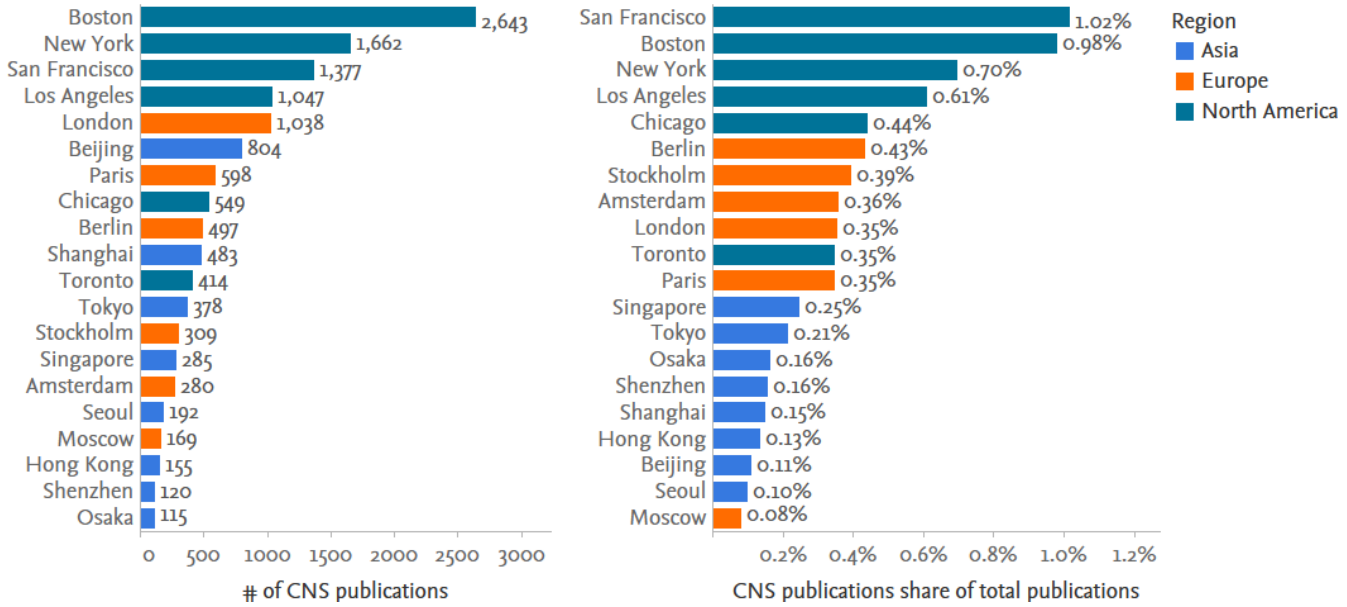


FIGURE 1-13 Number and share of CNS publications for the 20 global cities (2016–2020).
Source: Scopus

Shenzhen's CAGR of CNS publications (2016–2020) reached 67.4%, possibly given its small base value. It was followed by Hong Kong (CAGR of 27.8%) and Seoul (CAGR of 24.6%). Notably, the six fastest-growing cities in terms of CNS publications (Shenzhen, Hong Kong, Seoul, Osaka, Shanghai, and Beijing) were all from Asia. Comparing total publication growth rate with that of the CNS publications, 17 of the 20 global cities showed a higher annual growth of CNS publications; Osaka led for this measure with a CAGR of CNS publications that was 5.8 times that of its total publications (FIGURE 1-14), followed by Seoul (4.1 times that of its total publications).

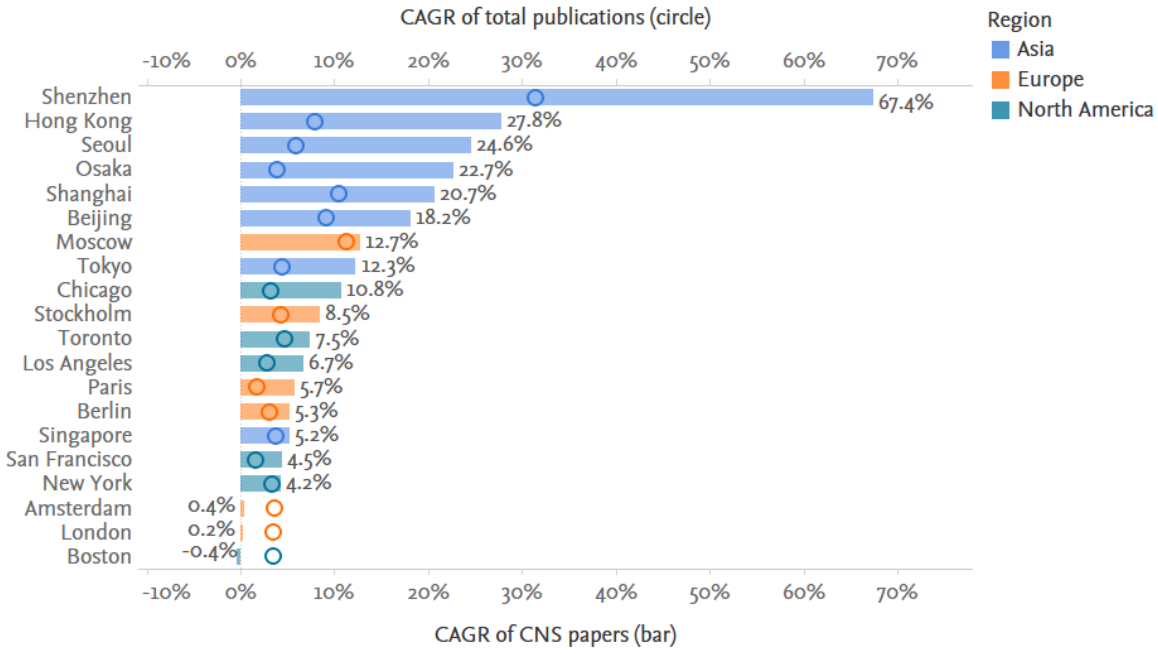


FIGURE 1-14 CAGR of CNS publications and CAGR of total publications for the 20 global cities (2016–2020) (Label is CAGR of CNS publications).
Source: Scopus

Chapter 2

Mobility and collaboration in research

Key findings

Seoul, Shenzhen, San Francisco, and Osaka

were the top four cities based on the share of "inflow" of researchers among the 20 cities, with 16.9%, 13.2%, 13.0%, and 13.0% respectively.

Tokyo, Paris, and Seoul

were the top three cities based on the share of "outflow" of researchers among the 20 cities, with 31.9%, 28.2%, and 24.0% respectively.

Hong Kong, Singapore, and Stockholm

were the top three cities based on international collaborated publications share, with 71.4%, 66.8%, and 66.2% respectively.

20/20

cities had an increased international collaboration rate in the past 5 years.

2.1 Researcher mobility

For 12 of the 20 cities, "transitory" researchers had a higher FWCI, indicating that the scientists who moved were, on average, more highly cited than those who did not.

Researcher mobility analysis can reveal how talent in the research community flows and combines, and how that influences local research output and impact.

In past reports, Elsevier has typically measured researchers' international mobility, examining the movement of researchers between countries. However, in this study mobility was measured at the city level, examining researchers' movements between cities or metropolitan areas. While international mobility requires substantial effort—for example, international relocation and often learning a new culture and language—moving from an institution in a city to another one in the same country or even region can be easier. For example, at times it may simply entail a longer traveling to a new institution just outside the city. Because researchers are likely to move between institutions within their home country or region during their careers, the percentages of mobile researchers between cities were expected to be higher than those for internationally mobile researchers.

The approach presented here uses Scopus author ID data to trace the mobility history of active authors from the 20 global cities. In this study, active authors are those who produced 10 or more papers in 1996–2020 and at least 1 paper in the last 5 years (2016–2020), or those who produced 4 or more papers in the last 5 years. For mobility data, we consider a longer time frame of analysis to better understand the patterns and to focus on the 1996–2020 period. Based on the affiliations recorded in each author's published articles over time, authors are assigned to a mobility class defined by the type and duration of observed moves. Researchers are broadly divided into four mobility groups:

Sedentary: Researchers who have not published papers with affiliations outside of their city (resulting from attainment of faculty positions, for example).

Transitory: Researchers who stay in X city for less than two years, after which they depart again.

Inflow: Researchers who entered X city and did not leave. This group is divided into two subgroups:

- Inflow: Researchers who have moved to X city and remained there.
- Returnees inflow: Researchers who had left X city for more than two years, but thereafter returned.

Outflow: Researchers who left X city and did not return. This is divided into two groups:

- Outflow: Researchers who left X city and did not return.
- Returnees outflow: Researchers who had come to X city from elsewhere and stayed for more than two years, but thereafter left for other cities again.

As presented in FIGURE 2-1, the transitory researcher group represented the absolute majority for all 20 cities, with shares ranging from 42% to 69%. The high proportion of transitory researchers could be attributed to the high level of collaboration in scientific research in the past two decades. Shenzhen was the only city that had a larger share of inflowing researchers than outflowing researchers, suggesting that the city was able to attract and retain talent.

The top four cities based on the proportion of inflow researchers were Seoul (16.9%), Shenzhen (13.2%), and San Francisco and Osaka (effectively tied in third place, at 13.0% and 13.0% respectively), which suggests a higher attractiveness of these cities for talent, whether it was nationally or internationally. On the other hand, the top cities based on the proportion of outflow researchers were Tokyo (31.9%), Paris (28.2%), and Seoul (24.0%). Seoul had a high share of outflow researchers, as well as a high share of inflow researchers, which might indicate that researchers in the city were prone to long-term mobility (typically resulting from attainment of faculty positions). Meanwhile, the higher proportion of outflow researchers for some cities suggests that they may have insufficient advantages to induce research talent to continue to conduct research locally. Shenzhen had the lowest proportion of outflow researchers (7.5%) among the 20 cities here, reflecting this city's strong ability to retain local researchers.

In terms of the proportion of sedentary researchers, Moscow (41.2%), Shanghai (35.5%), and Beijing (27.5%) ranked top 3 among the 20 global cities. This proportion shows the advantage of these cities in encouraging local talent to continue research work in the city. Constant shares of "inflow of researchers" and "sedentary researchers" are important factors in ensuring the stable development of a city's scientific research. It should be noted that, on average, the sedentary researchers group usually has a lower FWCI compared to researchers from other mobility types (as shown in FIGURE 2-2).

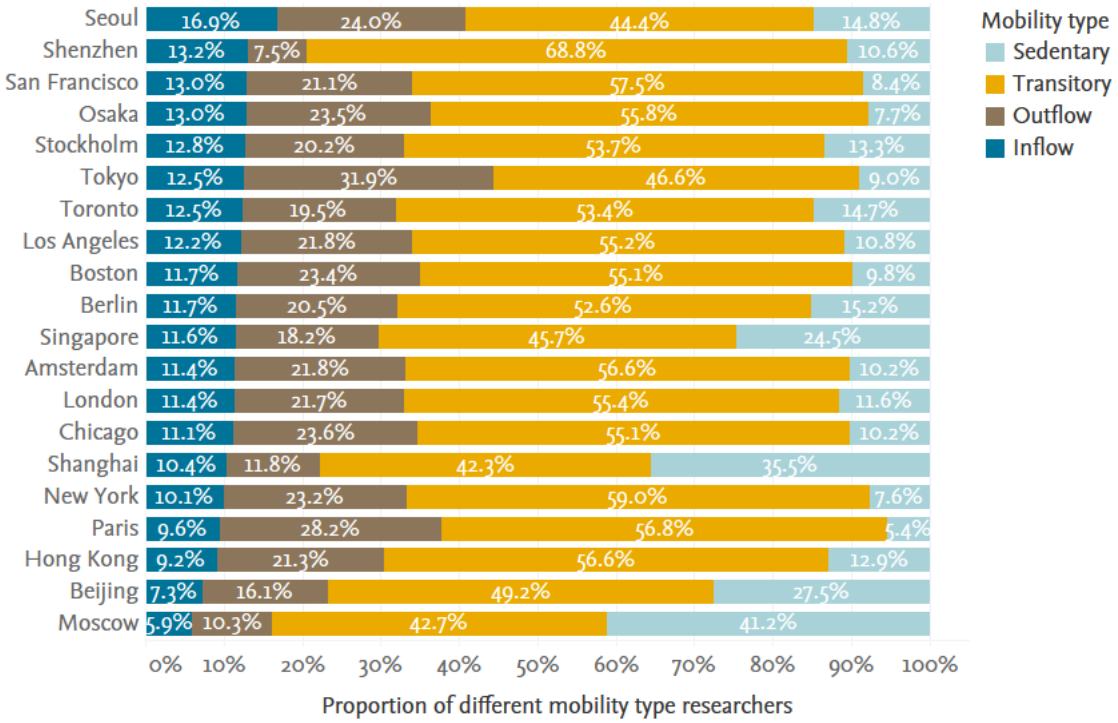


FIGURE 2-1 Proportion of researcher mobility groups for the 20 global cities (1996–2020).
Source: Scopus

The 20 cities' FWCI ranking order is clustered into three types based on the highest FWCI researcher group, as shown in FIGURE 2-2. It can be observed that the scientists who moved cities were, on average, more highly cited than those who did not. In 12 of the 20 cities, transitory researchers had the highest FWCIs, showing the positive effect of cooperation on scientific research impact. San Francisco, Boston, London, New York, and Shenzhen were the exceptions, where the highest FWCI scores were seen among the sedentary group, suggesting that these cities had the ability to retain high-impact researchers. For Los Angeles, Hong Kong, and Paris, the inflow researcher group had the highest FWCI, but the score was close to the FWCIs of transitory or outflow groups.

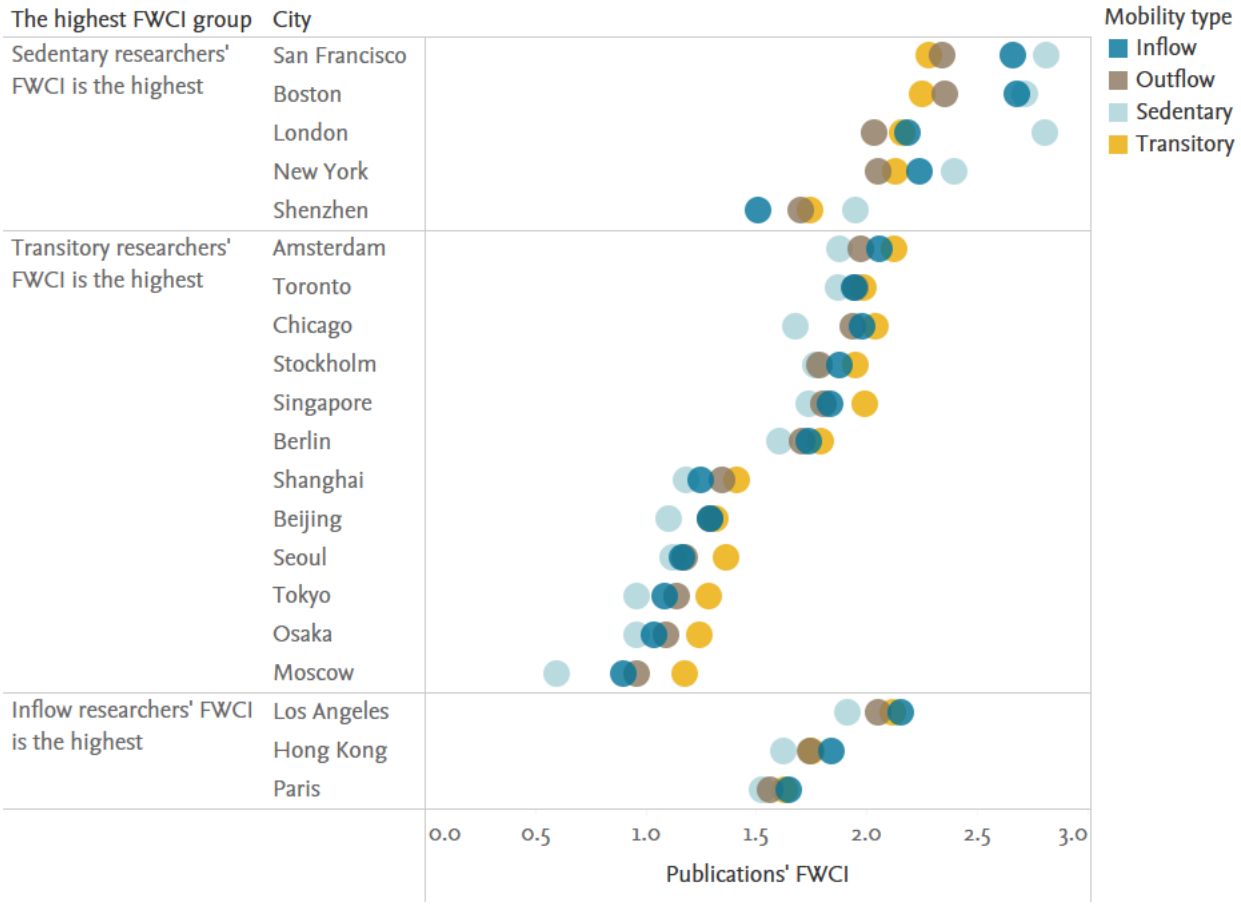


FIGURE 2-2 FWCI of different researcher mobility groups in the 20 global cities (1996–2020).
Source: Scopus

2.2 International collaboration

All the 20 cities had a rising share of international collaborated publications, as their scientific communities moved toward more open and collaborative practices.

Researcher mobility results in several types of cross-regional collaboration in science, of which international collaboration is one of the most important because, on average, internationally collaborated output will achieve a higher citation impact compared to other publication types. International collaboration is defined as publications resulting from the efforts of two or more authors from different countries. It can facilitate knowledge sharing and provide a source of inspiration across borders.

In terms of the count of international collaborated publications (those with authors from more than one country), Beijing ranked first, followed by London and Boston, which could be a result of the high volume of total output from these cities. When international publications are considered as a percentage of all of a city's publications, Hong Kong (71.4%) has the highest share of publications with international collaboration, followed by Singapore, Stockholm, Amsterdam, London, Berlin, Paris, and Toronto. These eight cities have more than half of their publications resulting from international collaboration. Except for Singapore and Hong Kong, international collaboration on publications was not as high for Asian cities as for European or US cities, with Moscow, Beijing, Osaka, Shanghai, and Seoul among the lowest ranked based on the percentage of publications resulting from international collaboration (FIGURE 2-3).

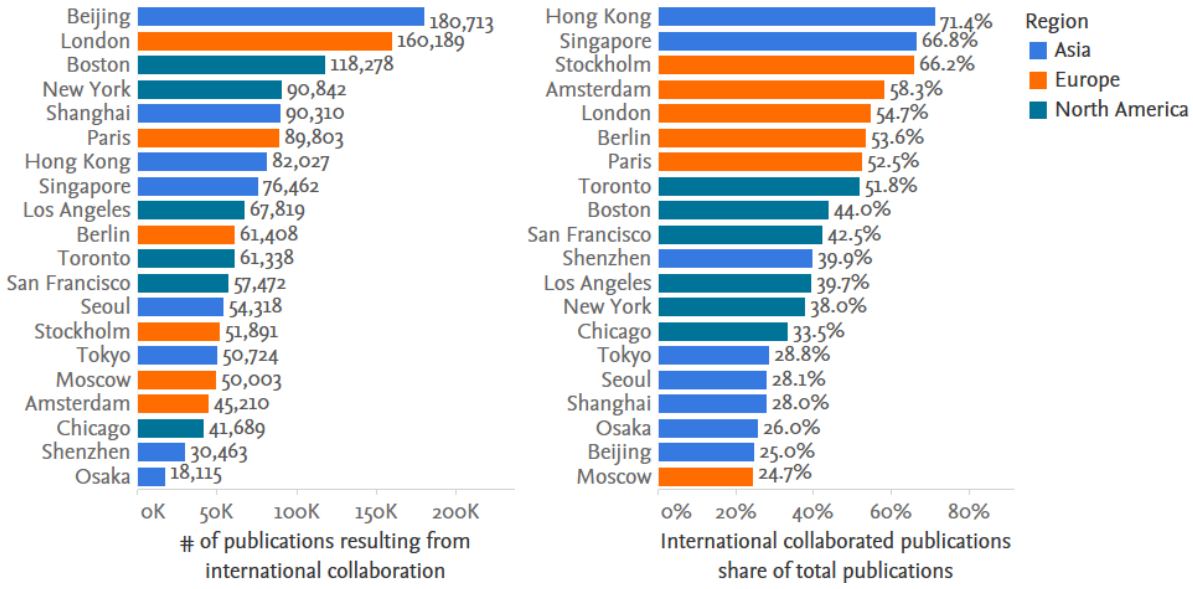


FIGURE 2-3 Scholarly output resulting from international collaboration in the 20 global cities (2016–2020).
Source: Scopus

The gaps between Asian and European cities in international cooperation might be related to several factors, including geographical location and language. European cities are geographically close, with many cultural ties and English as a lingua franca for the scientific community. Singapore and Hong Kong are typical global cities, and each has English as one of its official languages. Therefore, the degree of international cooperation in these cities is higher compared with other Asian cities studied in this report.

As shown in FIGURE 2-4, all of the 20 global cities had a higher CAGR for their international publications than for their total publications, reflecting the clear growth trend of international collaborations and that the worldwide research community is becoming more interconnected and cooperative.

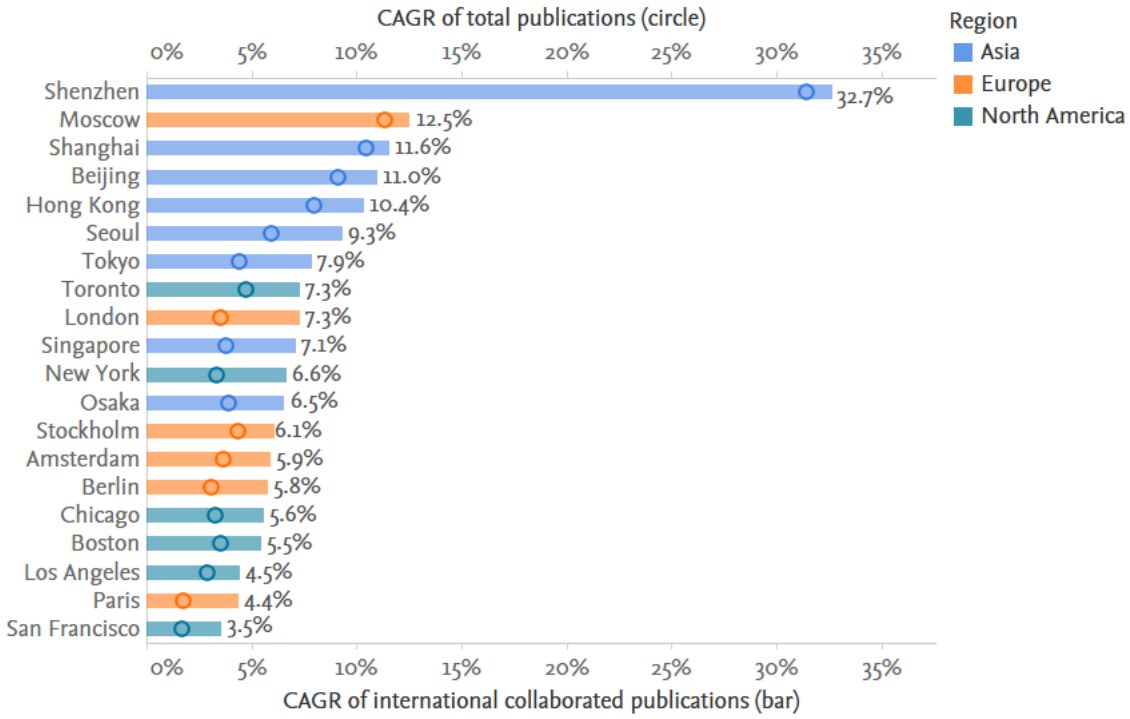


FIGURE 2-4 CAGR of the publications resulting from international collaboration vs. CAGR of total publications in the 20 global cities (2016-2020).
Source: Scopus

FIGURE 2-5 illustrates the yearly trend of international publications' share. As shown below, despite having a high international collaboration share to start with, London and Singapore saw the largest growth in their international collaboration share, with an 8 percentage point increase in the studied period. Hong Kong and Berlin followed with 6 percentage point increases.

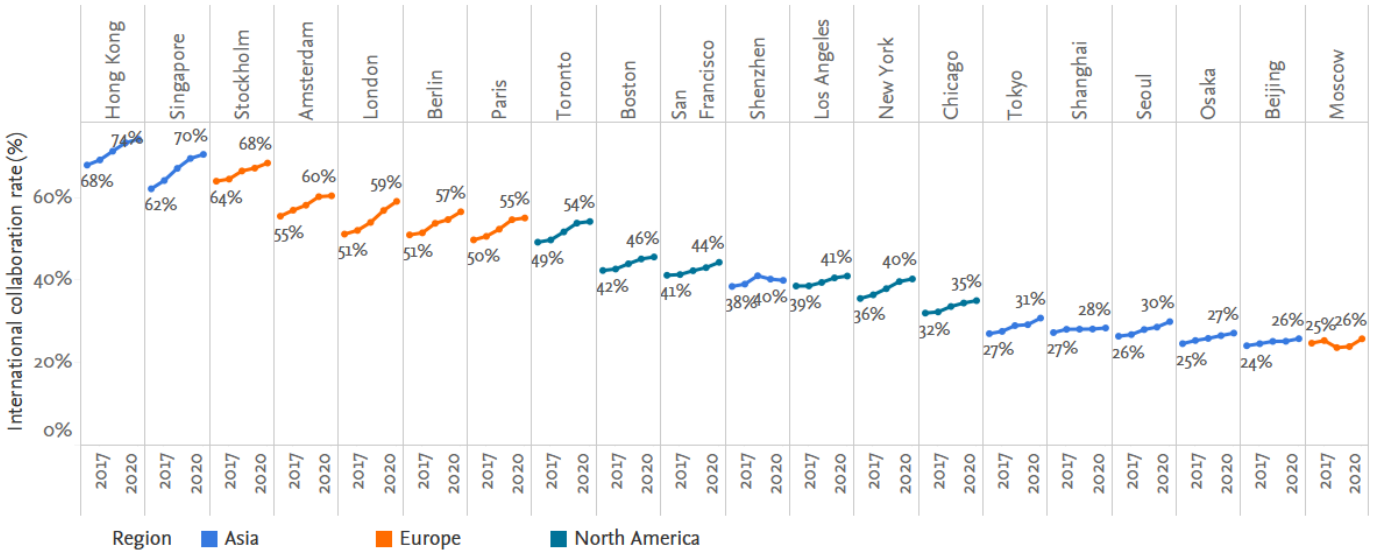
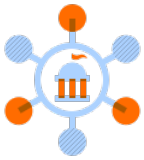


FIGURE 2-5 Yearly percentage of publications resulting from international collaboration for the 20 global cities (2016–2020).
Source: Scopus

Chapter 3

Innovative companies and patenting activity

Key findings



Tokyo

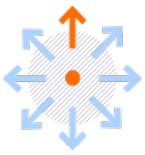
had 94 highly innovative companies, the highest number among the 20 global cities.

Seoul

ranked No. 1 for the integrated ranking score of all its highly innovative companies.

Tokyo

had the most patent applications (1.11 million patents applied).



Tokyo

had the highest number of PCT patent applications.

Hong Kong

had the highest CAGR of PCT patent applications (27.9%).

Paris

had the highest collaborated patent share (34.8%).

3.1 Innovative companies

Tokyo had the most highly innovative companies among the 20 global cities, while Seoul ranked first for the integrated ranking score of all its highly innovative companies.

Companies with a strong international reputation and influence are the major innovation engine for cities as they usually play a leading role in transferring the output of basic research into tangible benefits for society.

For this report, we identified the most innovative companies by using three ranking lists that assessed innovation at different companies. These ranking lists took different approaches in identifying innovation: *The 2018 EU Industrial R&D Investment Scoreboard* adopted the enterprise R&D investment index; *The World's Most Innovative Companies 2018* list, released by Forbes, was based on the enterprise innovation capability premium; and *The Most Innovative Companies 2019*, published by the Boston Consulting Group, used questionnaire results to generate the ranking results.

We combined the three lists to analyze the innovation capabilities of the cities in which the companies are located. Overall, there were 1,036 companies on the lists, distributed across 455 cities, and most of their headquarters were in Europe, on the east and west coasts of North America, and in East Asia. Of these, 403 companies (39%) were headquartered in the 20 cities covered in this report. Of the innovative companies on the EU list, 33% were headquartered in the studied cities; this figure was 28% for the Boston Consulting Group list and 20% for the Forbes list.

With 94 companies from the three lists, Tokyo had the highest number of innovative companies among the 20 cities during the study period, followed by Beijing (38 companies) and London (29 companies) (see FIGURE 3-1).

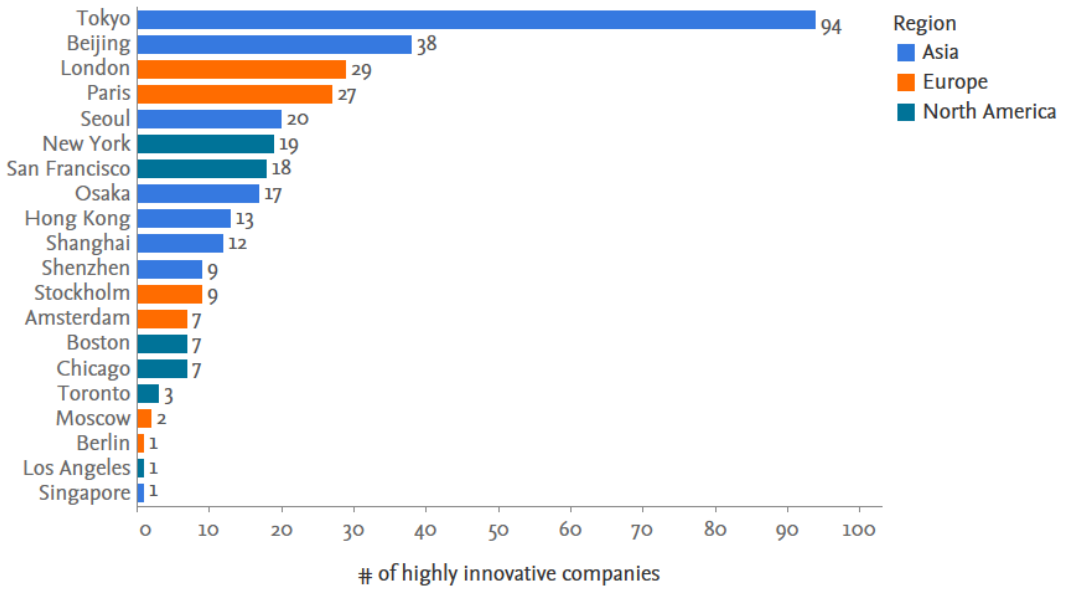


FIGURE 3-1 Number of highly innovative companies for the 20 global cities (2018/2019).
Source:
(1) Boston Consulting Group. (2019). The Most Innovative Companies 2019: The Rise of AI, Platforms, and Ecosystems.
(2) Forbes. (2018). The World's Most Innovative Companies 2018.
(3) European Union. (2018). The 2018 EU Industrial R&D Investment Scoreboard.

In total, 22 companies appeared among the top 10 most innovative companies in all three ranking lists, with 8 companies appearing in multiple lists. These companies were Alphabet (Google's parent company), Amazon, Microsoft, Apple, Samsung, Facebook, Netflix, and Tesla. Except for South Korea's Samsung, they are all US companies (FIGURE 3-2).

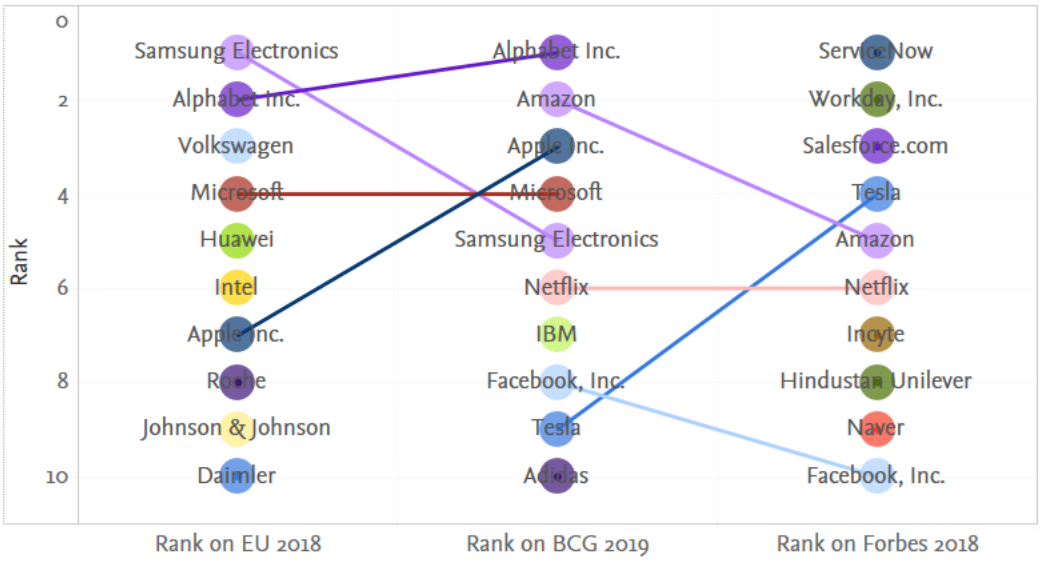


FIGURE 3-2 Top 10 companies on the three most innovative company lists (2018/2019).
Source:
(1) Boston Consulting Group. (2019). The Most Innovative Companies 2019: The Rise of AI, Platforms, and Ecosystems.
(2) Forbes. (2018). The World's Most Innovative Companies 2018.
(3) European Union. (2018). The 2018 EU Industrial R&D Investment Scoreboard.

The number of highly innovative companies can only provide one perspective of a city's innovative capabilities. A company's innovation score on the ranking list is also important. Here we summed the ranking score of all innovative companies from a city on the three ranking lists based on the formula below.

$$S_{i,j} = \begin{cases} 1 - \frac{r_{i,j} - 1}{50}, & r < 50 \\ \frac{1}{r_{i,j}}, & r \geq 50 \end{cases}$$

$$C_k = \sum_{i,j} I_k(S_{i,j}) S_{i,j}$$

$S_{i,j}$ – score of company I on j list; $r_{i,j}$ – ranking of company i on j list; C_k – score of city K

$I_k(S_{i,j})$ – a function to judge if company i is located at city K or not

Seoul, New York, and Shenzhen became the top three cities based on the integrated ranking score for highly innovative companies (FIGURE 3-3), although these cities were not in the top three based on the number of highly innovative companies. This is because the companies in these cities had a high ranking on the innovative companies list (such as Huawei in Shenzhen, Samsung in Seoul). In contrast, Tokyo and Beijing ranked in fifth and thirteenth positions, as many innovative companies from these cities appeared in the second half of the EU list.

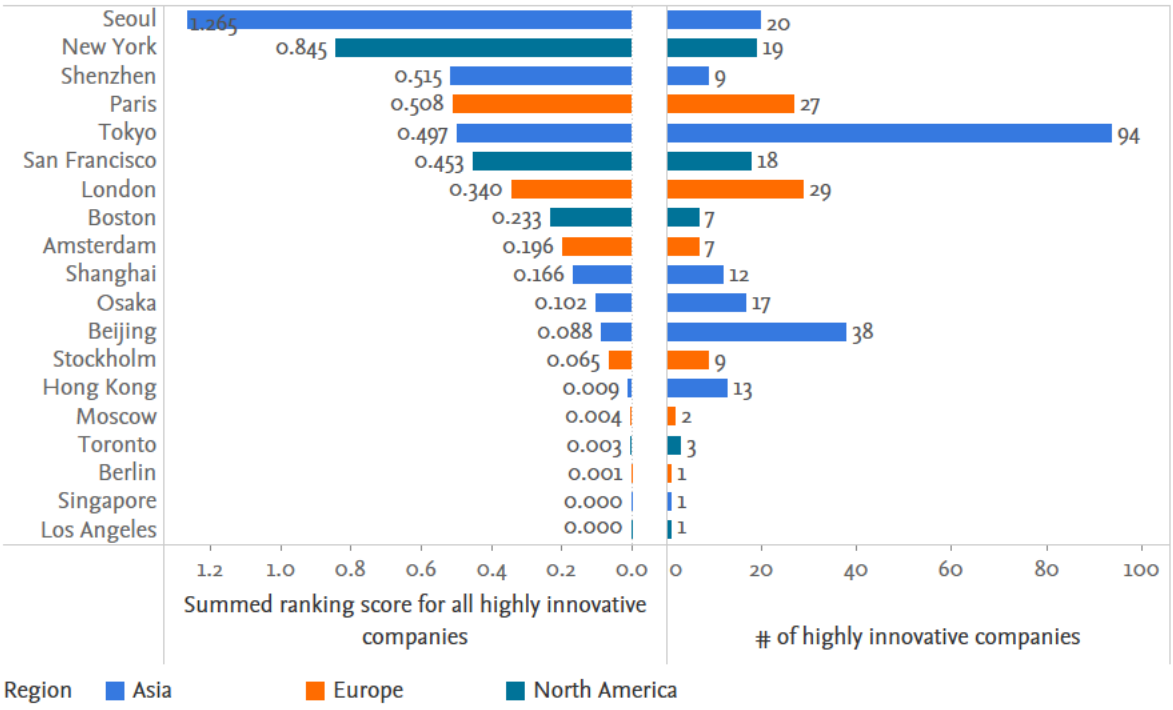


FIGURE 3-3 Summed innovation ranking score for highly innovative companies and the number of highly innovative companies in each of the 20 global cities (2018/2019).
Source:
(1) Boston Consulting Group. (2019). The Most Innovative Companies 2019: The Rise of AI, Platforms, and Ecosystems.
(2) Forbes. (2018). The World's Most Innovative Companies 2018.
(3) European Union. (2018). The 2018 EU Industrial R&D Investment Scoreboard.

3.2 Patent portfolio

Chinese cities had high growth rates for PCT patent applications, reflecting an increasingly international vision of intellectual property.

Patents represent the most economically valuable part of technology assets, and the quantity and quality of patents can therefore be a proxy for technology innovation level.

Patent applications

As shown in FIGURE 3-4, during the period 2014–2018, a total of 4.25 million patent applications were made from the 20 cities. Tokyo ranked first among the cities, with 1.11 million applications. All the top five cities were from Asia—Tokyo, Beijing, Shenzhen, Shanghai, and Seoul, in that order—and they accounted for 87.2% of all patent applications from the 20 cities. Based on the CAGR of patent applications during the study period, the top five cities also had the highest growth in applications.

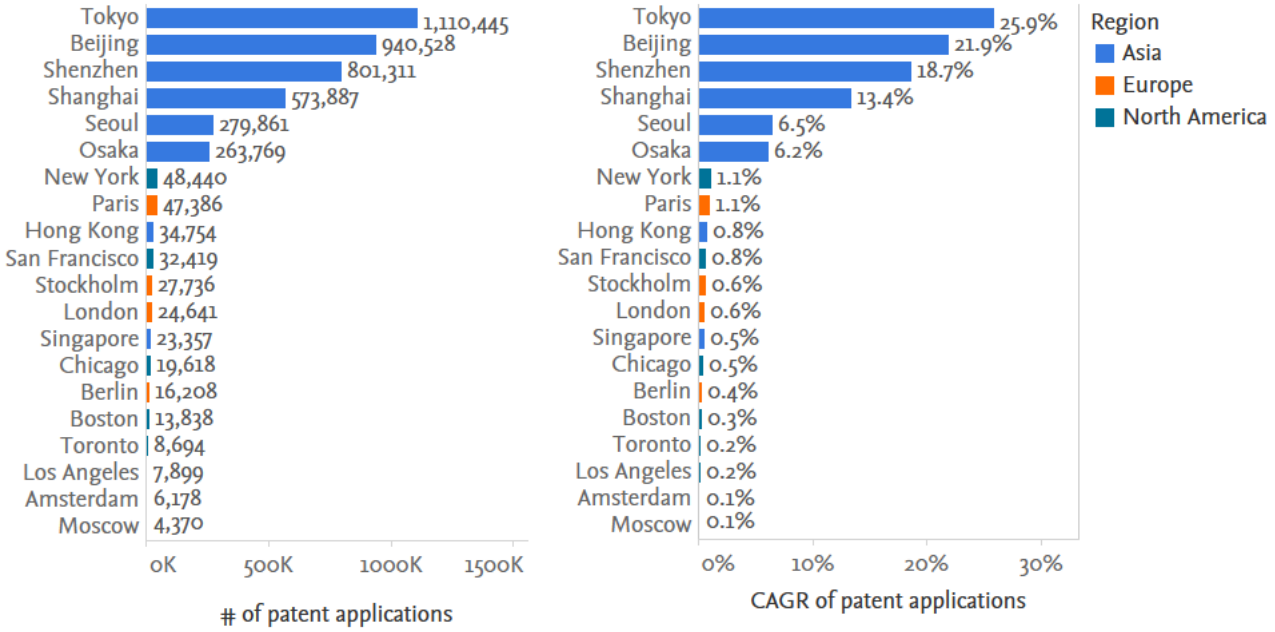


FIGURE 3-4 Number of patent applications and CAGR of patent applications for the 20 global cities (2014–2018).
Source: Patents from China National Intellectual Property Administration, European Patent Office, Japan Patent Office, South Korean Intellectual Property Office, and the United States Patent and Trademark Office.
Search date: 28 June 2019.

International patent applications: PCT patent applications

The Patent Cooperation Treaty (PCT) makes it possible to seek patent protection for an invention simultaneously in each of a large number of countries by filing an "international" patent application.[19] Such an application may be filed by anyone who is a national or resident of a PCT Contracting State. It may generally be filed with the national patent office of the Contracting State of which the applicant is a national or resident or, if the applicant so chooses, with the International Bureau of WIPO.[20]

As shown in FIGURE 3-5, during the period 2014–2018, among the 20 cities, the top 5 cities by PCT patent applications were all from Asia—Tokyo, Shenzhen, Osaka, Seoul, and Beijing—and the top 5 cities by CAGR of PCT patent applications were also all from Asia.

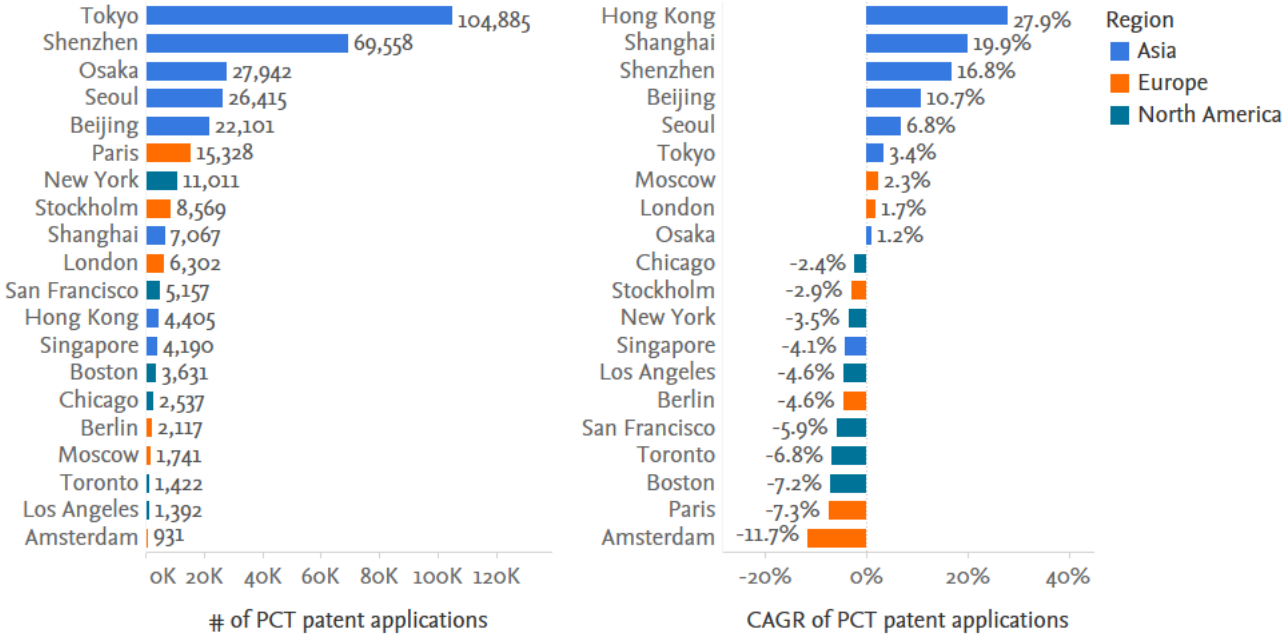


FIGURE 3-5 Number of PCT patent applications and CAGR of PCT patent applications for the 20 global cities (2014–2018).
Source: World Intellectual Property Organization (WIPO).
Search date: 28 June 2019.

[19] http://www.wipo.int/pctdb/en/

[20] WIPO is not a patent office but acts as a gateway to request international patent applications across multiple patent authorities using a single original patent application, greatly simplifying the process. Because of this, all WIPO patent applications should normally also be found in at least one other patent office.

3.3 Collaborated patents

Paris had the highest share of collaborated patent applications of the 20 cities, followed by Boston and Moscow.

"Collaborated patent applications" refers to patents applied for by two or more applicants.

During the period 2014–2018, the 20 cities had 620,000 collaborated patent applications in total. The collaborated patent applications represented one-seventh of the total patent applications in the 20 cities.

Asian cities took the top five positions for collaborated patent applications, with Beijing in the first place. Beijing had 219,000 collaborated patents—for a share of 23.2% of its total patent applications—followed by Tokyo, with 176,000 collaborated patent applications (FIGURE 3-6).

Based on the proportion of patents resulting from collaborations, Paris had the highest collaborated patent share (34.8%). Boston and Moscow followed Paris, with 26.6% and 24.5% respectively (FIGURE 3-6).

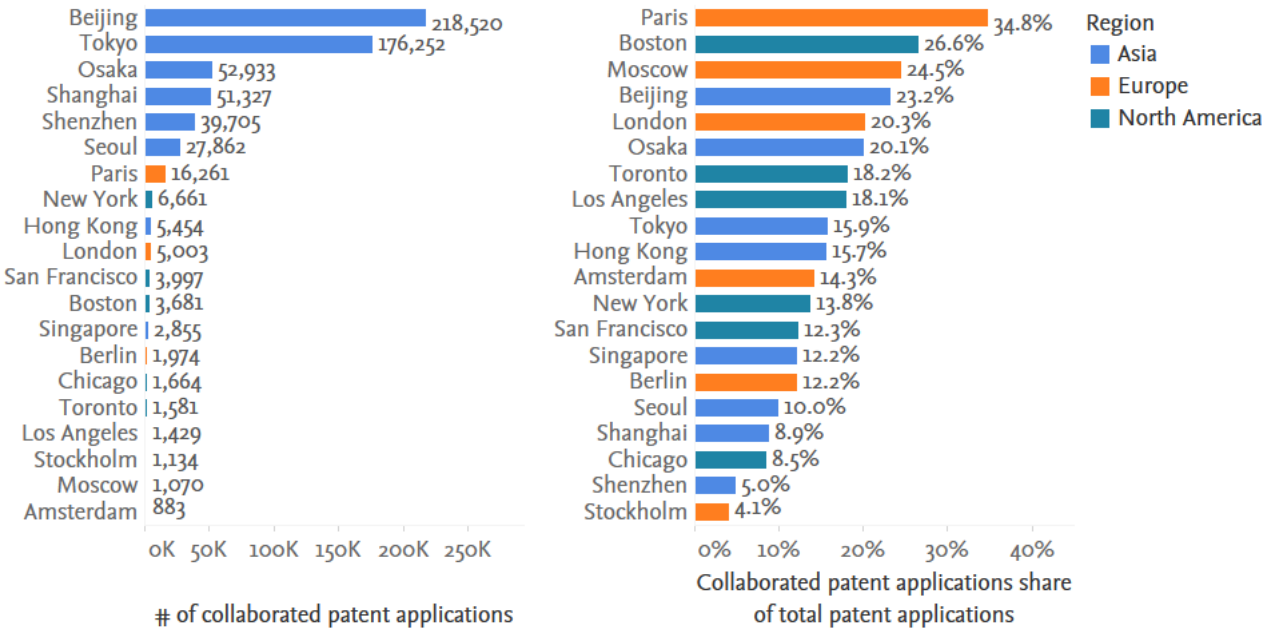


FIGURE 3-6 Count of collaborated patent applications and the share of collaborated patent applications for the 20 global cities (2014–2018).
Source: Patents from China National Intellectual Property Administration, European Patent Office, Japan Patent Office, South Korean Intellectual Property Office, and the United States Patent and Trademark Office.
Search date: 28 June 2019.

Chapter 4

Research to commercialization

Key findings

San Francisco, Osaka, and Boston

ranked top 3 for academic–corporate collaborated publication share, with 11.3%, 9.4%, and 9.3% respectively.

Hong Kong, Beijing, London, Singapore, San Francisco, and Osaka

had higher academic–corporate collaboration rates in 2020 than in 2016.

Boston's

publications had been cited by 7,674 patents, indexed in five major patent offices, ranking first among the 20 global cities.

Boston, San Francisco, and Singapore

were the only cities with a share of publications cited by patents of or over 1% (with 1.4%, 1.3%, and 1.0% respectively).

4.1 Academic–corporate collaboration

San Francisco, Osaka, Boston, and Tokyo showed close collaborations between academia and industry, with the highest shares of academic–corporate collaborated publications among the comparators.

"Academic–corporate collaboration" is defined as those publications that have authors from both the academic and corporate sectors and therefore shows direct collaboration between these different sectors. On average, over the study period, 2.7% of all publications worldwide were the result of academic–corporate collaboration, and China's baseline was 2.5%. Except for Moscow, all the 20 cities had collaboration rates higher than the world average (2.7%).

Beijing, Boston, and London ranked in the top three in terms of their numbers of academic–corporate collaborated publications, but if we look at the share of publications resulting from this collaboration, Beijing's score was much lower compared with the other cities (FIGURE 4-1). San Francisco (11.3%), Osaka (9.4%), and Boston (9.3%) ranked as the top three cities for academic–corporate collaboration share. Most Asian cities' cross-sector collaborated publication shares were lower than those of the other cities.

The cities with high academic–corporate publication shares were usually surrounded by the headquarters of international technology companies—for example, San Francisco neighbors the Bay Area's Google and large pharmaceutical R&D companies such as Genentech and Amgen; New York is surrounded by top companies such as IBM and Pfizer. We also found Japanese cities had high shares of academic–corporate collaborated publications—for example, Osaka ranked 2nd among the 20 cities based on academic–corporate collaborated publications share (FIGURE 4-1), with contributions from well-known companies such as Nippon Telegraph and Telephone Corporation, Panasonic, and Hitachi, Ltd.

Shenzhen had the highest academic–corporate collaborated publications share of the Chinese cities in this report, with 6.9%—higher than Beijing (5.1%), Hong Kong (3.9%) and Shanghai (3.7%). Shenzhen hosts the headquarters of several research-intensive enterprises such as Huawei, Tencent, and ZTE, which are some of China's IT giants, and some of those companies were active players in China's academic–corporate collaboration network.

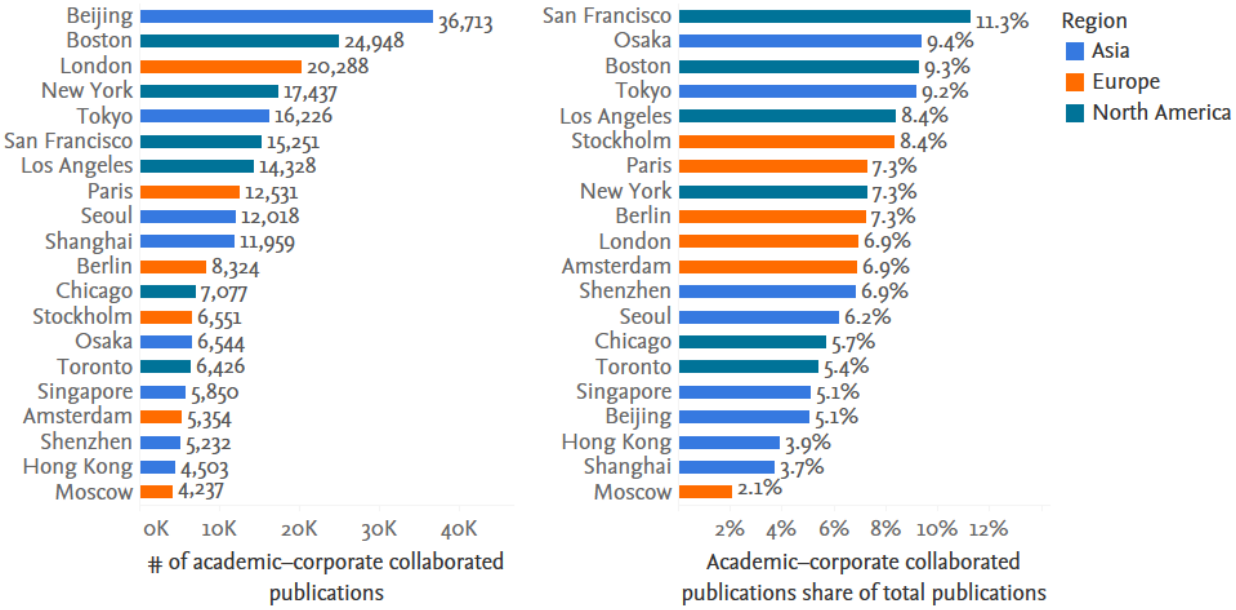


FIGURE 4-1 Number of academic–corporate collaborated publications and the share of academic–corporate collaborated publications for the 20 global cities (2016–2020).
Source: Scopus

In terms of the CAGR of academic–corporate collaborated publications, all the top five cities were from Asia, with Shenzhen, Hong Kong, and Beijing ranking in the top three. In particular, Hong Kong, Singapore, and Beijing, whose academic–corporate collaboration shares were some of the lowest among the 20 cities (FIGURE 4-1), showed a positive change over the study period. Overall, only 6 of the 20 global cities had a CAGR of publications with academic–corporate collaboration that was higher than their CAGR of total publications, indicating a decrease of academic–corporate collaboration in most cities (FIGURE 4-2). Los Angeles and Stockholm had negative growth for academic–corporate collaborated publications.

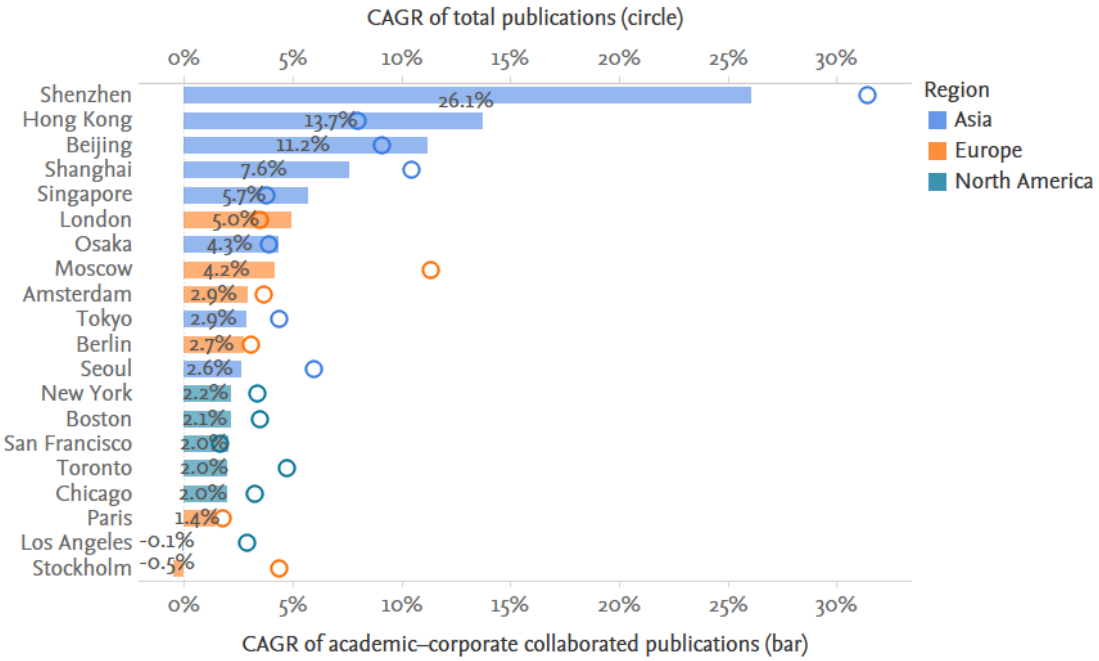


FIGURE 4-2 CAGR of total publications and CAGR of academic–corporate collaborated publications for the 20 global cities (2016–2020)
Source: Scopus

We illustrated the yearly trend of academic–corporate collaboration rates for each city between 2016 and 2020 (FIGURE 4-3). There were 10 cities—San Francisco, Osaka, Boston, Paris, New York, London, Amsterdam, Singapore, Beijing, and Hong Kong—that saw growth in their share of publications with academic–corporate collaboration from 2016 to 2019 and then a drop in 2020. There were 3 cities—Los Angeles, Seoul, and Shanghai—showing a continuous downward trend on academic–corporate collaboration strength in the period 2016–2020.

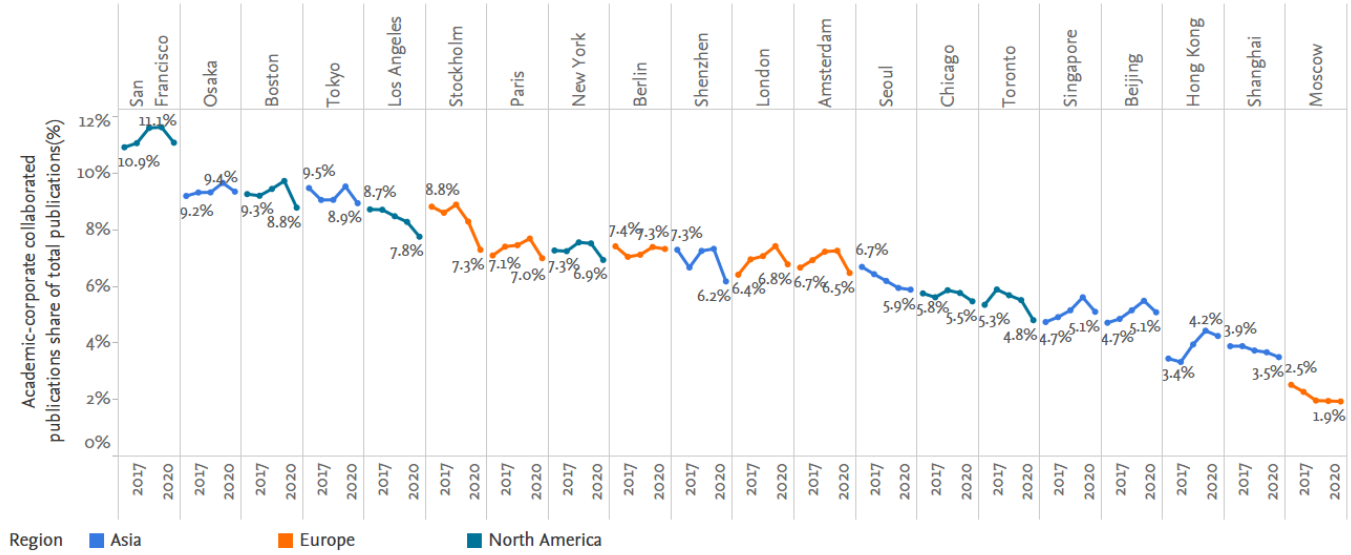


FIGURE 4-3 Trend of the share of academic–corporate collaborated publications for the 20 global cities (2016–2020) (Label is the value in 2016 and 2020).
Source: Scopus

4.2 Knowledge transfer: publications being cited by patents

The scholarly output from Boston, San Francisco, and Singapore had a relatively higher share of publications cited by patents compared with the other cities, with a rising trend in the study period.

The "knowledge transfer" refers to the application of academic research in the industrial sector. How to effectively shorten the period from basic research to industrial application is an important consideration for innovation competitiveness. This section introduces the citing-patents count, [21] as an alternative measure to track the economic impact of publications.

Count of patents citing a scholarly output

As shown in FIGURE 4-4, among the 20 global cities, the scholarly output from Boston received the highest number of citations by patents indexed by the five major patent offices, [22] with 7,674 patents citing the city's scholarly output. Meanwhile, Boston also ranked first in terms of the share of publications cited by patents. This could be attributable to the presence of Harvard, MIT, Northeastern University, and other world-renowned universities with mature management models in knowledge transfer, as scholarly output from these universities would be more cited by patents.

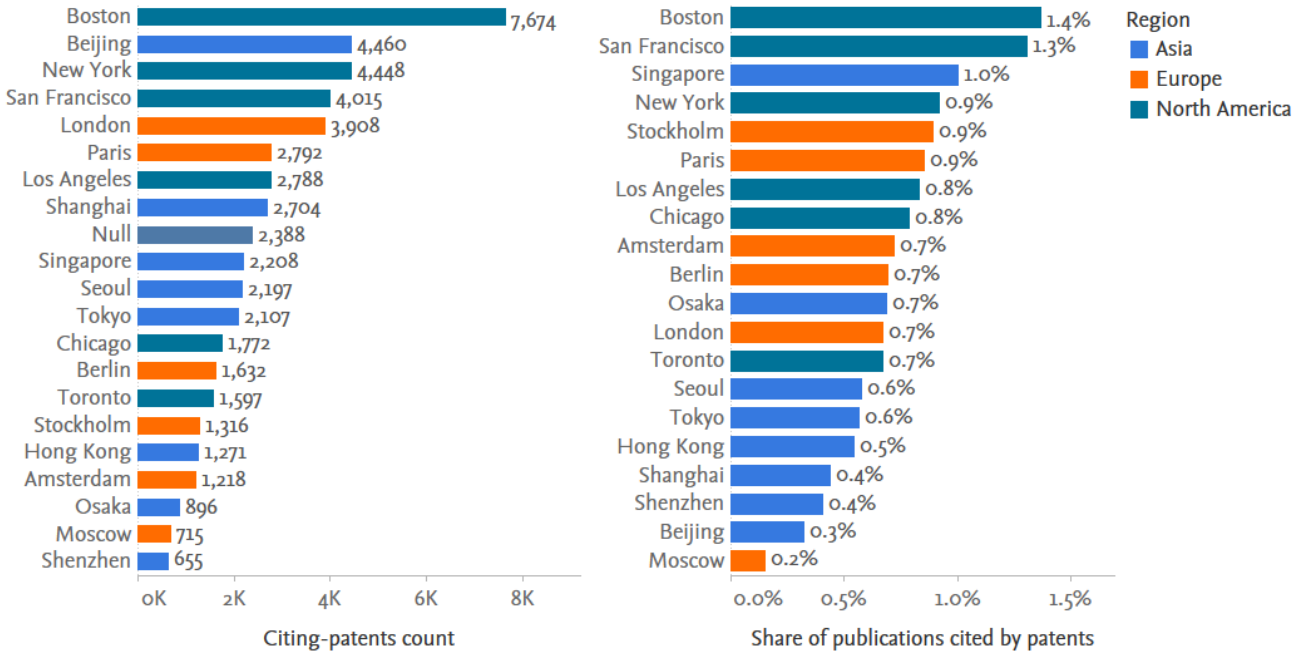


FIGURE 4-4 Citing-patents count and share of publications cited by patents for the 20 global cities (2016–2020).
Source: SciVal, Scopus

[21] Citing-patents count: count of patents citing the scholarly output published by the relevant entity.
[22] Patents are from the European Patent Office, UK Intellectual Property Office, Japan Patent Office, United States Patent and Trademark Office, and the World Intellectual Property Organization.

Trends in patent-citing strength

A high volume of publications may correlate with a higher volume of patent citations, so we calculated the share of publications from a city that were cited in patents relative to the share of publications that are cited in patents globally, to get a sense of how many publications are supporting innovation captured in patents. The calculation for this metric is presented below. If the relative share is above 1.0, it means the city has a relatively higher share of publications cited by patents compared to the global average.

The relative share of publications from a city that are cited by patents =

$$\frac{\textit{the total publications cited by patents from the city} \,/\, \textit{the total publications from the city}}{\textit{the total publications cited by patents globally} \,/\, \textit{the total publications globally}}$$

As shown in FIGURE 4-5, after adjusting for the volume of total publications, Boston still ranked first by the relative share of publications cited by patents, followed by San Francisco. Except for Moscow and Beijing, all the global cities studied here had a higher share of publications cited by patents than the global average (the value of the relative share is over 1). Except for Singapore, Asian cities ranked lower compared with European or North American cities. The patent citation data are not available for patents from the China National Intellectual Property Office and Korean Intellectual Property Office, which might underestimate some Asian cities' performance in patent citing.

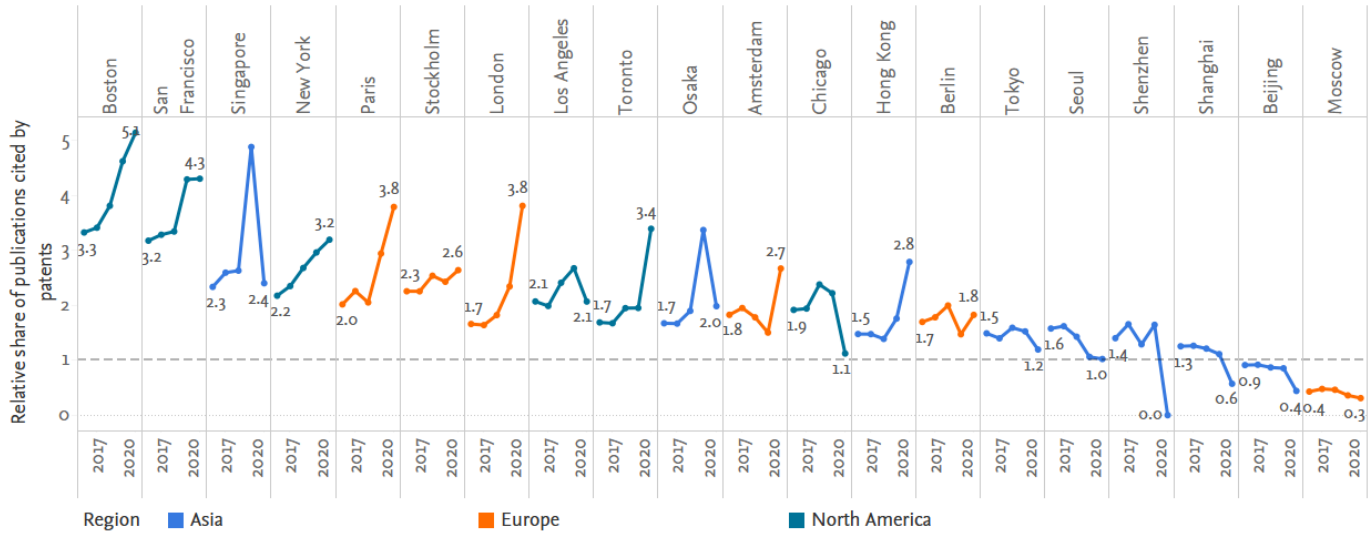


FIGURE 4-5 Trend of the share of publications cited by patents for the 20 global cities relative to the share observed globally (2016–2020 [23]).
Source: SciVal, Scopus

[23] Due to the longer time frame required for the publication of patents, patent citation data in 2020 are limited here.

The relationship between academic–corporate collaboration and patent-citing activities

We also compared the share of academic–corporate collaborated publications with the share of publications cited by patents for all the 20 cities, as shown in FIGURE 4-6. Generally, these two indicators had a positive correlation. Therefore, in some way, the cross-sector collaboration of researchers appears linked with the cross-sector knowledge exchange.

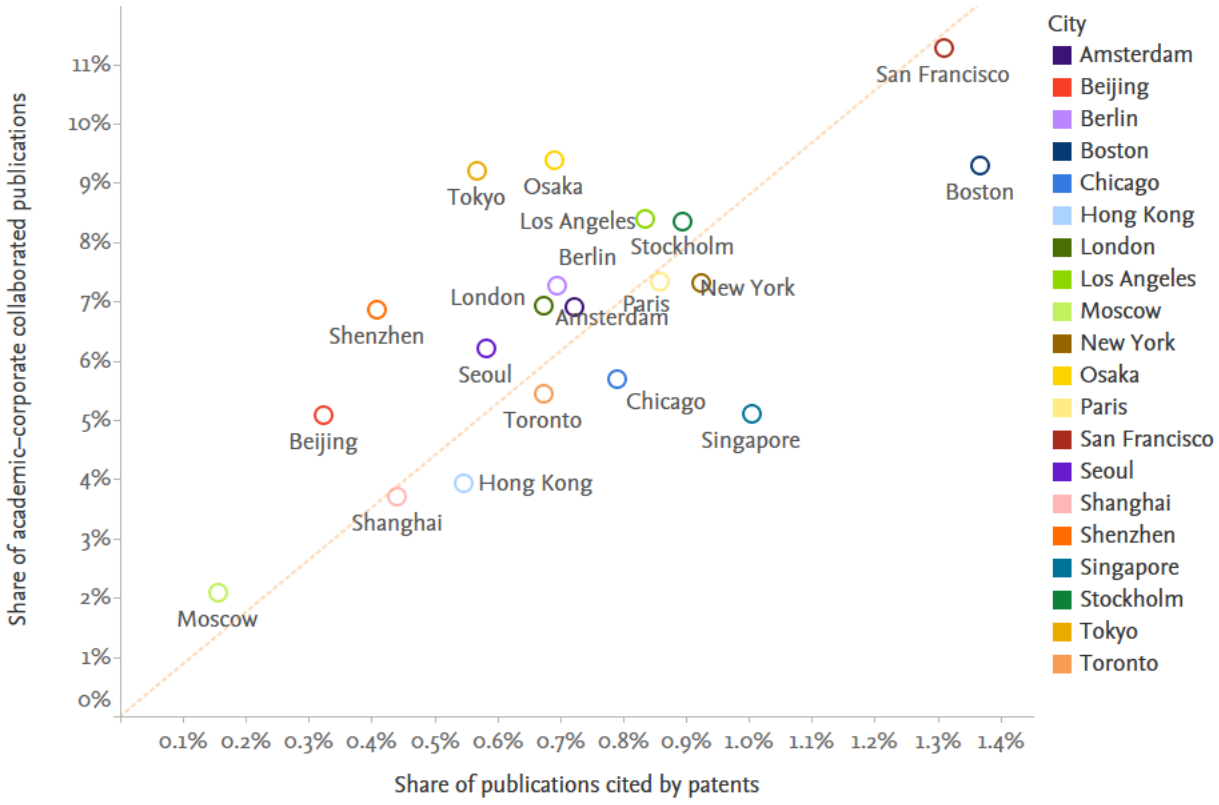


FIGURE 4-6 Share of academic–corporate collaborated publications vs. share of publications cited by patents for the 20 global cities (2016–2020).
Source: SciVal, Scopus

Conclusion

In a knowledge-driven economy, city and regional competitiveness is fueled by a pool of talents and ideas from research and innovation, often centered around universities and the surrounding ecosystem. Here, based on a selection from several indicators on innovation and competitiveness, 20 global cities have been benchmarked for their research output, impact, and patenting activities.

In all of the 20 global cities studied, the number of researchers was rising, especially in Shenzhen, Shanghai, Beijing, and Moscow. This growth in human capital translated into growth in total research output (as measured by CAGR of total publications), as well as in excellence (as measured by CAGR of top 1% highly cited publications) and in cross-regional and cross-sectoral collaborated outputs. Hong Kong and Moscow had higher productivity (as measured by the number of publications per researcher), while most other cities were quite close to each other in productivity performance. Hong Kong, San Francisco, and Boston ranked in the top three for the productivity of excellent output (as measured by the number of top 1% highly cited publications per 100 researchers).

When looking at scholarly impact, the traditional metrics used are mostly bibliographic metrics—for example, citations and publications in peer-reviewed journals that demonstrate the scholar's ability to establish academic merit. It is recognized that not everything can be found in the data and invisible areas of impact will not be tracked. However, traditional metrics have their value. They are often easily comparable, fairly standard, and understood by most scholars. In this report, we use the FWCI as a proxy for scholarly impact. This indicator normalizes citations by comparing the number of citations with the number of citations expected for a publication of the same document type, publication year, and subject. We found that the cities with strong scientific impact were still the traditional science hubs based in North America and Europe. This finding might be driven by the many prestigious universities and R&D-intensive companies located in these cities. Most Asian cities ranked lower for this measure. However, there is a clear shift toward Asia—for instance, the FWCIs of all Chinese cities were rising in the study period. In contrast, the cities with the top five highest FWCIs (except Hong Kong) showed a drop or small fluctuations in their FWCI. So not only were Asian cities publishing more, but they were also increasing their research output quality. From a Chinese perspective, these findings aligned well with the latest Chinese research evaluation policies. According to these policies, China will no longer pursue a high volume of publications but will instead focus on gaining the greatest impact on science and society.

With respect to patenting activities, except Singapore, all the Asian cities in this study had much stronger patent portfolios than cities in other regions, ranking in the top five by both volume and CAGR of patent applications. These cities also had higher volumes of PCT patent applications and higher CAGRs of PCT patent applications. Tokyo and Osaka showed a particularly strong patent portfolio compared with other cities in the report.

Cross-sector collaborations, as measured by the proportion of co-publications between academic and corporate entities, were more frequent in North American and Japanese cities. Most Chinese cities and Moscow ranked lowest for these collaborations. There might be two key driving factors for cross-sector collaboration. One is the subject concentrations of a given city, as generally there are more academic–corporate collaborated outputs in Life Sciences and Medicine than in other fields. In the report, we found the cities that were focused on Life Sciences or Medicine (for example, San Francisco, New York, and Boston) also had a high level of cross-sector collaboration. Another factor is the R&D-intensive companies located in the cities, such as those in the pharmaceutical, manufacturing, or ICT industries. For example, Osaka, Tokyo, and Shenzhen do not have an obvious subject concentration in the highly collaborative areas listed above, and yet still have a high level of cross-sector collaboration, reflecting the underlying industrial structure in these metropolitan regions.

In summary, our findings for these cities reflect their different profiles in terms of research and innovation activities. The findings of this report, prepared in collaboration with the Administrative Center of Shanghai R&D Public Service Platforms, may serve as guidance for policymakers in government, leaders at universities, or industry to support evidence-based decisions on funding or location of research and innovation activities.

Appendix A

Data source

SciVal [24] offers quick and easy access to the research performance of over 10,000 research institutions and 230 regions and countries. Using advanced data analytics technology, SciVal processes enormous amounts of data to generate powerful visualizations in seconds. The 170 trillion metrics in SciVal are calculated from 46 million publication records published in the 21,915 journals of 5,000 publishers worldwide.

Scopus [25] is Elsevier's abstract and citation database of peer-reviewed literature, covering 79.8 million documents from more than 24,272 active journals, 59,700 book series, and 10.2 million conference proceeding publications by 5,000 publishers.

Scopus coverage is multilingual and global: approximately 46% of the titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing many countries in Europe, Latin America, Africa, and the Asia-Pacific region.

For this report, a static version of the Scopus database covering the period 2016–2020, inclusive, was aggregated by city and region.

Patenting activity data used throughout this report are sourced from patent databases released by the China Intellectual Property Office, which include collections of patents from the China National Intellectual Property Office, the European Patent Office, Japan Patent Office, South Korean Intellectual Property Office, and the United States Patent and Trademark Office.

[24] https://www.elsevier.com/solutions/scival
[25] https://www.elsevier.com/about/this-is-elsevier

Appendix B

Charts

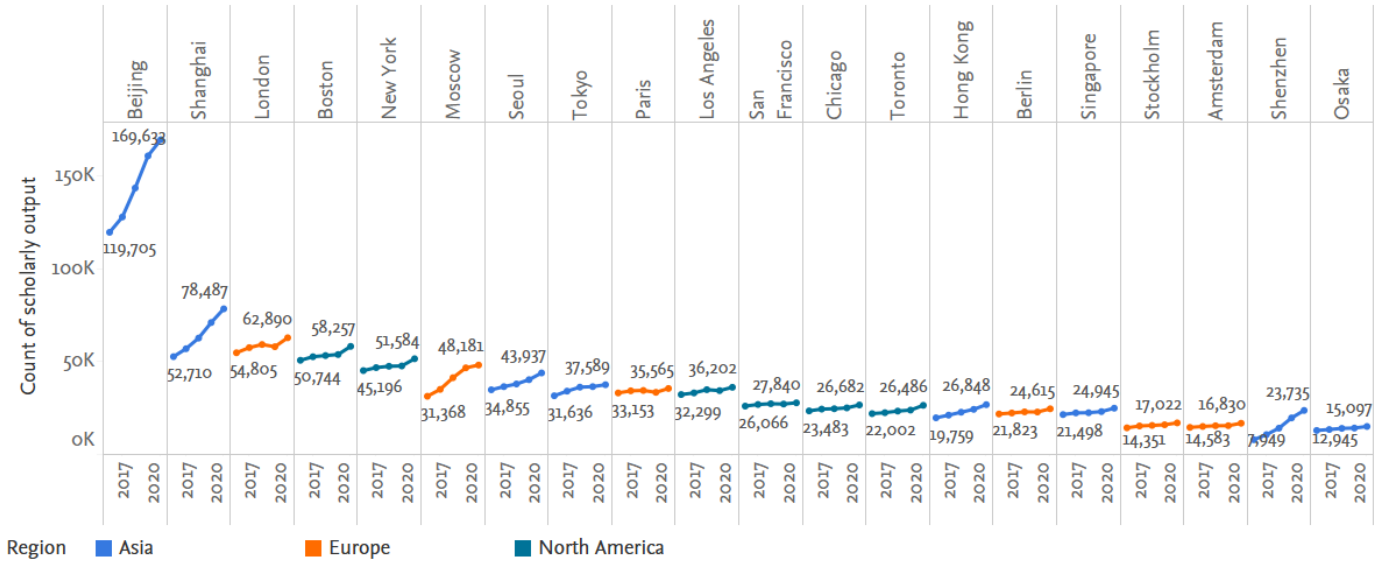


FIGURE 5-1 Yearly total publications of the 20 global cities (2016–2020).
Source: Scopus

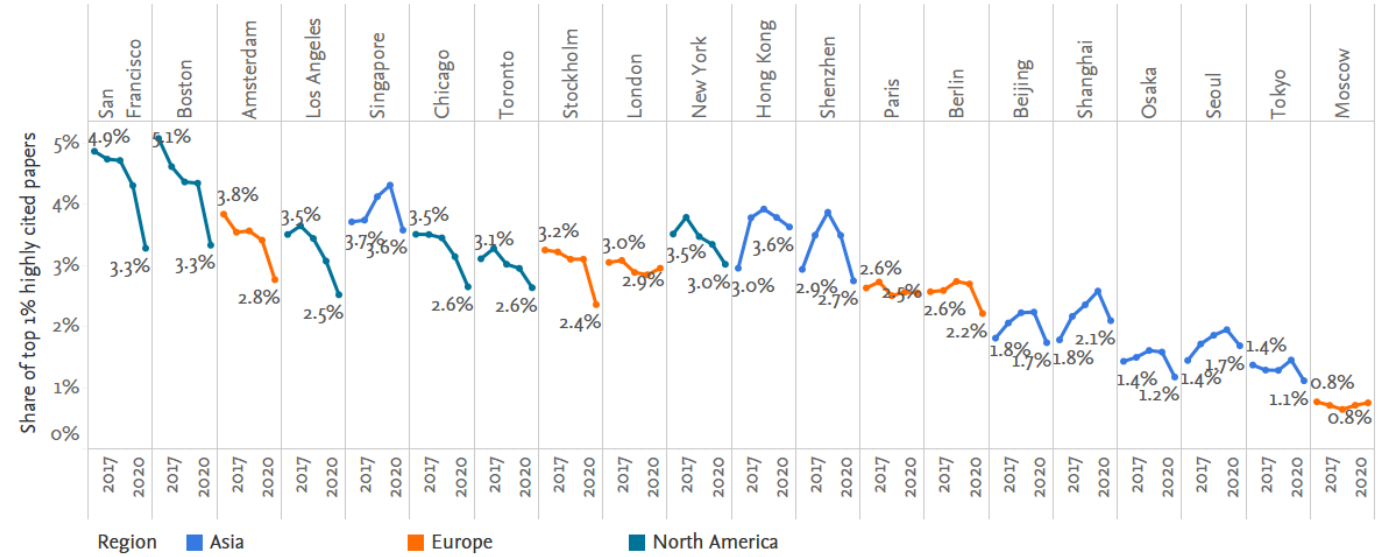


FIGURE 5-2 Yearly share of top 1% highly cited publications for the 20 global cities (2016–2020).
Source: Scopus

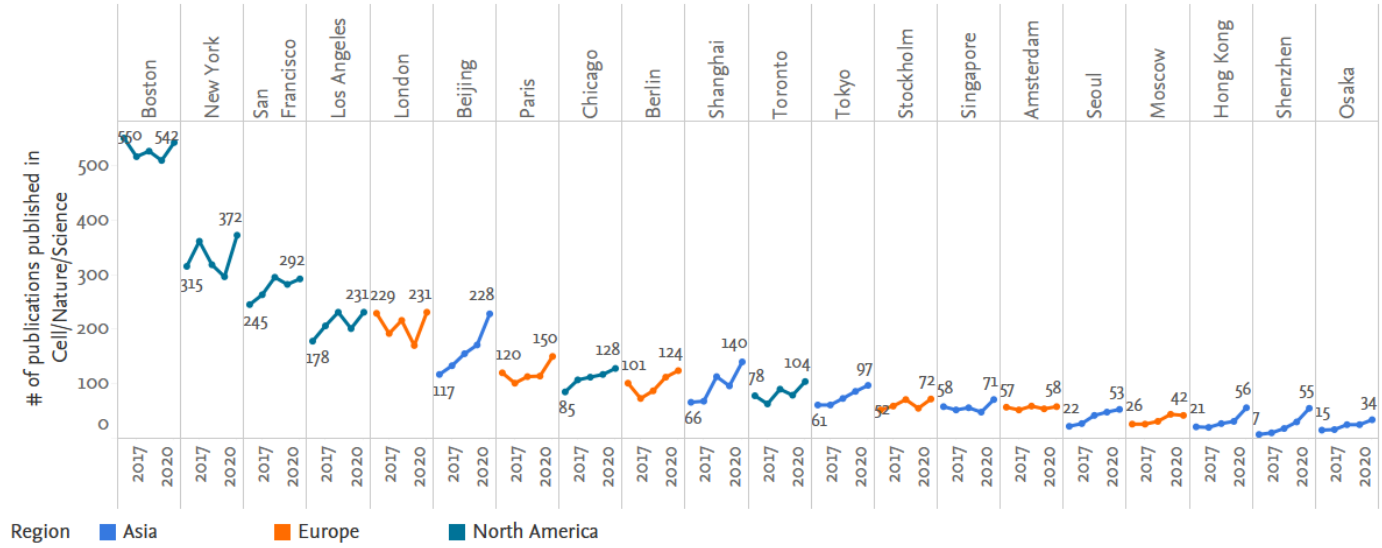


FIGURE 5-3 Yearly number of CNS publications for the 20 global cities (2016–2020).
Source: Scopus

Appendix C

Glossary of terms

Indicators	Description
Academic–corporate collaboration	In Scopus, institutions are classified into one of four main sectors (Corporate, Academic, Government, and Medical). In this report, academic–corporate collaboration is analyzed via the proxy of publications whose authors' affiliations belong to both the academic and corporate sectors.
Researcher	Researchers who have publications indexed by Scopus in the study period.
Author	An author refers to an individual included in the authorship byline for each paper indexed in Scopus.
Citation	A citation is a formal reference to earlier work made in a paper or patent, frequently to other publications. A citation is used to credit the originator of an idea or finding and is typically used to indicate that the earlier work supports the claims of the work citing it. The number of citations received by a paper from subsequently published publications can be used as a proxy of the quality or importance of the reported research.
Compound annual growth rate	Compound annual growth rate (CAGR) is defined as the year-over-year constant growth rate over a specified period. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series. $$\mathrm{CAGR} = (\frac{v_e}{v_b})^{\frac{1}{n}} - 1$$ V_e = finish value; V_b = start value; n = number of years
CNS publications	Publications published in the journals *Cell, Nature,* or *Science.*
Citing-patents count	A count of patents citing the scholarly output published by a relevant entity.
Field-weighted citation impact	Field-weighted citation impact (FWCI) is an indicator of mean citation impact and compares the actual number of citations received by a paper with the expected number of citations for publications of the same document type (article, review, or conference proceeding), publication year, and subject area. When the paper is classified in two or more subject areas, the harmonic mean of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (e.g., reviews typically attract more citations than research articles), as well as subject-specific differences in citation frequencies overall and over time and document types. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

International collaboration	International collaboration in this report is indicated by publications with at least two different countries listed in the authorship byline.
Output or scholarly output	Output or scholarly output for a country is the count of publications with at least one author from that country (according to the affiliation listed in the authorship byline). All analyses make use of "whole" rather than "fractional" counting: a paper representing international collaboration (with at least two different countries listed in the authorship byline) is counted once each for every country listed.
Patent	A patent is an exclusive right granted for an invention, which is a product or a process that provides, in general, a new way of doing something, or offers a new technical solution to a problem. To get a patent, technical information about the invention must be disclosed to the public in a patent application.
Patent applications	The total number of patent applications is the sum of the number of invention patent applications, utility model patent applications, and design patent applications. The total number of patents filed in a city is screened by date of filing and address of filing.
Patent Cooperation Treaty	The Patent Cooperation Treaty (PCT) is an international patent law treaty, concluded in 1970. It provides a unified procedure for filing patent applications to protect inventions in each of its contracting states. A patent application filed under the PCT is called an international application or a PCT application.
Researcher	Throughout the report, we use "researchers" when referring to indicators that are based on author profiles containing all the information we have for each author, and use "authors" to refer to the ascribed authors for each paper.
Top 1% highly cited publications	Citation percentiles analysis represents the number of high-impact publications that an entity has produced in terms of those publications falling into the top 1% percentile of the most cited publications, using a world benchmark.

Appendix D

Cities

The top 20 cities on each ranking list

Rank	Innovation Cities Global Index	Savills Tech Cities Index	ATK Global Cities Index	Global Power City Index	2018 Global Survey of the "Ideal City" for Scientists	The Global Urban Competitiveness Report	WIPO, Global Innovation Index
1	San Francisco	New York	New York	London	New York	New York	Tokyo-Yokohama
2	New York	San Francisco	London	New York	London	Los Angeles	Shenzhen-Hong Kong
3	London	London	Paris	Tokyo	Paris	Singapore	Seoul
4	Los Angeles	Amsterdam	Tokyo	Paris	Tokyo	London	San Jose-San Francisco, California
5	Seoul	Boston	Hong Kong	Singapore	Boston	Shenzhen	Beijing
6	Taipei	Singapore	Los Angeles	Seoul	Seattle	San Jose	Osaka-Kobe-Kyoto
7	Boston	Los Angeles	Singapore	Amsterdam	San Francisco	Munich	Boston-Cambridge, Massachusetts
8	Singapore	Austin	Chicago	Berlin	Frankfurt	San Francisco	New York
9	Toronto	Stockholm	Beijing	Hong Kong	Chicago	Tokyo	Paris
10	Chicago	Copenhagen	Brussels	Sydney	Berlin	Houston	San Diego, California
11	Dallas	Toronto	Washington DC	Los Angeles	Toronto	Hong Kong	Nagoya
12	Tokyo	Seattle	Seoul	Frankfurt	Stockholm	Dallas	Shanghai
13	Stockholm	Tokyo	Madrid	Beijing	Moscow	Shanghai	Washington DC-Baltimore, Maryland
14	Vancouver	Paris	Moscow	Vienna	Singapore	Guangzhou	LA, California
15	Amsterdam	Shanghai	Sydney	Shanghai	Seoul	Seoul	London
16	Beijing	Berlin	Berlin	Stockholm	Shanghai	Dublin	Houston, Texas
17	Shanghai	Beijing	Melbourne	San Francisco	Beijing	Miami	Amsterdam-Rotterdam
18	Montreal	Tel Aviv	Toronto	Zurich	Shenzhen	Boston	Seattle, Washington
19	Bangalore	Dublin	Shanghai	Toronto	Hangzhou	Beijing	Chicago, Illinois
20	Shenzhen	Hong Kong	San Francisco	Copenhagen	Hong Kong	Frankfurt	Cologne

The metropolitan areas / cities in this report

City in the report	Administrative division	Country code
Amsterdam	Amsterdam	NLD
Amsterdam	Amstelveen	NLD
Amsterdam	Diemen	NLD
Beijing	Beijing	CHN
Berlin	Berlin	DEU
Berlin	Potsdam	DEU
Boston	Boston	USA
Boston	Cambridge	USA
Boston	Waltham	USA
Boston	Framingham	USA
Boston	Newton	USA
Chicago	Chicago	USA
Chicago	Evanston	USA
Chicago	Schaumburg	USA
Chicago	Des Plaines	USA
Chicago	Naperville	USA
Chicago	Skokie	USA
Chicago	Gary	USA
Chicago	Elgin	USA
Chicago	Bolingbrook	USA
Chicago	Hoffman Estates	USA
Hong Kong	Hong Kong	CHN
London	London	GBR
London	Uxbridge	GBR
London	Brentford	GBR
London	Middlesex	GBR
London	Richmond	GBR
London	Harrow	GBR
London	Sutton	GBR
London	Sutton	GBR
London	Twickenham	GBR
London	Croydon	GBR
Los Angeles	Los Angeles	USA
Los Angeles	Pasadena	USA
Los Angeles	Irvine	USA
Los Angeles	Long Beach	USA
Los Angeles	Santa Monica	USA
Los Angeles	Orange	USA
Los Angeles	Torrance	USA
Los Angeles	Glendale	USA
Los Angeles	Burbank	USA
Los Angeles	Carson	USA
Los Angeles	Newport Beach	USA
Los Angeles	Santa Ana	USA
Los Angeles	Costa Mesa	USA
Los Angeles	Fountain Valley	USA
Los Angeles	Anaheim	USA
Los Angeles	Tustin	USA
Los Angeles	Arcadia	USA
Los Angeles	Gardena	USA
Moscow	Moscow	RUS
New York	New York	USA
New York	Newark	USA
New York	New Brunswick	USA
New York	Lakewood	USA
New York	White Plains	USA
New York	Jersey City	USA
Osaka	Suita	JPN
Osaka	Osaka	JPN
Osaka	Sakai	JPN
Osaka	Ibaraki	JPN
Osaka	Higashiosaka	JPN
Osaka	Takatsuki	JPN
Osaka	Hirakata	JPN
Osaka	Osakasayama	JPN
Osaka	Neyagawa	JPN
Osaka	Kadoma	JPN
Osaka	Izumi	JPN
Osaka	Toyonaka	JPN
Osaka	Kashiwara	JPN
Osaka	Daito	JPN
Osaka	Moriguchi	JPN
Osaka	Sennan	JPN
Osaka	Tondabayashi	JPN
Osaka	Kishiwada	JPN
Osaka	Ikeda	JPN
Osaka	Habikino	JPN
Osaka	Yao	JPN
Osaka	Matsubara	JPN
Osaka	Izumisano	JPN
Osaka	Kaizuka	JPN
Osaka	Kawachinagano	JPN
Osaka	Minoh	JPN
Osaka	Settsu	JPN
Osaka	Izumiotsu	JPN
Osaka	Katano	JPN

City in the report	Administrative division	Country code
Osaka	Fujiidera	JPN
Osaka	Takaishi	JPN
Osaka	Hannan	JPN
Osaka	Shijonawate	JPN
Paris	Paris	FRA
Paris	Villejuif	FRA
Paris	Villetaneuse	FRA
Paris	Cachan	FRA
Paris	Nanterre	FRA
Paris	Meudon	FRA
Paris	Saint-Denis	FRA
Paris	Boulogne-Billancourt	FRA
Paris	Fontenay-aux-Roses	FRA
Paris	Maisons-Alfort	FRA
Paris	Clichy	FRA
Paris	Rueil-Malmaison	FRA
Paris	Issy-les-Moulineaux	FRA
Paris	Bobigny	FRA
Paris	Gentilly	FRA
Paris	Clamart	FRA
Paris	Courbevoie	FRA
Paris	Bondy	FRA
Paris	Garches	FRA
Paris	Suresnes	FRA
San Francisco	San Francisco	USA
San Francisco	Berkeley	USA
San Francisco	Livermore	USA
San Francisco	Oakland	USA
San Francisco	San Ramon	USA
San Francisco	Redwood City	USA
San Francisco	Walnut Creek	USA
San Francisco	San Rafael	USA
San Francisco	Pleasanton	USA
San Francisco	San Mateo	USA
San Francisco	South San Francisco	USA
Seoul	Seoul	KOR
Shanghai	Shanghai	CHN
Shenzhen	Shenzhen	CHN
Singapore	Singapore	SGP
Stockholm	Stockholm	SWE
Stockholm	Huddinge	SWE
Stockholm	Solna	SWE
Tokyo	Tokyo Metropolis	JPN
Toronto	Toronto	CAN
Toronto	Mississauga	CAN
Toronto	Brampton	CAN

About

Shanghai R&D Public Service Platform Management Center

Shanghai R&D Public Service Platform Management Center (hereinafter referred to as "the Center"), established in November 2015, is a public institution directly under the Science and Technology Commission of Shanghai Municipality (STCSM), led by STCSM, to construct the Shanghai R&D public service platform (hereinafter referred to as "the R&D Platform"). The core goal of the Center is to build a science and technology innovation center with a global influence, to implement the project "Enable open access to national major scientific research infrastructure and large-scale scientific research equipment in Shanghai", to agglomerate as well as to integrate science and technology resources, to fulfill the "Innovation Voucher" policy, to construct the Shanghai Science and Technology Innovation Resource Center, and to preserve the Shanghai Science and Technology Service Hotline.

Through more than a decade of development since the establishment of the Center, the R&D Platform has accumulated a large quantity of science and technology resources, which include scientific research institutions, high-level talent, large-scale equipment, R&D experimental bases, and much more. The R&D Platform has comprised sharing the state of large-scale equipment and appraised the situation of how large and medium-sized enterprises, medium-sized and small enterprises, universities, institutions, and other innovative units use science and technology resources. The R&D Platform has made contributions to promoting open access to science and technology resources, put innovation-driven development into effect, and serves society to encourage people to do business creatively and drive innovation.

For more information, please visit: www.sstir.cn

Elsevier

Elsevier is a global information analytics business that helps scientists and clinicians find new answers, reshape human knowledge, and tackle urgent human crises. For 140 years, we have partnered with the research world to curate and verify scientific knowledge.

Today Elsevier is committed to bringing that rigor to a new generation of platforms. Elsevier provides digital solutions and tools in the areas of strategic research management, R&D performance, clinical decision support, and professional education, including ScienceDirect, Scopus, SciVal, ClinicalKey, and Sherpath.

This report was prepared under the lead of Elsevier's Analytical Services, part of Elsevier's Research Intelligence portfolio of products and services.

Our Analytical Services team is experienced in serving policymakers, funders, and academic and corporate research institutions around the world. Our offerings range from simple, targeted reports to comprehensive multidimensional studies, as well as data delivery and web integration services, to meet your research management needs.

For more information, please visit: www.elsevier.com

Authors and contributors

Shanghai R&D Public Service Platform Management Center

Wang Qian
Department Head
The Department of Resources and Data
The Administrative Center of Shanghai R&D Public Service Platforms

Wang Yang
Data Mining
The Department of Resources and Data
The Administrative Center of Shanghai R&D Public Service Platforms

Ruan Shu
Intelligence Analyst
The Department of Resources and Data
The Administrative Center of Shanghai R&D Public Service Platforms

Liu Meihua
Data Analyst
The Data Center
The Administrative Center of Shanghai R&D Public Service Platforms

Elsevier

Xingxing He
Analyst, Analytical Services, Elsevier

Dennis Yu
Data scientist, Research Analytics and Data Services, Elsevier

Basak Candemir, PhD
Head of Analytical Services Europe & Emergia, Elsevier

Yingying Zhou, PhD, MPH
Head of Analytical Services China, Elsevier

Beverley Mitchell
Editor-in-chief, Science-Metrix, Elsevier

Bamini Jayabalasingham, PhD
Head of Analytical Services NOAM, Elsevier

Anders Karlsson, PhD
Vice President, Global Strategic Networks, Asia Pacific, Elsevier

Analytical Services