香港中文大學
The Chinese University of Hong Kong

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Driving innovation in the Guangdong-Hong Kong-Macao Greater Bay Area: Research impact and contribution by The Chinese University of Hong Kong

Executive summary

Comprising Hong Kong, Macao, and nine cities in southern China's Guangdong province, the Guangdong – Hong Kong – Macao Greater Bay Area (GBA) is one of the most dynamic and innovative regions in the world, housing leading universities, and global high-tech companies. With strong governmental support, the GBA is seeing rapid development in science and technology (S&T) innovation, vibrant in both research publication and patent invention.

To understand the research landscape of the GBA and assess its research strengths, this report, developed in partnership with the Chinese University of Hong Kong (CUHK), provides an overview of the research performance of the GBA and a highlight of the research development of Hong Kong (HK), based on analysis of research output data in 2018–2022. Using bibliometric analysis and case studies, it also offers a deep dive into CUHK's contribution to HK and the GBA's research and knowledge transfer.

Rapid research development in the GBA and HK's role in driving research in the GBA

Over the past five years, the GBA has markedly increased its research output, which **nearly doubled** from just under 74,000 publications in 2018 to almost 143,000 publications in 2022. The compound annual growth rate (CAGR) of research output in the GBA between 2018 and 2022 was **17.9%**, higher than the growth rate of China's research output and the world's.

Hong Kong is a powerhouse in driving the GBA's research and innovation, contributing about **28%** of its overall research output and **40%** of its 'excellent' research. While HK's population only comprises 8.5% of that of the GBA, **16%** of the GBA's active researchers were affiliated with HK institutions.

The research output of the GBA generated relatively high scholarly impact. In the period 2018–2022, the field-weighted citation impact (FWCI) of the GBA publications was **1.5**, suggesting that the GBA publications were, on average, 50% more cited than the world average. The FWCI of Hong Kong in this period was even higher, reaching **1.9**.

Engineering, **Medicine**, and **Computer Science** were the three most published subject areas in HK and the GBA, suggesting their common research interests. HK and the GBA also have their specialised research areas. Comparatively, HK has a strong research emphasis on Social Science, while the GBA has a stronger presence on Materials Science.

Highlights and achievements of CUHK

CUHK is among the top 10 academic institutions in the GBA by number of publications and showed **the highest research impact as** measured by FWCI. At CUHK, the FWCI of all subject areas surpassed the global average, indicating CUHK's **comprehensive strengths** across the full range of scientific research.

Medicine is the most prominent subject area at CUHK, with its increasing output driving CUHK's overall research growth. It also had the highest FWCI across all subject areas at CUHK, supported the most start-ups, and contributed the second-most academic–corporate collaborations. Moreover, CUHK outperformed other top publishing GBA institutions in **Medicine** in terms of FWCI, propelling this subject area's research impact in the GBA and HK.

Computer Science is also a strong subject area for CUHK in terms of output volume and FWCI, with the second-highest relatively activity index (RAI) at CUHK. It contributed the second-most academic–corporate collaborations and supported the second-most start-ups.

Biochemistry and **Social Sciences** showed increasing FWCI over recent years, driving CUHK's overall research impact.

CUHK's research has higher FWCI than the GBA in all 5 strategic fields, with **Clean Energy** having the highest FWCI, a strong impact lead over the GBA, and **Artificial Intelligence** the biggest proportion of outputs, making it a specialty contribution to the region.

CUHK's research not only shows **higher FWCI**, but also a higher proportion of **excellent output**, **more media mentions and policy uptake**, and more **diversified teamwork** than those of the GBA, driving up the GBA's research impact overall.

Nearly **40%** of CUHK's publications involve collaboration with other GBA institutions, highlighting CUHK's important role in strengthening research connections between the GBA and beyond.

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Introduction

In response to collaborative regional initiatives, this report assesses The Chinese University of Hong Kong's pivotal role in driving research and innovation development within the Guangdong – Hong Kong – Macao Greater Bay Area. Through bibliometric analysis and impact case studies, the report highlights the university's contributions to regional advancement and global competitiveness.

On 1 July 2017, amidst the 20th anniversary celebrations of Hong Kong's return, the National Development and Reform Commission, along with the governments of Guangdong Province, the Hong Kong Special Administrative Region and the Macao Special Administrative Region signed the 'Framework Agreement on Deepening Guangdong-Hong Kong-Macao Cooperation in the Development of the Greater Bay Area'. This pivotal agreement outlined the collaborative goals and principles, setting the stage for joint efforts to develop the Guangdong - Hong Kong - Macao Greater Bay Area (GBA). Subsequently, in February 2019, China's central government issued the Outline Development Plan for the GBA, marking a new milestone in the development of the GBA. The plan envisaged an important role for the GBA in the next stage of China's development, as a vibrant and internationally competitive first-class bay area and a world-class city cluster that would help enhance China's global competitiveness and innovation strengths.

Comprising nine cities [1] in southern China's Guangdong Province and the two Special Administrative Regions (SARs) of Hong Kong and Macao, the GBA covers an area of 56,000 km^2 and has a population of over 80 million people. It is one of the most open and active economic regions in China. The nine mainland cities in the Pearl River Delta economic zone have constituted a key pillar of Chinese manufacturing success, while Hong Kong and Macao play a crucial role in bridging China's integration with global markets. With its existing strengths, the GBA achieved a GDP of USD 1.94 trillion in 2022, approximately 10.8% of China's total GDP that year.[2]

Highlighted in China's 13th Five-Year Plan[3], the GBA initiative points to new growth opportunities in the region and marks an important national strategy for China's economic development. As the GBA is positioned as China's next engine of economic growth, driven by innovation and technology development, the development focus is set on enhancing coordinated innovation in the region and in-depth integration of industries, academia, and research.[4] This highlights the role of scientific research in driving science and technology innovation.

Driven by the policy initiative, the GBA is seeing rapid development in science and technology (S&T) innovation. In the 2023 edition of Global Innovation Index (GII) released by the World Intellectual Property Organization (WIPO), the core GBA region of Shenzhen-Hong Kong-Guangzhou is ranked as the second largest global S&T cluster, following the Tokyo-

[1] The nine cities of Guangdong Province in Chinese mainland are: Shenzhen, Guangzhou, Zhuhai, Foshan, Zhongshan, Dongguan, Huizhou, Jiangmen, and Zhaoqing.

[2] Source of economic indicators of the GBA in 2022: https://research.hktdc.com/en/article/MzYzMDE5NzQ5

[3] Outline of the Thirteenth Five-Year Plan for National Economic and Social Development of the People's Republic of China. http://www.xinhuanet.com//politics/2016lh/2016-03/17/c_1118366322_14.htm

[4] The Central Government of China. (2019). Outline Development Plan for Guangdong-Hong Kong- Macao Greater Bay Area. https://www.bayarea.gov.hk/filemanager/en/share/pdf/Outline_Development_Plan.pdf

Yokohama cluster.[5] This showcases the GBA's vibrance in patent invention and research publication.

With the rapid S&T development of the region, underpinned by research and knowledge transfer, it is important to understand the research landscape of the GBA and assess its research strengths. This report, based on scholarly output in the peer-reviewed literature, will provide an overview of the research performance of the GBA and will highlight the research development of Hong Kong with quantitative evidence.

The focus on Hong Kong is because of its position as an important gateway connecting the Chinese mainland and the world, and its notable contribution to research development in the GBA. As a core city in the region, Hong Kong has a vital role to play in its development into an international innovation and technology (I&T) hub. A fundamental aspect underscoring Hong Kong's significance lies in its robust academic and research capacities. As the only city within the GBA home to 5 of the world's top-100 universities[6] and renowned research institutions, Hong Kong serves as fertile ground for cultivating cutting-edge knowledge and pioneering discoveries. This research prowess fosters an environment conducive to innovation, collaboration, and technological advancement.

Hong Kong's important role in the GBA's S&T innovation landscape, with its strong universities, highlights the significance of university research in driving regional innovation. With the growing discussion on how research should contribute to addressing societal challenges, more and more universities are beginning to focus on the socioeconomic impact of their research. As one of the most innovative universities in Hong Kong as well as in the GBA, The Chinese University of Hong Kong (CUHK) stands at the forefront of driving research excellence and innovation, not just for the scientific community, but also for society at large. The report, developed in partnership with CUHK, will provide a deep dive into CUHK's contribution to HK and the GBA's research and knowledge transfer.

Founded in 1963, CUHK is today home to over 30,000 students and 8,000 staff members. It is not the largest university in the GBA, but it is globally recognized as a leading research-intensive university and one of the finest in Asia. Aligned with its visionary role in propelling the technological, research, and entrepreneurial landscape, CUHK strives to foster collaboration with industry, and to make an impact on the local economy, the GBA and wider society. By leveraging its expertise, resources, and collaborative networks, CUHK contributes to catalysing transformative change, driving economic growth, societal advancement, and global competitiveness within the GBA.

To provide an evidence-based assessment of CUHK's research contribution and impact on the high-quality development of research innovation in the GBA and beyond, this report uses bibliometrics to analyse CUHK's research performance over the past five years (2018–2022), after giving an overview of the research landscape of the GBA and Hong Kong. Chapter 1 introduces the research performances of the GBA and Hong Kong and benchmarks their performances against those of the world and China. The chapter also analyses specialised research subjects of the region and the potential for knowledge transfer. Chapter 2 delves into CUHK's research contribution and impact by examining its overall research performance, specialised subject fields, progress in knowledge transfer, and contribution to research innovation in the GBA via research collaboration. To better capture the socioeconomic impact of CUHK's research, Chapter 3 utilises case studies to illustrate representative research projects that lead to significant social and economic impact.

While bibliometric analysis offers insights into research contributions and impact, it is only one facet of the whole picture of research innovation. However, examining scientific output helps to assess the socioeconomic impact of university research. This report, using research output data, aims to offer a better understanding of CUHK's role in driving research and innovation within the GBA and beyond, with potential implications for other universities seeking to contribute to societal advancement and economic development. It also seeks to give quantitative evidence of the research development in the GBA and Hong Kong to help identify opportunities for future development.

[5] See the press release by WIPO: https://www.wipo.int/pressroom/en/articles/2023/article_0009.html

[6] The world's top 100 universities are based on results of the QS World University Ranking 2024. Available from https://www.topuniversities.com/world-university-rankings;

Chapter 1

Research landscape of the Greater Bay Area and Hong Kong

1.1 Overview of research performance in the GBA and Hong Kong

Over the last five years, the research output of the GBA has nearly doubled, now contributing 13% of China's total research output. Hong Kong is a powerhouse in driving the GBA's research and innovation, contributing about 28% of its overall research output and 40% of its 'excellent' research.

In February 2019, China's central government released the Outline Development Plan for the Greater Bay Area (GBA), which outlines strategic goals for the development of the region, with a focus on establishing a globally influential international innovation and technology (I&T) hub. This vision aims to position the GBA on par with world-renowned bay areas such as New York, San Francisco, and Tokyo. The realisation of an international I&T hub is closely linked to research and innovation initiatives and the research capabilities of the region. This chapter surveys the research landscape of the GBA and Hong Kong by examining research performance, specialised research subjects, and the potential for knowledge transfer. It also underscores the pivotal role of Hong Kong in supporting the GBA's development into an international I&T hub.

Scholarly output

Over the past five years, the GBA has markedly increased its research output, which nearly doubled from just under 74,000 publications in 2018 to nearly 143,000 publications in 2022 (Figure 1.1.1). This has amounted to nearly 530,000 publications, accounting for 13% of China's total research output in the same period. The compound annual growth rate (CAGR) of research output in the GBA between 2018 and 2022 was as high as 17.9%, higher than the growth rate of China's research output and the world's.

As a core city of the GBA, Hong Kong's research output has grown steadily from 24,800 to almost 36,400 publications between 2018 and 2022. Despite having a population comprising only 8.5% of that of the GBA[6], Hong Kong contributes about 28% of the region's total research output. The CAGR of Hong Kong's research output, though not as high as that of the rest of the GBA, was notably higher than that of the world for the same period, suggesting the vibrant growth of research in the region as compared with other parts of the world.

[6] Population source: https://research.hktdc.com/en/article/MzYzMDE5NzQ5.

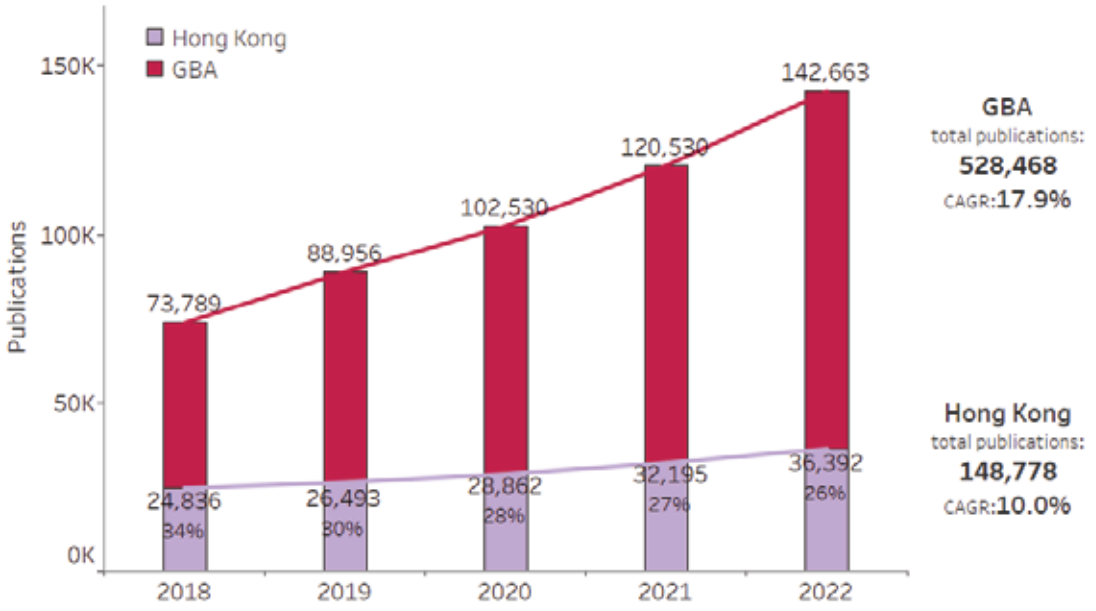


Figure 1.1.1 Research output for the GBA and Hong Kong, 2018–2022. The percentage in the figure indicates the share of the annual research output in the GBA produced by Hong Kong.
Source: Scopus

The increase in research output observed in the GBA and Hong Kong is supported by the growing number of active researchers in both regions. As shown in Figure 1.1.2, the number of active researchers in the GBA doubled from 2018 to 2022, totalling 421,300. About 66,900 of them were affiliated with institutions in Hong Kong, representing 16% of the GBA's total active authors.

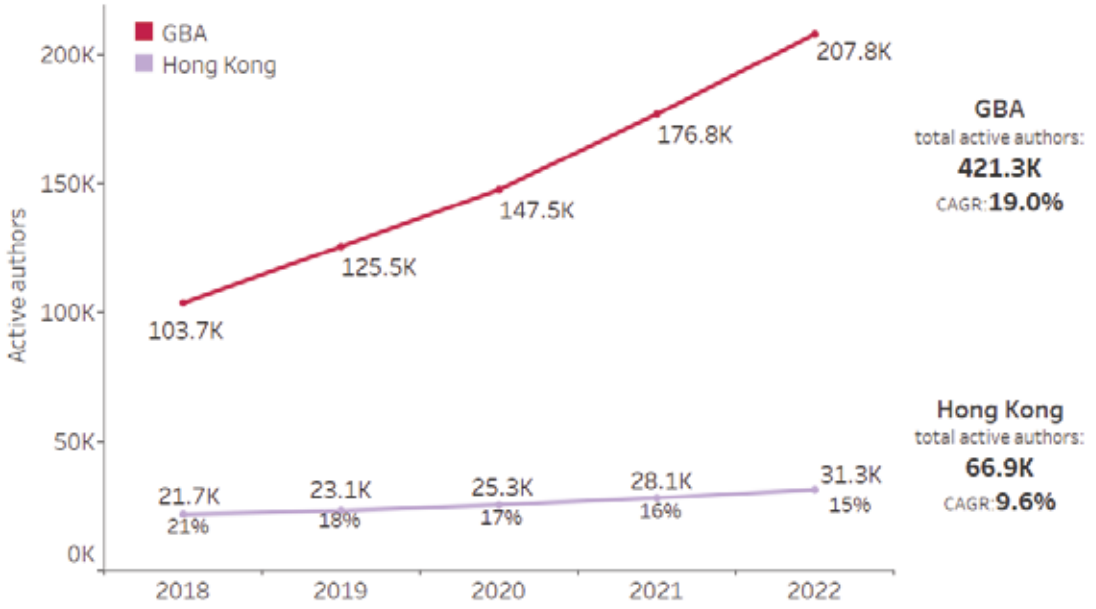


Figure 1.1.2 The yearly count of active authors for the GBA and Hong Kong, 2018–2022. The percentage in the figure indicates Hong Kong's share of annual active researchers in the GBA.
Source: Scopus

Scholarly impact

The research output of the GBA generated relatively high scholarly impact. As shown in Figure 1.1.3, in the period 2018–2022, the average number of citations per publication for the GBA was 15.3, surpassing the average levels of China and the world. The field-weighted citation impact (FWCI)[7] of the GBA publications was 1.5, suggesting that the GBA publications are, on average, 50% more cited than the world average. This can be attributed to a relatively high proportion of 'excellent' output in the GBA, defined as research published in the world's top 1% high impact journals [8]. Between 2018 and 2022, 5.2% of the GBA research output was published in the world's top 1% high impact journals, which was about 70% and 90% higher than that of the country and the world respectively.

Hong Kong's significant role in propelling the GBA's scholarly impact is evident. Between 2018 and 2022, the average number of citations per publication for Hong Kong's research output was 19.4, 27% higher than that of the GBA. The FWCI of Hong Kong in the period was 1.9, indicating that Hong Kong publications were cited 90% more than the world average for publications of the same type, higher than the citation impact of the GBA publications. Notably, 7.5% of Hong Kong publications were published in the world's top 1% high impact journals. This share was 44% higher than that of the GBA. Excluding Hong Kong publications, the citations per publication, FWCI, and share of publications in the top 1% high impact journals for the GBA all dropped, suggesting the role of Hong Kong's research output in promoting the scholarly impact of the GBA's research.

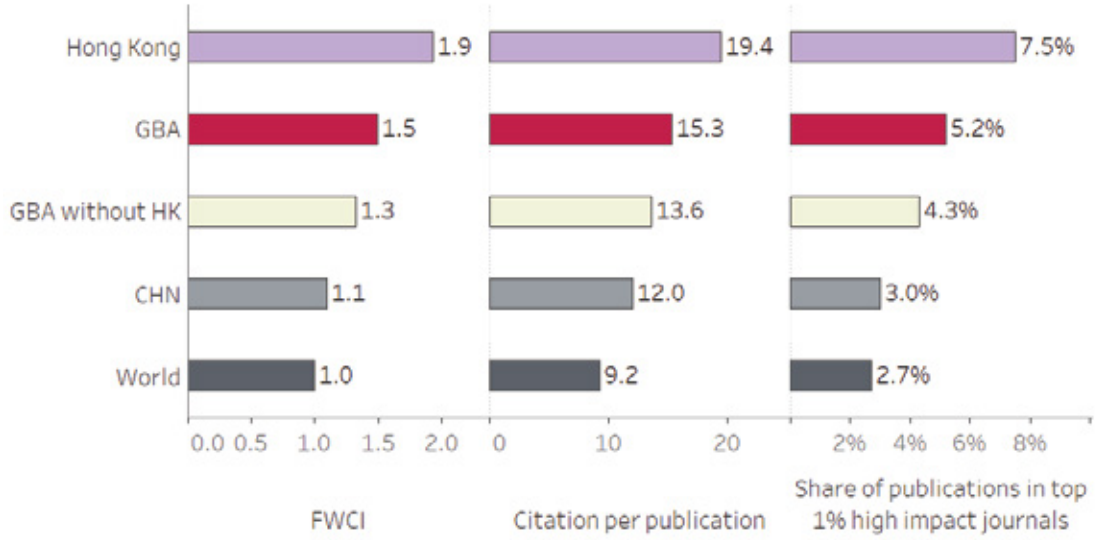


Figure 1.1.3 The FWCI and citations per publication of total publication, and the share of publications in top 1% high impact journals for Hong Kong, the GBA, the GBA without Hong Kong, China, and the world, 2018–2022.
Source: Scopus

[7] FWCI is an indicator of the citation impact of a publication. It is calculated by comparing the number of citations a publication received with the number of citations expected for a publication of the same type, publication year and subject area. 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 details, please refer to Appendix A.

[8] Top 1% high impact journals refer to the journals ranked among the world's top 1% by CiteScore Percentile in the studied period, normalised by subject field (CiteScore is a metric measuring citation impact of journals indexed in Scopus). Publication in top journal percentiles indicates the extent to which an entity's publications are present in the most-cited journals indexed in Scopus.

Research productivity

Hong Kong's substantial role in supporting the GBA's research output and research excellence can also be demonstrated by its high researcher productivity. Over the period 2018–2022, an active author in Hong Kong on average produced 2.2 publications, which was about 70% higher than the average number of publications per active author in the wider GBA (Figure 1.1.4). In terms of researcher productivity for excellent publications, an active author in Hong Kong, on average, produced 0.14 publications in the world's top 1% high impact journals. This was more than twice the number of excellent publications per active author in the GBA.

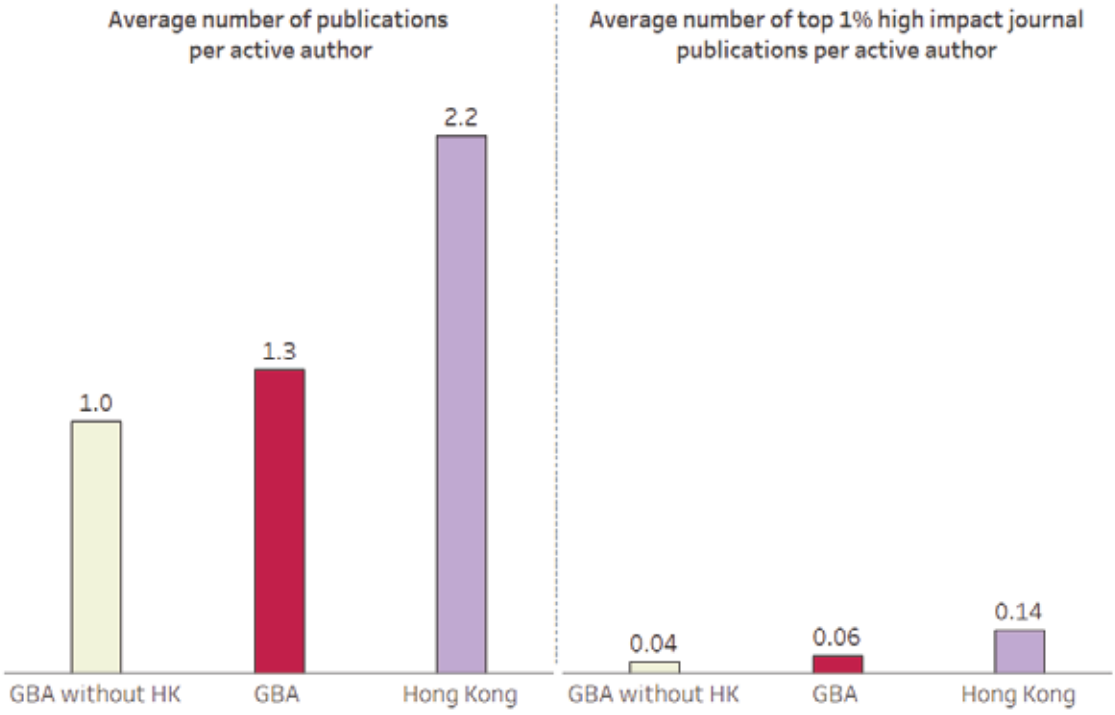


Figure 1.1.4 The researcher productivity of active authors for the GBA, the GBA without Hong Kong, and Hong Kong, 2018–2022.
Source: Scopus

Types of contributing organisations

Looking at the types of contributing organisations in the GBA, about 87% of the GBA research output was produced by academic institutions (Figure 1.1.5). This underscores the leading role of universities as the driving force behind research and innovation in the GBA. Despite a modest publication share of 2.3%, government-type organisations had the highest scholarly impact of research output. Over the study period, the FWCI of publications produced by government organisations was 1.79, which was 15% higher than that of academic institutions. This is mainly attributable to the significant contribution of the GBA-based institutes under the Chinese Academy of Sciences, the largest government-type organisation in China's research and innovation landscape. Corporate-type institutions also play an important role in the GBA research landscape, contributing 3.7% of the GBA's research output, and achieving an FWCI of 1.66 for their publications, comparable to that of academic institutions. While some of these publications are made by corporates alone, over 75% of corporate publications are co-authored with academic and/or government institutions. This also reflects an important aspect of knowledge interactions between academia and corporates, more to be detailed in a later section. Although corporate and government organisations collectively contributed only 6% of the total research output in the GBA, they played an important role in augmenting the scholarly impact of the overall research output in the GBA.

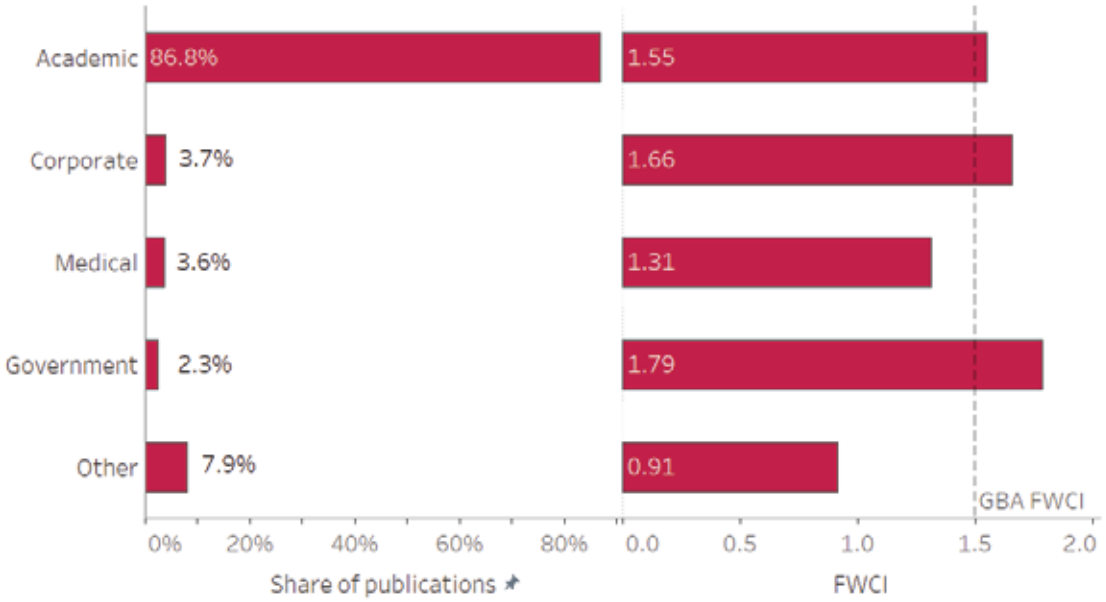


Figure 1.1.5 The share and FWCI of publications by different types of GBA institutions, 2018–2022. The dotted line indicates the average FWCI of the GBA. Government type institutions are institutions affiliated with the national or provincial government; they mainly include all kinds of research centres, research institutions or laboratories at the provincial level and national level.

Source: Scopus

Leading institutions

The top 10 leading institutions by scholarly output in the GBA are shown in Figure 1.1.6. These institutions represent the major research engines for the GBA. Sun Yat-Sen University was the clear leader in terms of output volume, with a total of 74,485 publications from 2018 to 2022. The second most published institution was South China University of Technology, with a total of 48,332 publications. The University of Hong Kong (HKU), Shenzhen University, and The Hong Kong Polytechnic University (PolyU) followed closely, with publication volume between 31,000 and 35,000.

Note that given the size advantage of Chinese mainland universities, 6 of the top 10 most published institutions in the area are from Guangdong, but that the presence of 4 institutions from Hong Kong in the top 10 signifies an important role played by Hong Kong in driving research and innovation in the GBA. Also, the 4 Hong Kong institutions ranked among the top 10 by output volume all had higher FWCI than the average of the GBA, and they produced research output with higher scholarly impact than most of the other most published institutions in the GBA.

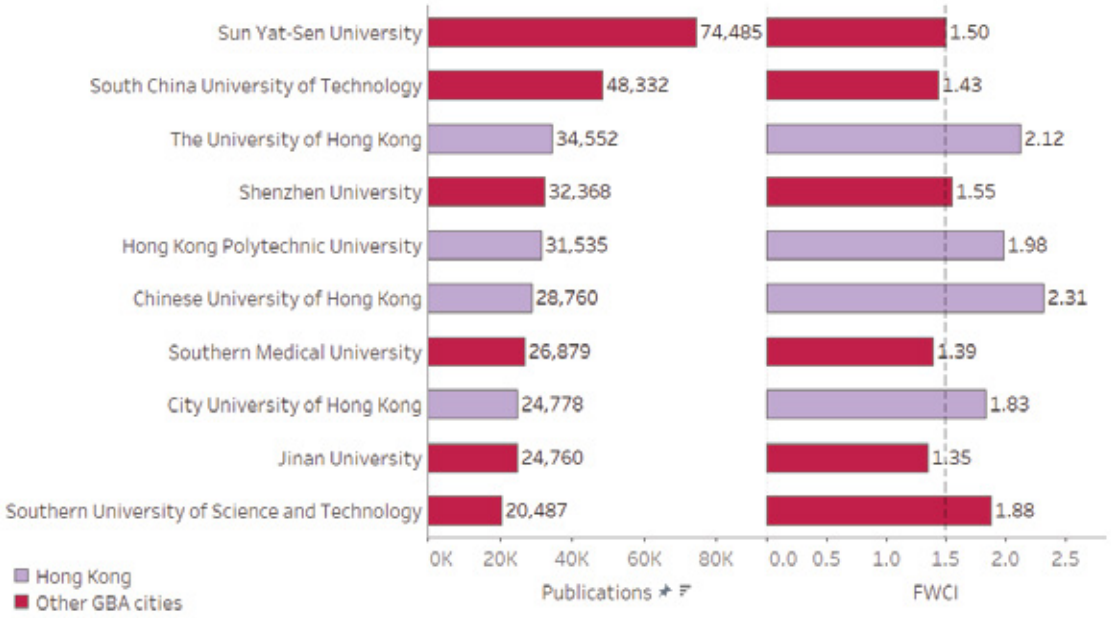


Figure 1.1.6 Top 10 GBA academic institutions by research output and their FWCI, 2018–2022. The dotted line indicates the average FWCI of the GBA.
Source: Scopus

For a closer look at institutions with high scholarly impact, the 10 best-performing institutions based on FWCI were selected among the 15 most published academic institutions in the GBA (Figure 1.1.7). Out of them, five were universities located in Hong Kong, with four of them ranking among the top five, indicating the leading role of Hong Kong institutions in driving the scholarly impact of the GBA. The Chinese University of Hong Kong (CUHK) had the highest scholarly impact, with an FWCI of 2.31. It was followed closely by HKU, which had an FWCI of 2.12. The Hong Kong University of Science and Technology (HKUST) and Poly U also performed well, with an FWCI of 1.98 each. Southern University of Science and Technology was the only Chinese mainland university ranked in the top five by FWCI, with an FWCI of 1.88.

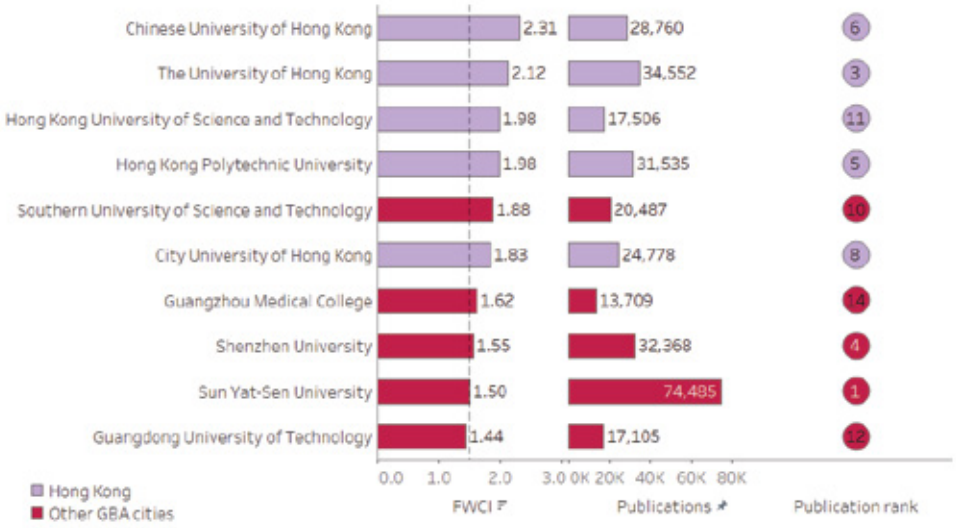


Figure 1.1.7 Top 10 GBA academic institutions with the highest FWCI (of the 15 most published institutions), their publication output, and their publication rank in the GBA, 2018–2022. The dotted line indicates the average FWCI of the GBA.
Source: Scopus

Given the role played by corporate institutions in the research output of the GBA, Figure 1.1.8 presents the top 10 corporates in the GBA based on their research output volume. China Southern Power Grid, a large state-owned enterprise, was the most published

corporate in the GBA, with a total of 5,503 publications in the study period. However, the scholarly impact of its research output was not high, with an FWCI of 0.61, lower than the global average. High-tech IT companies Huawei and Tencent followed as the second and third most published corporations in the GBA respectively, and notably, they also achieved high FWCI of their research output. SenseTime Group, a leading AI software company based in Hong Kong, had the highest scholarly impact among the top 10 most published corporates, achieving an FWCI as high as 4.63. Their research advancements in computer vision and image processing, such as publications related to instance segmentation, medical image analysis, and visual tracking have attracted a high number of citations. The 10 most published corporates are mostly concentrated in sectors such as power and energy (China Southern Power Grid, China Unclear Power Engineering, China General Nuclear Power Group), information technology and telecommunications (Huawei, Tencent, ZTE), and artificial intelligence (SenseTime), suggesting active research activities in these industrial sectors.

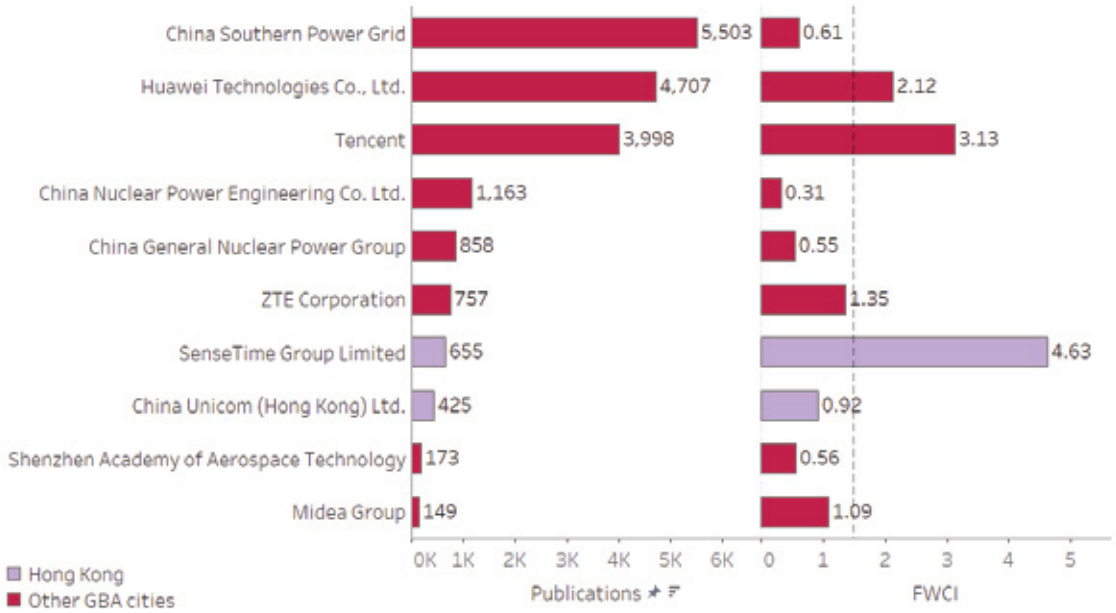


Figure 1.1.8 Top 10 GBA corporates by research output and their FWCI, 2018–2022. The dotted line indicates the average FWCI of the GBA.
Source: Scopus

1.2 Specialised subject areas of the GBA and Hong Kong

Engineering, Medicine, and Computer Science are the three most productive subject fields for the GBA and Hong Kong. Hong Kong also shows specialisation in the subject field of Social Science and the subfields of Software and Civil and Structural Engineering.

To become an international I&T hub, the GBA needs to align its research strengths with the region's competitive economic strengths and maximise the complementary research advantages of Hong Kong and the Chinese mainland. Understanding the research fields that Hong Kong and the GBA specialise in or focus on helps to uncover their field-specific research capabilities and distinctive research strengths. This will support leveraging the complementary research advantages of Hong Kong and the GBA more effectively to achieve synergistic development in scientific research and innovation.

Dominant subject areas

As shown in Figure 1.2.1, the five most published subject areas (based on the All Science Journal Classification, ASJC 27) in the GBA were *Engineering; Medicine; Computer Science; Materials Science;* and *Biochemistry, Genetics and Molecular Biology*. Although Hong Kong and the GBA shared most of their top 10 most published subject areas, Hong Kong had a higher output share in *Social Sciences*, while the GBA had a stronger presence in *Chemical Engineering*.

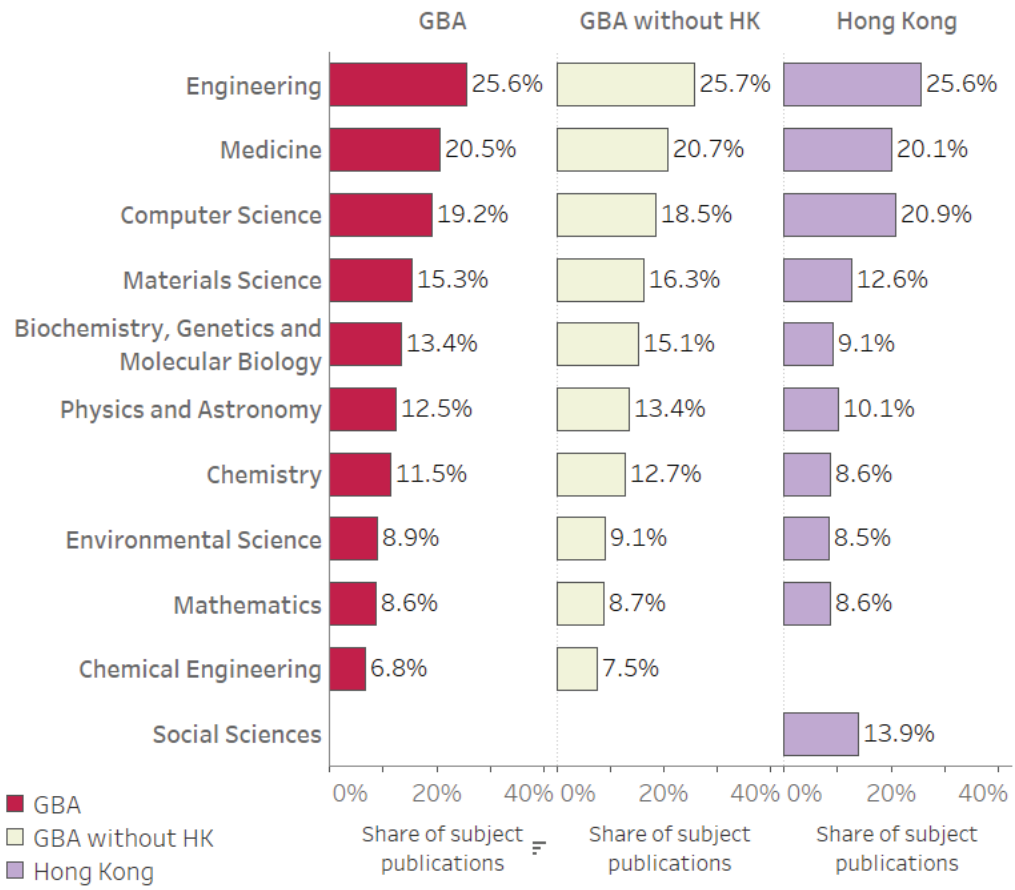


Figure 1.2.1 The 10 most published subject areas for the GBA, GBA without Hong Kong, and Hong Kong, and their subject output share, 2018–2022. The absence of an output share in the chart indicates that the corresponding subjects are not among the entity's top 10 published subjects.
Source: Scopus

Figure 1.2.2 displays the 10 most published subfields of research (based on ASJC 334) in Hong Kong and the GBA. The two regions had eight dominant subfields in common, which were concentrated in the subject fields of *Computer Science, Chemistry, Materials Science*, and *Engineering*, with four subfields from *Computer Science*. *Electrical and Electronic Engineering* was the most published subfield in both Hong Kong and the GBA, with an output share of 9.0% and 9.9%, respectively.

In addition to these common research focuses, Hong Kong also showed research in subfields different from those in the wider GBA. Notably, subfields such as *Civil and Structural Engineering,* and *Renewable Energy, Sustainability and the Environment* were ranked among the most published in Hong Kong, but not in the GBA. *Electronic, Optical and Magnetic Materials,* and *Condensed Matter Physics* were more present in the GBA.

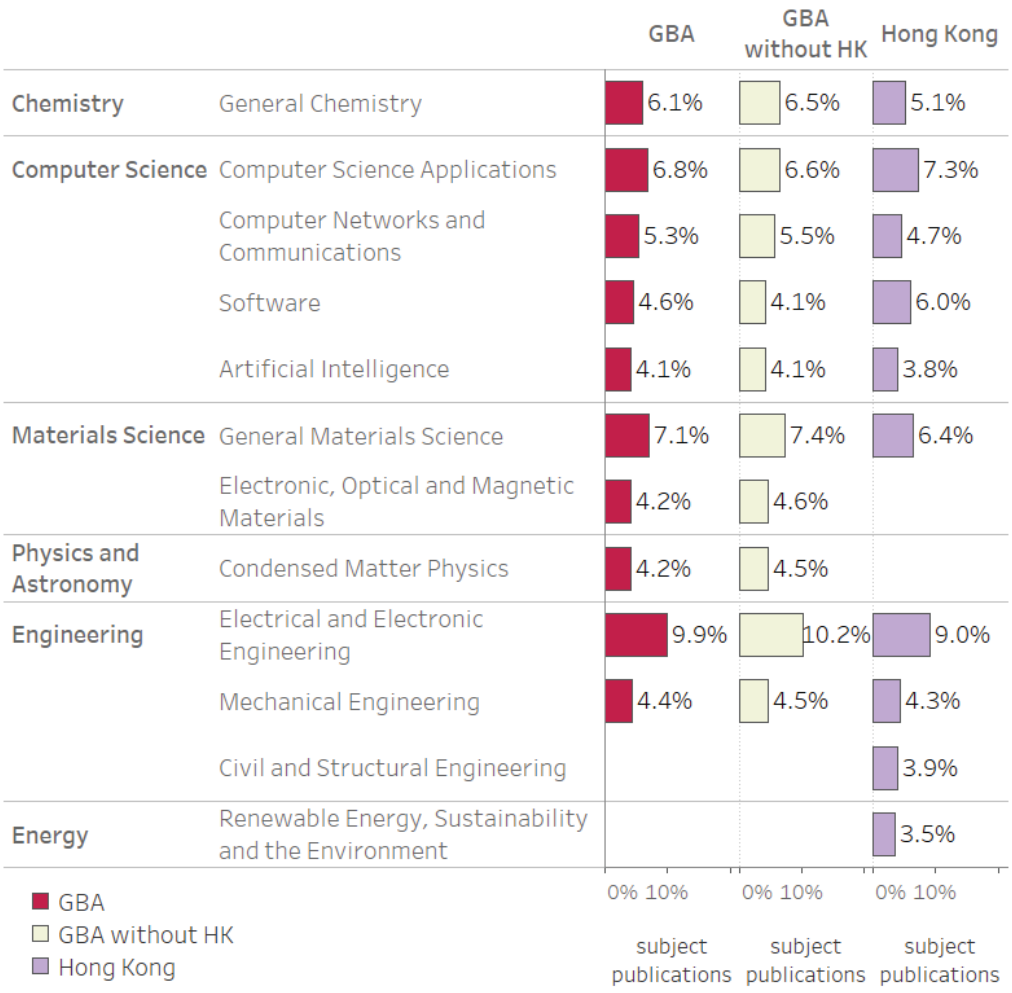


Figure 1.2.2 The 10 most published research subfields for the GBA, GBA without Hong Kong, and Hong Kong, and their subfield output share, 2018–2022. The absence of an output share in the chart indicates that the corresponding research subfields are not among the entity's top 10 published subfields.
Source: Scopus

Specialised subjects

Another indicator for comparing the GBA's specialised subject areas with those of Hong Kong is the relative activity index (RAI). The index represents an entity's share of publications in a specific subject area relative to the worldwide share of publications in the same area. If an entity's RAI is higher than the global level of 1.00, then this entity can be said to have a higher-than-average specialisation in a given area.

As seen in Figure 1.2.3, although the GBA and Hong Kong had the highest output share in *Medicine,* surpassing that of Chinese mainland, their RAI was lower than 1. This indicates that the research activity in *Medicine* in both regions was relatively less active compared to the rest of the world.

Notably, Hong Kong had a high degree of specialisation in *Social Sciences*. *Computer Science* was another subject in which Hong Kong showed slightly higher research activity than the GBA (excluding Hong Kong), and both Hong Kong and the GBA had higher specialisation in *Computer Science* than the world average. In contrast to Hong Kong, the GBA (excluding Hong Kong) had high specialisation in research on *Biochemistry, Genetics and Molecular Biology; Chemical Engineering; Chemistry;* and *Materials Science,*

with RAI in these subject areas almost 50% higher than the world average. The GBA area excluding Hong Kong was also more specialised in *Physics and Astronomy* and *Environmental Science* than Hong Kong.

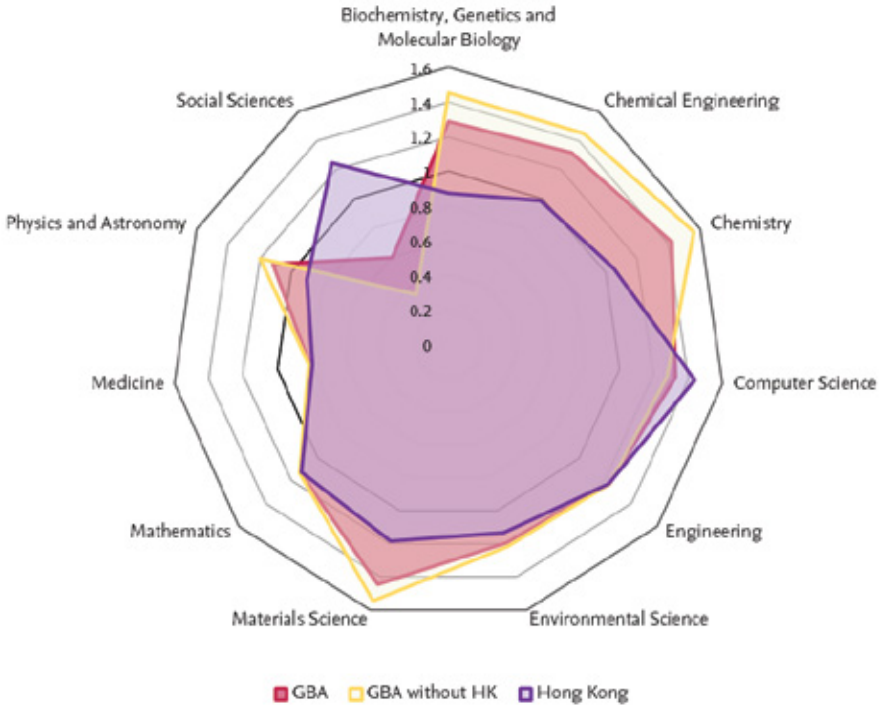


Figure 1.2.3 The 10 most published subject areas for the GBA, GBA without Hong Kong, and Hong Kong, and their RAI against the world, 2018–2022. An RAI higher than 1.0 implies a greater emphasis in certain subject for the region than the world; and an RAI lower than 1.0 suggests a lesser focus.
Source: Scopus

In terms of research subfields (ASJC 334), the GBA and Hong Kong showed higher levels of RAI in all their 10 most published subfields than the world, suggesting that both regions had higher research activity than the world in these subfields.

Compared with the GBA, Hong Kong was especially active in Software, Civil Structural Engineering, and Computer Science Applications, with particularly high research concentration in the former two subfields, in which Hong Kong had an RAI more than twice that of the world average (see Figure 1.2.4). In contrast, the GBA, when excluding Hong Kong, was notably more specialised in Condensed Matter Physics, Electronic, Optical and Magnetic Materials, General Material Science, and General Chemistry.

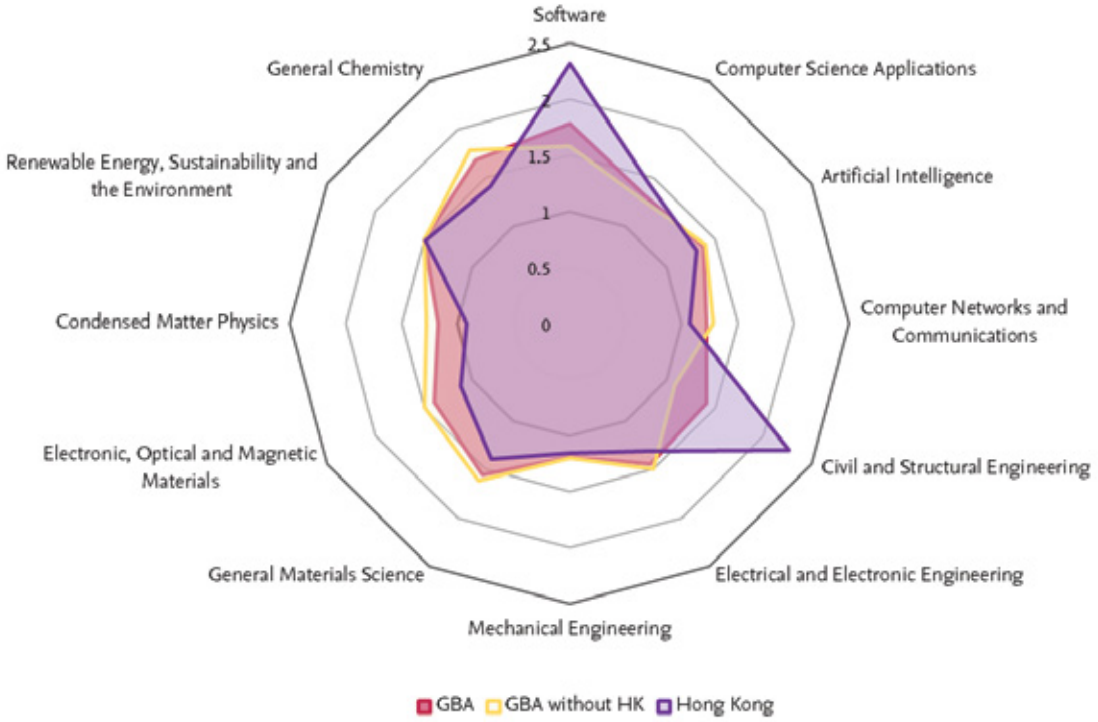


Figure 1.2.4 The 10 most published subfields for the GBA, GBA without Hong Kong, and Hong Kong, and their RAI against the World level, 2018–2022. An RAI higher than 1.0 implies a greater emphasis in a certain subfield for the region than the World level; and an RAI lower than 1.0 suggests a lesser focus.
Source: Scopus

Leading institutions in dominant subject areas

Figure 1.2.5 displays the five GBA institutions leading in scholarly output across the GBA's five core subject areas. These institutions represent the major contributors to the research output in the GBA's most published subject areas. Overall, universities in the Chinese mainland had a scholarly output advantage over their peers in Hong Kong, especially in the subject area of Biochemistry, Genetics and Molecular Biology, in which all five leading universities were based in the mainland. This is primarily due to the larger scale of Chinese mainland universities, in terms of faculty and student population size and campus area, as compared with peers in Hong Kong. Notably, Sun Yat-Sen University was among the leading institutions across the five core subject areas of the GBA. South China University of Technology led by research output volume in Engineering and Materials Science among the GBA institutions.

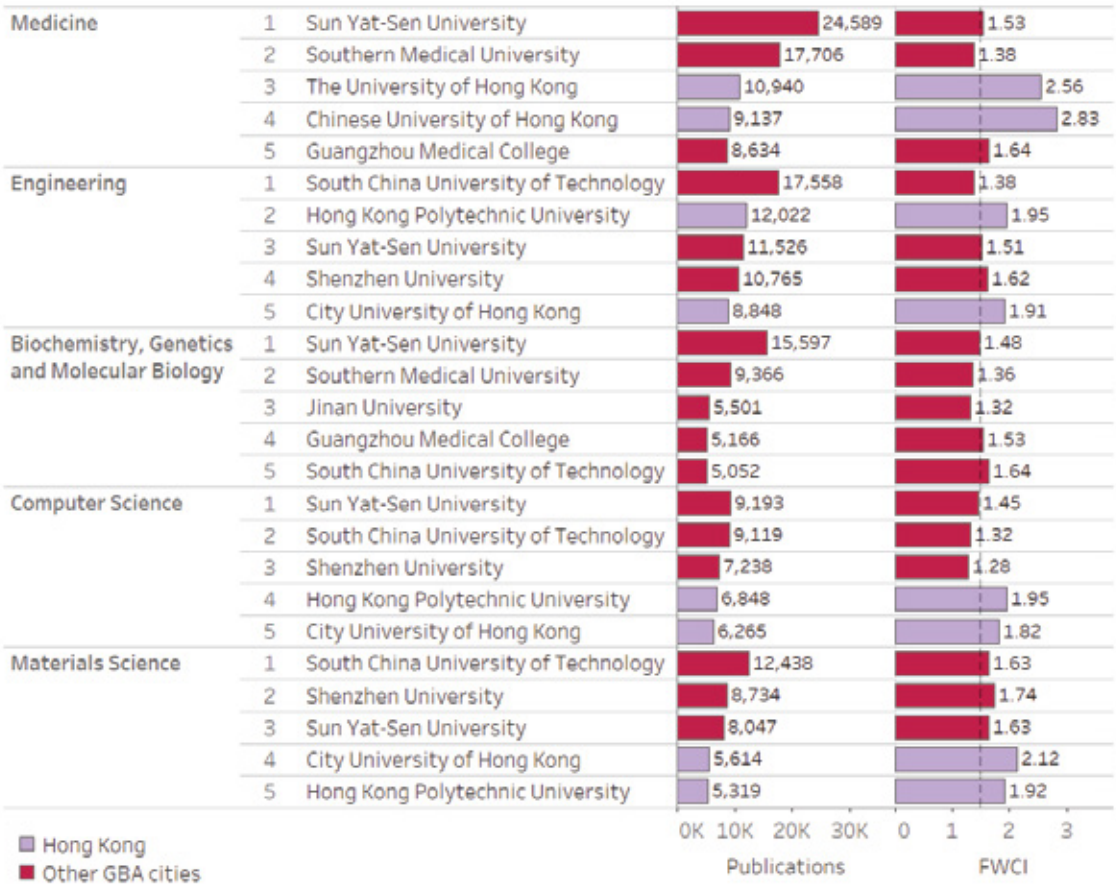


Figure 1.2.5 Top five institutions by scholarly output for the GBA's five most published subject areas, 2018–2022. The dotted line indicates the average FWCI of the GBA.
Source: Scopus

When considering the scholarly impact of research, the leading institutions become more concentrated in Hong Kong, rather than in Chinese mainland. Figure 1.2.6 shows the top five GBA institutions ranked by FWCI (out of the top 10 most published institutions) across the five core subject areas. These institutions play significant roles in driving forward the high-quality development of research and innovation within the GBA. Hong Kong universities had a stronger presence in subjects such as Engineering, Computer Science, and Material Science, despite their relatively smaller output volume in these subject areas. Notably, CUHK was among the top five for four core subject areas, and ranked first in Medicine and Computer Science, suggesting the strong scholarly impact of its research in these core research areas of the GBA.

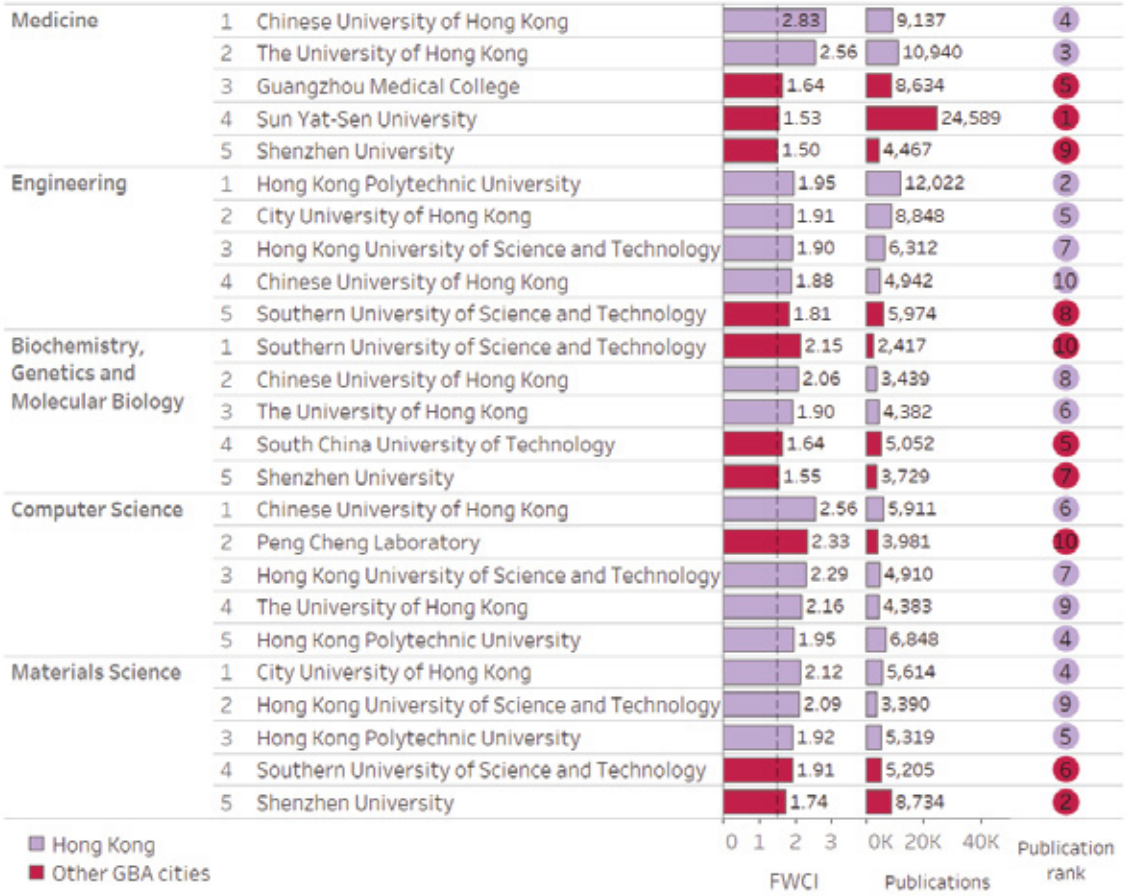


Figure 1.2.6 Top five institutions by FWCI (out of the 10 most published institutions) for the GBA's five most published subject areas, 2018–2022. The dotted line indicates the average FWCI of the GBA.
Source: Scopus

1.3 Knowledge transfer potential in the GBA and Hong Kong

Over the last five years, the GBA has shown strong knowledge transfer potential. About 4.8% of GBA research is performed in collaboration with industrial partners, which is almost twice the global rate. Hong Kong contributes significantly to knowledge transfer within the GBA, with a higher rate of academic–corporate collaboration[9], a stronger scholarly impact, and a larger proportion of publications cited by patents than the rest of the GBA.

Knowledge transfer between academic institutions and industry accelerates the development and application of cutting-edge technologies and is a cornerstone of the GBA's aspiration to become an international I&T hub. Using 2018–2022 publications, this section will provide analysis of the knowledge transfer potential of research in the GBA and Hong Kong, by first examining how academic and corporate sectors collaborate in research, and then by how research is taken up by patents. This section will also identify major contributors to knowledge transfer in the GBA, by pinpointing institutions active in academic–corporate collaboration and institutions with high rates of patent citation of their research output.

Academic–corporate collaboration

As one of the proxies of cross-sectoral collaboration, academic-corporate co-publication measures results of collaborations that are then published in the academic literature. The GBA research shows strong emphasis on academic–corporate collaboration. In the last five years, 4.8% of GBA research was conducted in collaboration between academic and corporate partners, which was around 1.7 times the global rate. The scholarly impact of academic–corporate collaborative publications in the GBA, as measured by FWCI, was also higher than that of China and the world, with an FWCI of 2.47, around 1.5 times the global level (Figure 1.3.1). Hong Kong contributed significantly to the overall scholarly impact of the academic–corporate collaborative publications in the GBA. The FWCI of academic–corporate collaborative publications in Hong Kong was as high as 4.06, which was more than double the FWCI of the collaborative publications of the rest of the GBA.

[9] An entity's academic-corporate collaboration encompasses a wide range of intersectoral activities, including research partnerships, joint ventures, and collaborative educational programs. Due to the availability of data, this report utilises academic-corporate co-publications as a proxy for assessing this type of collaboration. An academic-corporate co-publication is defined as a publication that has at least one author from the academic sector and at least one from the corporate sector and therefore shows the direct research collaboration between these sectors.

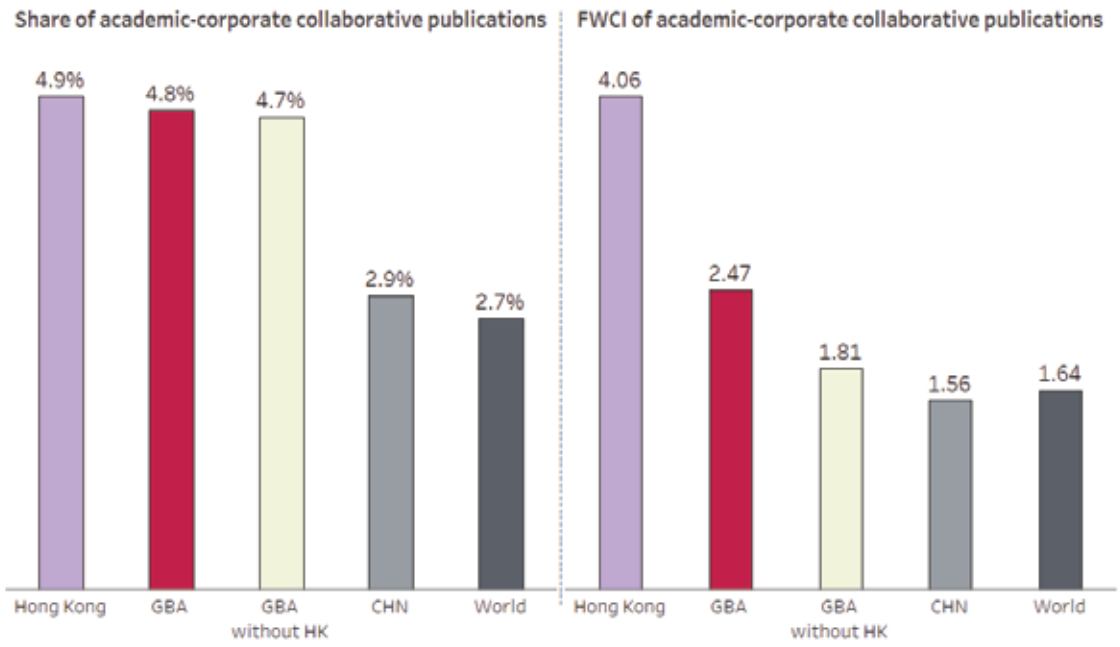


Figure 1.3.1 The share and FWCI of academic–corporate collaborative publications of the GBA, the GBA without Hong Kong, Hong Kong, China, and the world, 2018–2022.
Source: Scopus

Leading institutions in academic–corporate collaboration

Large companies are active in producing research in collaboration with academic institutions. As shown in Figure 1.3.2, which displays the top 10 GBA institutions in terms of academic–corporate collaborative output between 2018 and 2022, Huawei, Tencent, and China Southern Power Grid, all in the corporate sector, were the institutions leading in the volume of academic–corporate collaborative output in the GBA. Each of them had more than 3,000 academic–corporate collaborative publications in this period, accounting for more than 60% of their total research output. Sun Yat-Sen University was the academic institution with the highest volume of academic–corporate collaborative publications in the GBA, largely due to the large size of its overall research output. It was closely followed by CUHK, which had a high share of academic–corporate collaborative research output among the leading academic institutions in the GBA, indicating its emphasis on building research partnerships with industry and on research translation.

While Hong Kong academic institutions had a smaller volume of collaborative output, their collaborative output demonstrated a relatively high scholarly impact compared to most of the mainland institutions. Notably, CUHK showed the highest FWCI for its collaborative work with corporate partners, with an FWCI as high as 6.54. It should be noted that all the GBA academic institutions active in academic–corporate research collaboration had higher FWCI of their collaborative output than their overall research output, suggesting the high quality and scholarly impact of their research collaboration with corporate partners.

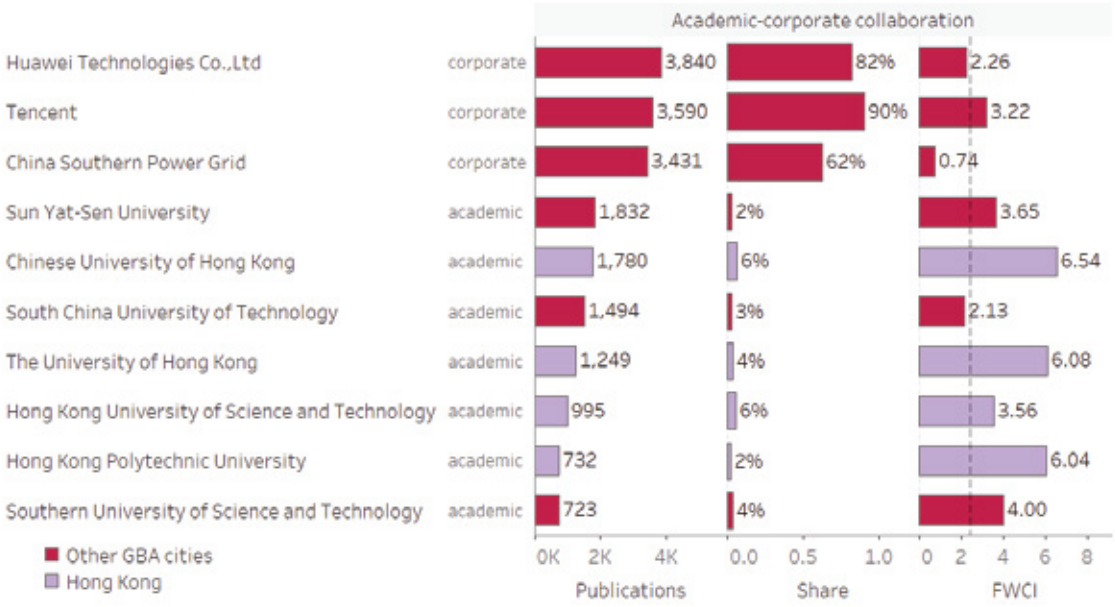


Figure 1.3.2 Top 10 GBA institutions by academic–corporate collaborative output, 2018–2022. The dotted line indicates the average FWCI of the GBA's academic–corporate collaboration.
Source: Scopus

Impact on patents

Another proxy of the knowledge transfer is how much of scholarly publications are cited in patents (note that the patents may be filed not only by corporates, but also by academic and government institutions). Between 2018 and 2022, a total of 1,854 GBA publications were cited at least once by international patents.[10] Of these, 667 (35%) publications were produced with the participation of Hong Kong institutions (Figure 1.3.3). Overall, Hong Kong had a higher proportion of publications cited by international patents than the rest of the GBA, suggesting that research in Hong Kong has higher potential for transfer into patented technologies. But it could also simply be that research in Hong Kong has higher visibility globally and is more likely to be cited by international patents.

[10] International patents refer to patents from the European Patent Office (EPO), Japan Patent Office (JPO), UK Intellectual Property Office (UK IPO), United States Patent and Trademark Office (USPTO), and World Intellectual Property Organization (WIPO).

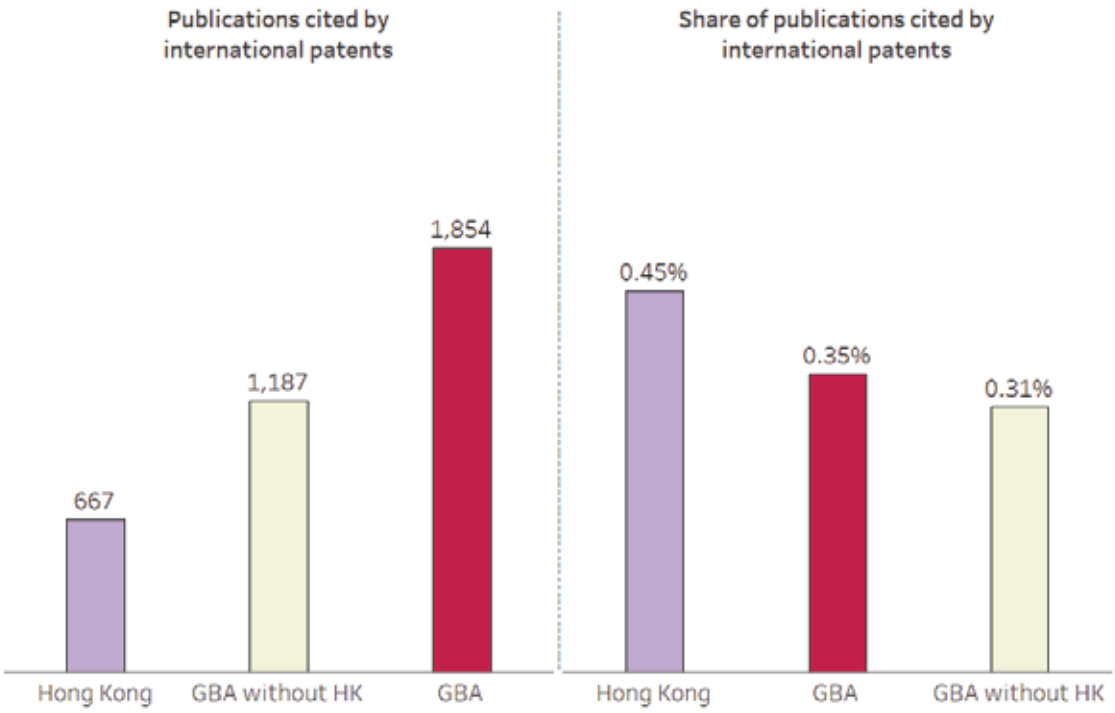


Figure 1.3.3 The count and share of publications cited by patents for the GBA, the GBA without Hong Kong, and Hong Kong, 2018–2022. The patents come from five Patent Offices (World, Japanese, European, UK and US Patent Offices).
Source: Scopus

Figure 1.3.4 displays the top 10 GBA institutions with the most citations from international patents for their publications between 2018 and 2022. Sun Yat-Sen University was the leading university, given its large volume of research output, receiving a total count of 566 patent citations for its 286 publications. HKU and CUHK followed with patent citation counts of 402 and 296, respectively. Tencent, ranking 6th, and the only corporate entity in the top 10 list, received 234 patent citations for its research publications. It is also the institution among the top 10 list with the largest share of publications cited by international patents.

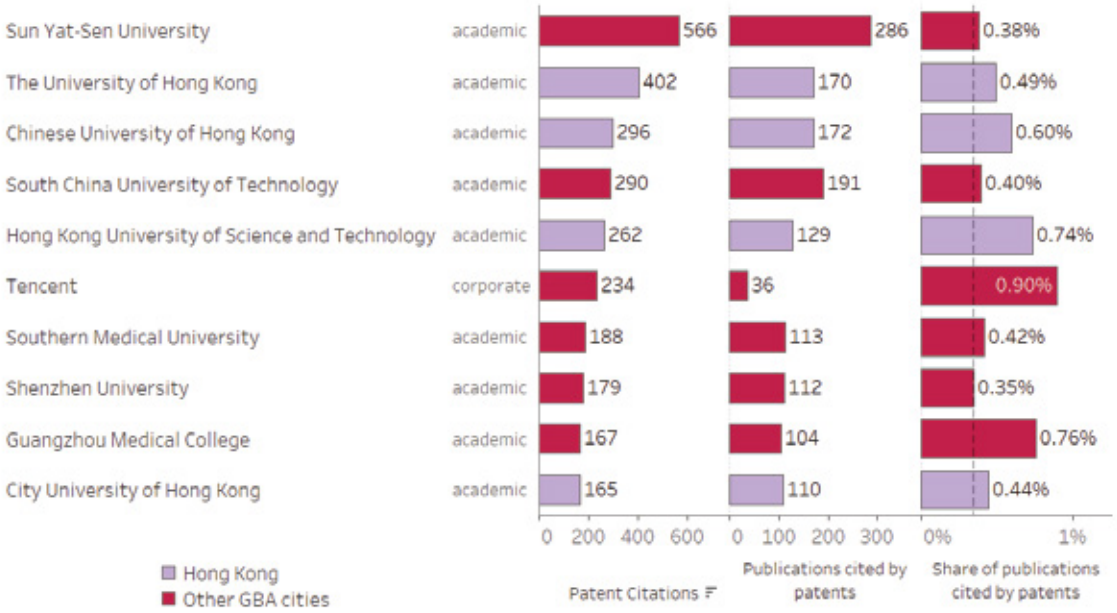


Figure 1.3.4 Top 10 GBA institutions by patent citations, 2018–2022. The dotted line indicates the GBA's average publication share cited by patents.
Source: Scopus

Chapter 2

In-depth analysis of CUHK's research impact

2.1 Research overview of CUHK

CUHK's research output grew at an annual rate of 6.9% between 2018 and 2022, with its 'excellent' research growing at an even faster pace. As the sixth largest contributor of research output in the GBA, CUHK exceeded its GBA peers in scholarly impact. Moreover, CUHK research was highly interdisciplinary in terms of bringing authors of diverse backgrounds together, and attracted ample attention from mass media, social media, and policymakers.

CUHK is one of the most innovative universities in Hong Kong and in the Greater Bay Area (GBA). As shown in the analysis of the research landscape in Chapter 1, CUHK was the sixth largest contributor to research output in the GBA over the five years 2018–2022, and it surpassed other GBA institutions in terms of scholarly impact. As a top Hong Kong university with a comprehensive presence in the GBA, CUHK is committed to propelling technology, research and entrepreneurship and cultivating talent to create scientific and technological innovation centres with global influence. This chapter, through investigating the CUHK's overall research performance, specialised subject fields, knowledge transfer potential, and research collaboration, aims to provide an evidence-based assessment of CUHK's research contribution and impact on the high-quality development of research and innovation in the GBA and beyond.

Scholarly output

Over the five years between 2018 and 2022, CUHK's overall research output has grown continuously at a compound annual growth rate (CAGR) of 6.9%, amounting to nearly 28,800 publications in total (Figure 2.1.1). Particularly, the growth accelerated since 2020, after the outbreak of the COVID-19 pandemic. Analysis of research output by subject fields shows that the growth was mainly driven by a surge in publications in the field of Medicine, a predominant subject field at CUHK.

The excellent research output in CUHK, as defined by the number of publications in the world's top 1% high impact journals, grew at an even faster pace than its overall research, with a CAGR of 10.4% in the period 2018–2022. Specifically, a surge is observed in 2022, in which output of excellent research increased by 21.3% from the year before. In the five-year period, more than 1.8K of CUHK's research was published in the world's top 1% high impact journals, accounting for 7.2% of its total research output.

Figure 2.1.1 The annual publications, publications in the world's top 1% high impact journals, and the share of publications in the world's top 1% high impact journals of CUHK, 2018–2022 (left panel). The annual publications in the top five subject fields of CUHK, 2018–2022 (right panel).
Source: Scopus

Scholarly impact

Between 2018 and 2022, CUHK contributed 5.4% to overall research and 7.4% to excellent research in the GBA, suggesting an important role CUHK plays in shaping the research, particularly driving high-quality research in the region. However, for both overall research and excellent research, CUHK's shares in the GBA have been declining, mostly due to the faster growth rate of research in the GBA region (Figure 2.1.2).

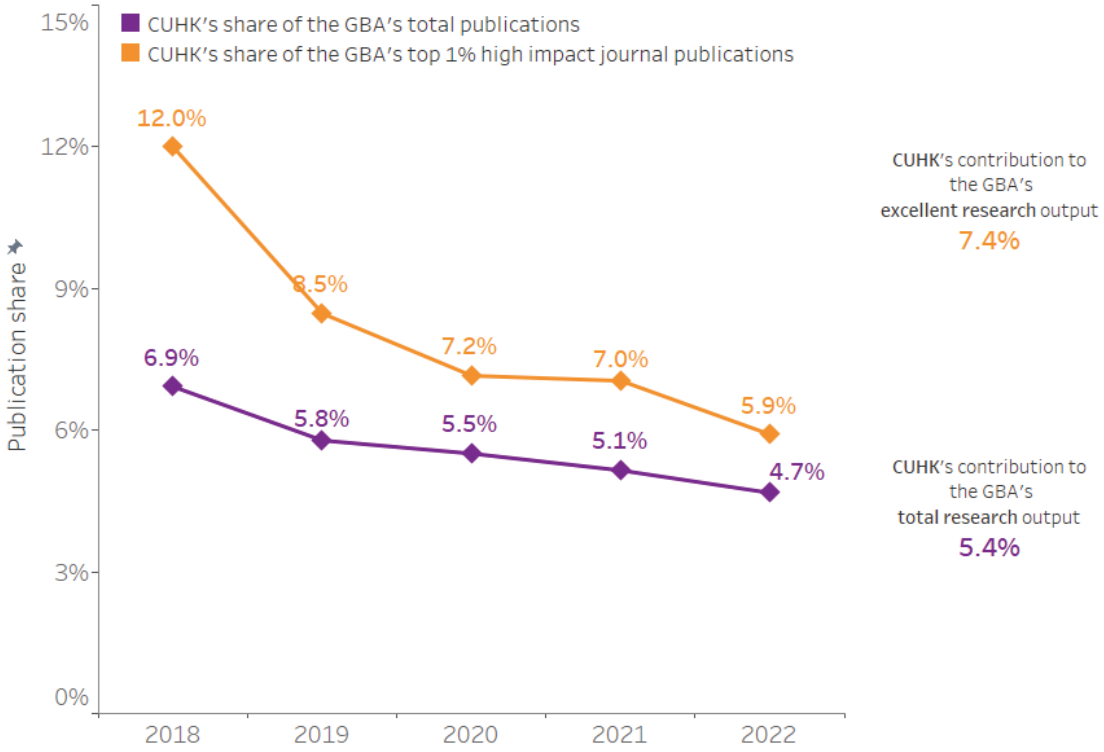


Figure 2.1.2 Output contribution of CUHK as a share of the GBA's total publications and publications in top 1% high impact journals, 2018–2022.
Source: Scopus

Overall, the scholarly impact of CUHK in terms of FWCI is relatively stable during the study period, with an average FWCI of 2.31, suggesting that CUHK's research output was cited about 130% more than what would be expected for the same category publications globally. The FWCI of CUHK was also higher than that of the GBA (FWCI=1.5) and Hong Kong (FWCI=1.9), indicating the strong scholarly impact of CUHK's research.

The FWCI of the top five predominant subject areas of CUHK show an upward trend in the areas of Biochemistry, Genetics and Molecular Biology and Social Sciences, indicating that CUHK's scholarly impact in these two subject areas has been increasing in recent years (Figure 2.1.3). Note that the spike of FWCI for Medicine in 2020 was mainly due to the publications related to COVID-19. With the massive attention drawn by this topic during 2020, COVID-19 related publications boosted the citation level of Medicine in that year.

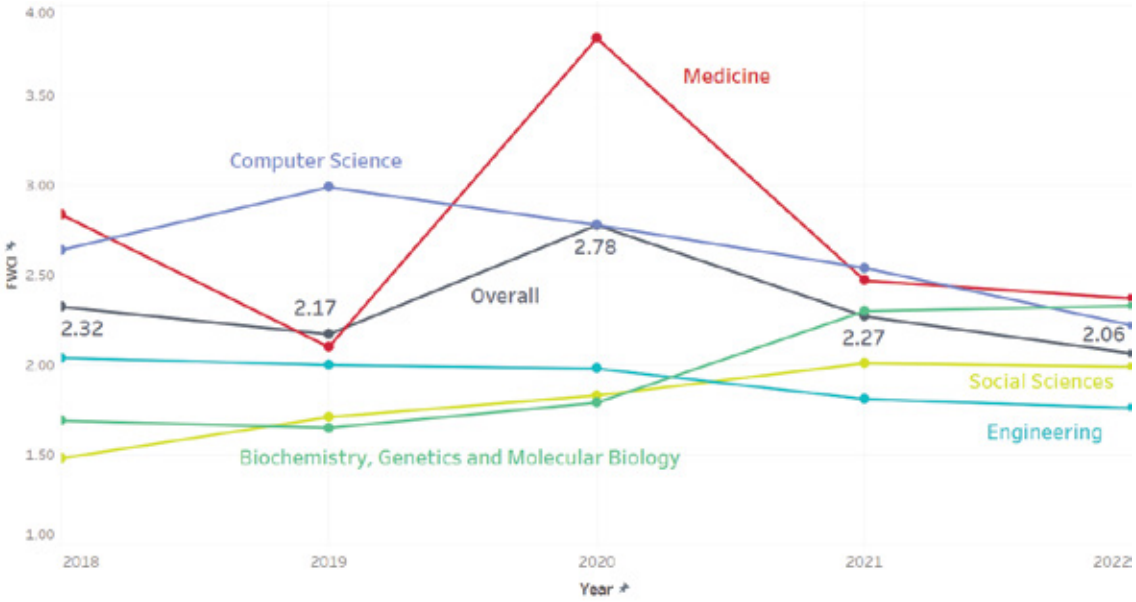


Figure 2.1.3 Annual FWCI of CUHK's top 5 published subject areas, 2018–2022.
Source: Scopus and SciVal

Research interdisciplinarity

CUHK's leading position in scholarly impact within the GBA can be attributed to its pronounced emphasis on interdisciplinary research that cuts across the boundaries of individual academic units. As seen in the left panel of Figure 2.1.4, between 2018 and 2022, 9.6% of CUHK's research was ranked among the world's top 10% highly multidisciplinary publications in terms of the disciplinary diversity of authors (DDA).[11] DDA reflects the diversity of the prior disciplinary backgrounds of a paper's co-authors. The higher the DDA, the greater diversify of the backgrounds of co-authors. CUHK's share of top 10% DDA publications was higher than that of the GBA and the world, suggesting its success in promoting collaboration between authors from diverse disciplinary backgrounds to produce research output.

However, there is still room for CUHK to improve its research interdisciplinarity in integrating knowledge from different subject fields. Research interdisciplinarity based on disciplinary diversity of references (DDR)[12] captures diversity in the range of disciplines covered by the references of a given research publication, and reflects the diversity of knowledge that the given publication is based on (i.e. whether the research has cited publications of the same subfield or a variety of subject fields). As shown in the right panel of Figure 2.1.4, 6.9% of CUHK's research was among the world's top 10% highly interdisciplinary publications based on the DDR. This share is slightly below that of the GBA and the world, indicating that the disciplinary diversity of CUHK's research in terms of references is currently lagging the GBA and the world level. But on the other hand, it may suggest that CUHK has greater specialisation in each of its subject fields.

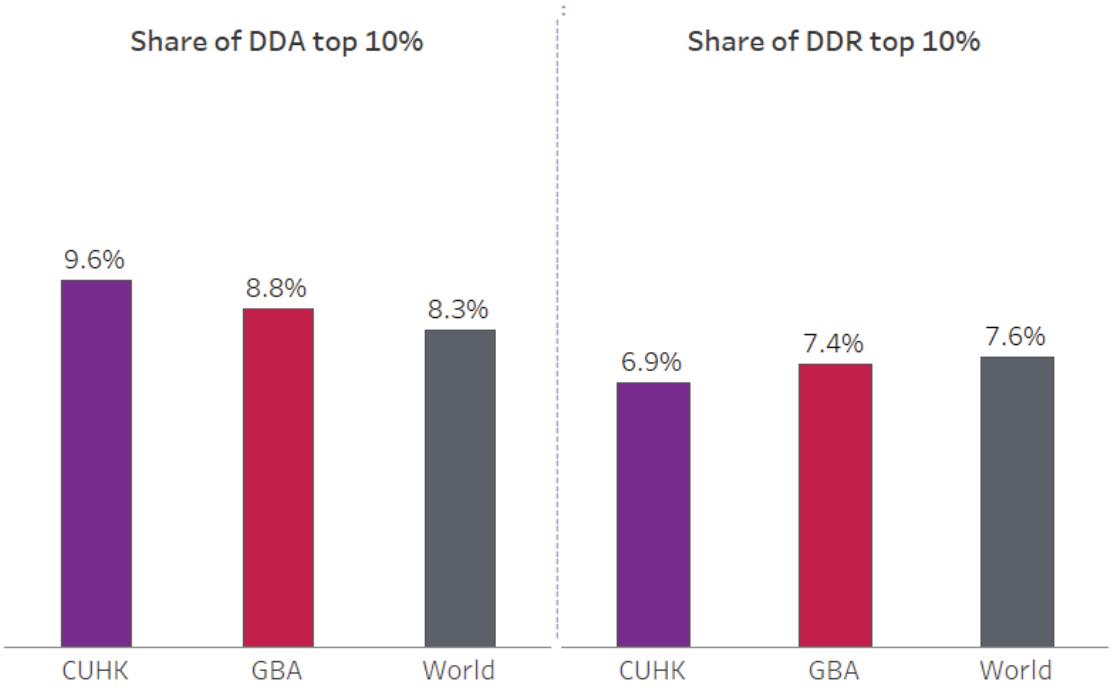


Figure 2.1.4 Research interdisciplinarity based on the disciplinary diversity of authors (DDA) and disciplinary diversity of references (DDR) for the scholarly output of CUHK, the GBA, and the World, 2018–2022.
Source: Scopus

[11] The detailed description of disciplinary diversity of authors (DDA) is shown in Appendix A.
[12] The detailed description of disciplinary diversity of references (DDR) is shown in Appendix A.

Societal impact

CUHK's research impact is far-reaching and extends beyond academia. While arguably much of the societal impact of academic institutions come from its students who after graduation move into the workforce, here we focus on the broader impact of research activities of universities. As a proxy of this broader research impact, notably public attentions, Figure 2.1.5 shows how much attention CUHK's research has attracted from media channels, social media platforms, and policy documents in comparison with Hong Kong, the GBA, and the rest of the GBA region excluding Hong Kong.

Three altmetric indicators[13] derived from PlumX and Overton databases are used here, namely, policy citations, media mentions, and social media mentions. Policy citations count the number of policy documents that have referenced CUHK publications. Media mentions refer to the number of mentions of CUHK publications by news outlets, blog posts, Wikipedia references, or online reviews or comments. Social media mentions count the number of Facebook or YouTube likes and shares regarding CUHK publications, making it possible to track the 'buzz' or attention garnered by CUHK's research. Further information about the metrics and data sources can be found in the Appendices.

As shown in Figure 2.1.5, in general, there were more social media mentions of research than mass media mentions or policy citations. This can be possibly explained by the nature of social media platforms, which enable more convenient, frictionless information exchange. As would be expected, CUHK's research work was more likely to be taken up by social media, while policy uptake was least likely. Between 2018 and 2022, 10.3% of CUHK's research was mentioned by social media. On average, a CUHK publication was mentioned 9.75 times by social media. Both the proportion of publications mentioned by social media and the average number of social media mentions per publication for CUHK were well above those of the GBA.

Note that the altmetrics databases have much better coverage of sources in Western languages, with a limited number of sources in Chinese; and Chinese-language policy documents are not covered at all. Also, major Chinese social media platforms are not included in the source list of PlumX. This results in disproportionally low numbers of policy citations, media mentions, and social media mentions for research produced in Chinese mainland. In this regard, a comparison of CUHK's performance with the overall performance of its Hong Kong peers helps better demonstrate how much attention CUHK's research has attracted from international mass media, social media, and policymakers. As shown in Figure 2.1.5, CUHK's research outperformed the overall research in Hong Kong either in terms of journalistic news uptake, social media mention, or policy citations, showing a better performance in generating social impact of research than that of the average of Hong Kong.

The above analysis suggests that CUHK's research output has received high level of attention from mass media, social media, and policymakers, thereby indicating a broad societal impact. It is worth acknowledging that while social media metrics offer valuable insights, they serve as a proxy rather than a definitive measure of societal impact.

[13] Refer to Appendix A for more explanation of altmetric indicators.

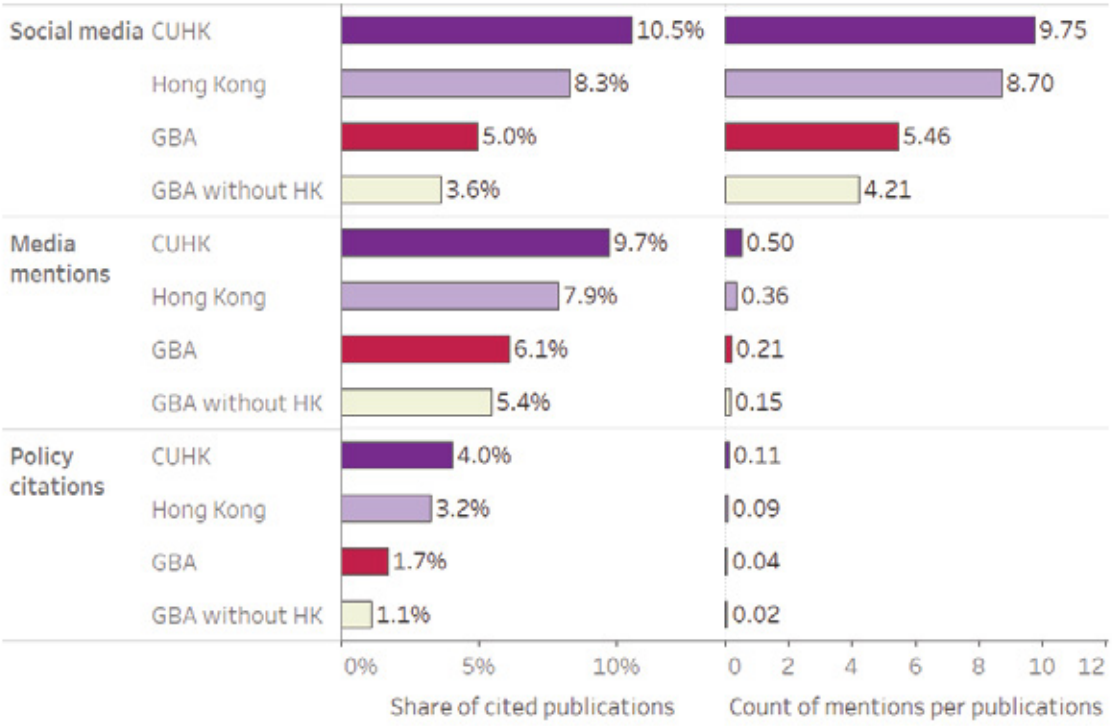


Figure 2.1.5 Social media mentions, media mentions, and policy citations of CUHK's publications compared with those of Hong Kong, GBA, and GBA without Hong Kong, 2018–2022.
Source: PlumX and Overton databases

2.2 Specialised subject areas of CUHK

CUHK shows research strengths in the subject areas of Medicine and Computer Science, in terms of research output volume and scholarly impact. Moreover, CUHK contributes substantially to the scientific and technological advancement of the GBA in the industry fields of national strategic importance such as Biomedicine, Artificial Intelligence, and Clean Energy.

CUHK's overall research performance has distinguished the university in driving high-quality development of research and innovation in the GBA. Exploring CUHK's competitive strengths in research and innovation can help make CUHK better prepared to effectively harness its research power to support the GBA in becoming a globally influential innovation and technology (I&T) hub.

By analysing research output by subject fields, this section provides an overview of the subject field-specific research capabilities and distinctive research strengths of CUHK. Furthermore, CUHK's strengths in supporting the larger research blueprint of the GBA and China will be examined by looking into its research contribution and impact on the core (predominant) subject fields of the GBA and industry fields of national strategic importance.

Leading research strengths

As shown in the left panel in Figure 2.2.1, five subject areas stood out as CUHK's pillars of research in terms of publication share. They are *Medicine* (31.77%), *Computer Science* (20.55%), *Engineering* (17.18%), *Social Sciences* (12.50%), and *Biochemistry, Genetics and Molecular Biology* (11.96%). CUHK demonstrated scholarly impact above the world average (FWCI=1) across all 27 subject fields, indicating CUHK's strong academic influence across a full range of research disciplines (right panel in Figure 2.2.1). Particularly, the subject areas of *Medicine, Computer Science, Biochemistry, Genetics and Molecular Biology, Physics and Astronomy*, and *Earth and Planetary Sciences* showed exceptional performance, with not only high volume of scholarly output (publication volume above 1,000), but also high scholarly impact (FWCI above 2.0). Prominently, *Medicine* is the clear research strength of CUHK, being its most productive subject area and the subject area with the highest scholarly impact (FWCI=2.83) at CUHK.

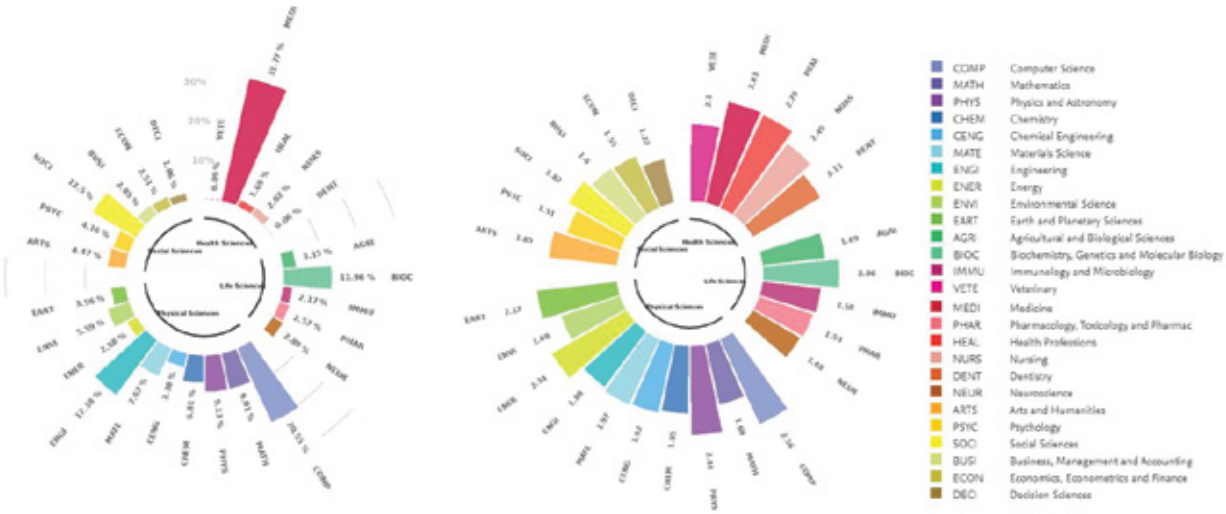


Figure 2.2.1 The output share (left) and FWCI (right) per subject area (ASJC 27) of CUHK, 2018–2022.
Source: Scopus

Distinctive research specialisations

To identify subject areas that CUHK specialises in compared with Hong Kong and the GBA, Figure 2.2.2 shows the relative activity index (RAI)[14] for CUHK, Hong Kong, and the GBA across 10 subject areas where CUHK exhibits above-world-level research specialisation (RAI above 1). As shown in the graph, CUHK has higher research activity than Hong Kong and the GBA in *Psychology, Medicine, Neuroscience, Health Professions*, and *Nursing*. This suggests CUHK's distinctively high level of research specialisation in these subject areas, which mostly lie in health-related sciences. Notably, CUHK has the highest RAI in *Psychology*, followed by *Computer Science* and *Medicine*, but its research activity in *Computer Science*, while higher than that of the GBA, was slightly below the average level of Hong Kong.

[14] The RAI represents an entity's share of publications in a specific subject field relative to the worldwide share of publications in the same field. If an entity's RAI is higher than the global level of 1.00, then this entity can be said to have a higher-than-average specialisation in a given field.

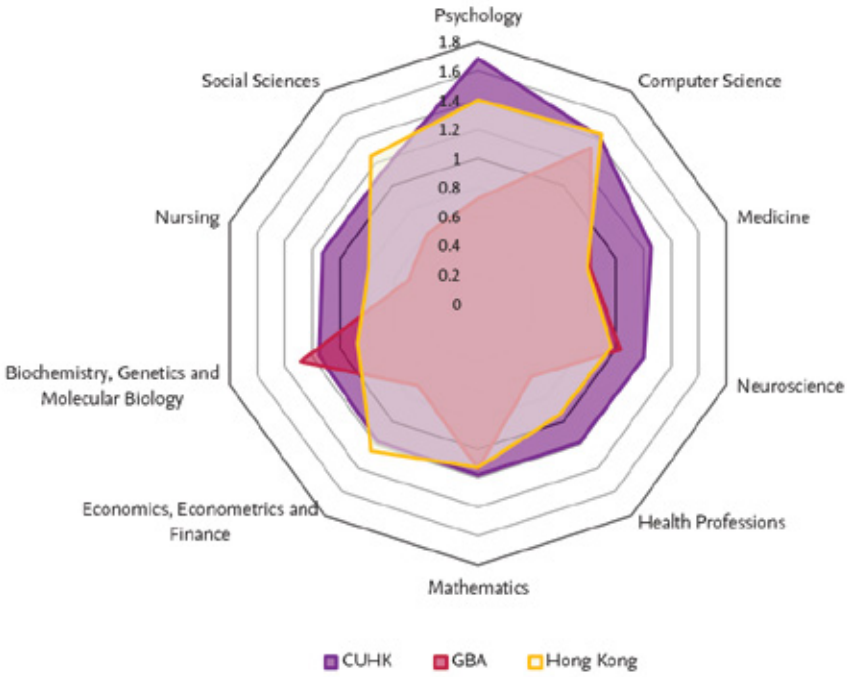


Figure 2.2.2 Research activity (RAI) comparison among CUHK, Hong Kong and the GBA, 2018–2022. Only subject areas of CUHK with RAI greater than 1 are shown.
Source: Scopus

Contributions to the GBA's five core subjects

CUHK's research output as a share of the output in the GBA's core subject areas provides a clearer view of CUHK's research contribution and impact in the region. Among the five subject areas in which GBA published most, CUHK contributed the most to research output in *Medicine* and *Computer Science*, with CUHK output accounting for 8.4% and 5.8% of the scholarly output of the GBA in the two subject areas respectively (Figure 2.2.3). Moreover, CUHK has a higher level of specialisation in these two subject areas than the GBA (as measured by RAI), particularly in *Medicine*, with an RAI in *Medicine* 54.3% higher than the GBA's. Considering that *Medicine* and *Computer Science* are also subject areas with the highest scholarly impact (as measured by FWCI) for CUHK, these two subjects can be recognised as specialised research strengths of CUHK, where it can greatly influence the research development of the GBA.

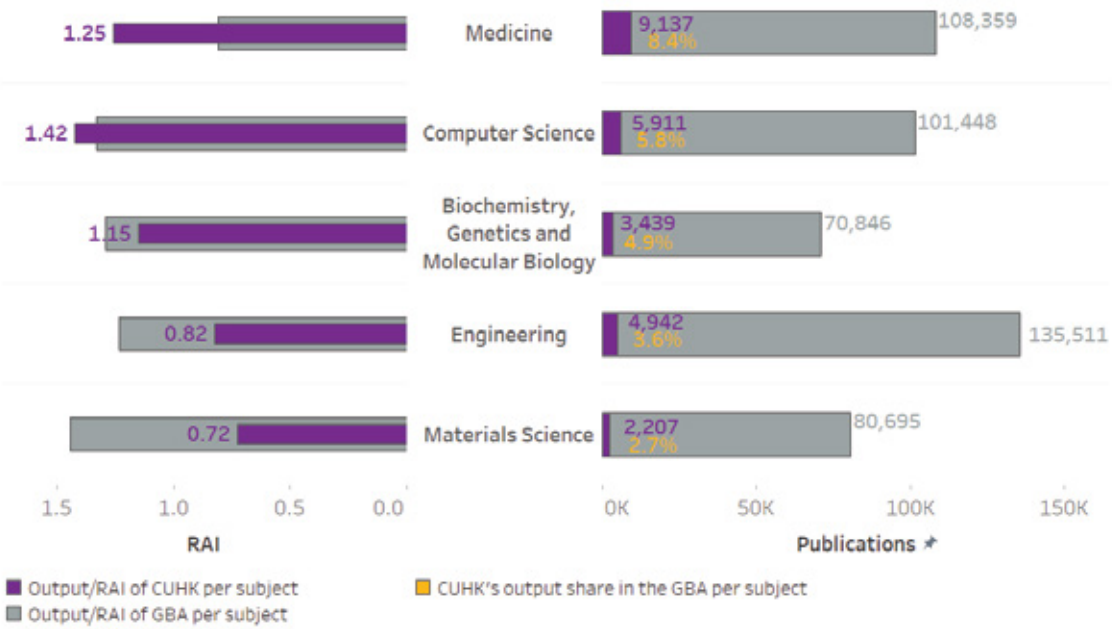


Figure 2.2.3 CUHK's publication output, publication share, and the research activity index (RAI) in the GBA's five most published subject areas, 2018–2022.
Source: Scopus

Contribution to the five industry fields of national strategic importance

The GBA's developmental goal to grow into an international I&T hub is deeply connected to the nation's strategic goal for industrial and technological development. Among the five research areas mapped to industry fields of national strategic importance[15]—Biomedicine, Environmental Science, Clean Energy, Artificial Intelligence (AI) and Quantum Technology—the GBA had most research output in the research areas of Biomedicine, Environmental Science, and Clean Energy (Figure 2.2.4), indicating strength and critical mass in these industry fields. Notably, the GBA has the most research output in Biomedicine, with over 61,000 publications in the field over the past five years.

Because CUHK is one of the most important driving forces of research and innovation in the GBA, CUHK caters to the needs of the GBA to align with national planning for research and innovation development in strategic industrial fields. CUHK accomplishes this through active engagement in cutting-edge research and technology development. CUHK's strategic research focuses—on China: Tradition and Modernity, Innovative Biomedicine, Information and Automation Technology, and Environment and Sustainability[16]—strongly resonate with the national strategic industry fields. As shown in Figure 2.2.4, among the five research areas, CUHK contributed its largest research output in Biomedicine, with a total of 3,265 publications. AI was the field in which CUHK had the largest output share, contributing 5.8% of the GBA's research output in the field. As for scholarly impact, CUHK had FWCI surpassing that of the GBA across all five fields. Particularly, in Clean Energy, CUHK had an FWCI as high as 3.19, leading the GBA by a large margin. Similarly, CUHK's FWCI in AI was also considerably higher than that of the GBA. These indicate the significant role that CUHK can play in propelling the scholarly impact of the GBA in these respective fields. The above findings also suggest that, in alignment with CUHK's research focuses outlined in its Strategic Plan, CUHK is contributing prominently to extending the research frontier and supporting the technological advancement of the GBA in Biomedicine, AI, and Clean Energy.

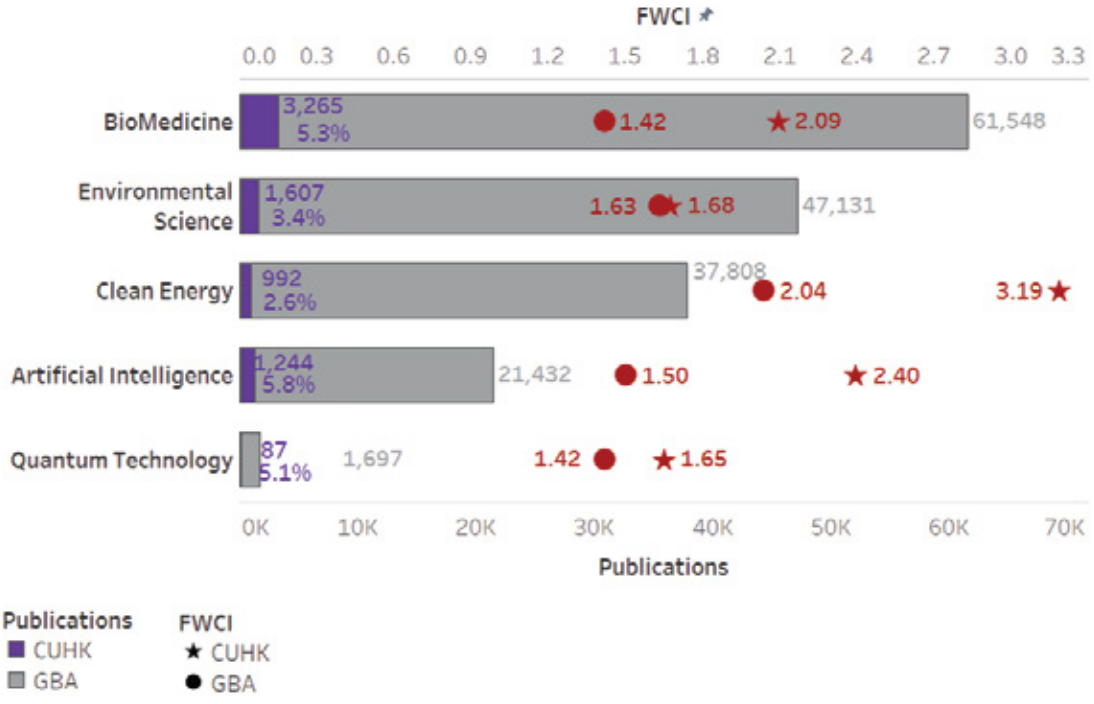


Figure 2.2.4 CUHK's publication output, publication share in the GBA, and FWCI for the five research areas that are mapped to the industry fields of national strategic importance, 2018–2022.
Source: Scopus

[15] Refer to Appendix C for details on data set creation for the five industry fields.
[16] CUHK has adopted in its Strategic Plan 2021–2025 the strategy of focusing its research investments in four already distinguished fields of academic enquiry within the University. https://www.cuhk.edu.hk/strategicplan/cuhk2025/research.html

To show the specific research focuses of CUHK in Artificial Intelligence, Biomedicine, and Clean Energy, Figure 2.2.5 displays the keyphrase clouds based on CUHK's publications in each of the fields. The keyphrases suggest that CUHK's research in Biomedicine over the past five years has mostly focused on COVID-19 and related respiratory syndromes, as well as cancer research (ranging from liver cancer and lung cancer to nasopharyngeal cancer and breast cancer), stem cell biology and regenerative medicine. Furthermore, there has been an emphasis on the interdisciplinary research that brings together biomedical science and engineering (e.g. robot assisted surgery, magnetic resonance imaging), as well as brain science and research on neurological diseases (e.g. cognitive dysfunction, Alzheimer's).

The keyphrase cloud for CUHK's publications related to Artificial Intelligence reveals a strong research focus on robotics applications, including surgical robotics, agricultural robots, leg exoskeletons, etc. Other AI-related research focuses of CUHK include reinforcement learning and learning systems, deep learning and neural networks, and computer vision.

The research field of Clean Energy generally falls under CUHK's strategic research focus in 'Environment and Sustainability'. In the past five years, CUHK's publications related to Clean Energy have primarily focused on organic solar cell technology (including organic, perovskite, and polymer solar cell, thin film technology, and nanogenerators), energy storage and solutions (such as lithium-ion and sodium-ion batteries), hydrogen evolution and production, and energy efficiency and harvesting.

Artificial Intelligence

Biomedicine

Clean Energy

Figure 2.2.5 Keyphrase clouds for CUHK's publications in research fields of Biomedicine, Artificial Intelligence, and Clean Energy, 2018–2022.
Word size indicates relevance.
Source: Scopus and SciVal

2.3 Knowledge transfer at CUHK

CUHK's academic–corporate collaborative publications, which are mainly in the subject areas of Medicine (32%) and Computer Science (51%), are growing in scale. Committed to supporting university spin-offs and technology transfer, by mid-2023, CUHK reported a total of HK$309 million in income from 346 IP licences.

Scientific findings and published research may form the basis of innovations, such as new technologies, products or services that help advance economy, and promote a healthier and more sustainable society. With an emphasis on research translation and the societal impact of research, CUHK's 2025 strategic plan aims at integrating research, innovation and enterprise into a dynamic and productive continuum, a superhighway that enables the translation of research into tangible benefits and the delivery of innovation to the world. This section investigates CUHK's recent progress in knowledge transfer by focusing on three key components along the continuum of research to application, namely, academic–corporate collaboration, university spin-offs, and patent activities.

Academic–corporate collaboration

Between 2018 and 2022, CUHK's academic–corporate collaborative publications increased from 299 publications in 2018 to 440 publications in 2022 (see Figure 2.3.1). This adds up to nearly 1,800 publications, representing 6.2% of CUHK's total research output. This rate is around 1.3 times that of the GBA. The academic–corporate collaborative publications of CUHK grew at a CAGR of 10.1%, higher than the growth rate of its overall research (CAGR=6.9%).

CUHK's research prowess in Computer Science and Medicine is a significant driver of its academic–corporate research collaboration. As shown in Figure 2.3.1, contributions to output predominantly came from the subject areas of Computer Science and Medicine, accounting for 51% and 32% of CUHK's total academic–corporate collaborative output respectively.

CUHK's academic–corporate collaborative publications generated a high scholarly impact, achieving an FWCI of 6.54, much higher than that of CUHK's overall research output. The yearly trend of FWCI showed some fluctuation, mainly due to the relatively small volume of academic–corporate collaborative publications. The peak was seen in 2018, at an FWCI of 11.34. This is primarily attributable to a series of output from the collaborative 'Global Burden of Disease Study', which typically has a large number of co-authors from a variety of institutions and attracts an exceptionally high number of citations.

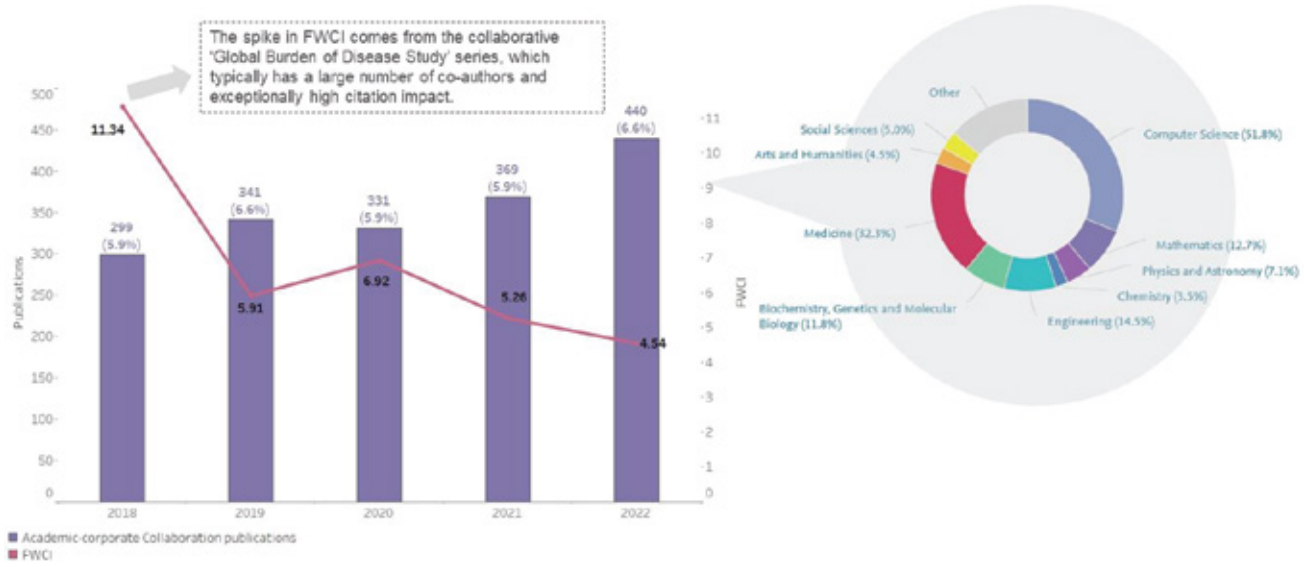


Figure 2.3.1 The annual count, share, and FWCI of CUHK's academic–corporate collaborative publications (left panel) and the subject area distribution of CUHK's academic–corporate collaborative publications (right panel), 2018–2022.
Source: Scopus

Supporting university start-ups

To unlock the potential of research translation and further promote knowledge transfer, CUHK provides a range of support from proof of concept, incubation, and raising venture capital to commercialisation. To strengthen its entrepreneurial culture, CUHK assists its researchers and students to apply for funding opportunities, including the PILOTS Lite programme that supports aspiring student entrepreneurs to prepare and fine-tune start-ups, Technology Start-up Support Scheme for Universities (TSSSU)[17] programme that empowers faculty to transform research output into real businesses, and Youth Entrepreneurship Assistant Scheme that provides full-time and part-time undergraduate, postgraduate students and alumni to further develop their business in the GBA.

Particularly, CUHK has become one of the key conduits for TSSSU. By 2022, CUHK had 61 of its start-ups supported by TSSSU, over half of which received funding in the past five years. As shown in Figure 2.3.2, the 61 CUHK start-ups operated in 13 industrial sectors, with a clear concentration in Biotechnology. By 2022, a total of 26 biotechnology start-ups had received funds from TSSSU. Other industries with over five start-ups supported by TSSSU were Information Technology, Electrical and Electronics, and Advanced Manufacturing/Process Development, suggesting CUHK's capabilities in research commercialisation in these fields.

[17] Launched by The Innovation and Technology Commission (ITC) of the Hong Kong SAR Government in 2014, TSSSU provides funding to six universities in Hong Kong to support their students, professors, and alumni in starting technology businesses and commercializing their research and development (R&D) results.

Figure 2.3.2 Number of CUHK start-ups per industry supported by Technology Start-up Support Scheme for Universities (TSSSU), 2018–2022.
Source: Office of Research and Knowledge Transfer Services of CUHK

Launched by CUHK I·CARE Centre for Whole-person Development, the Social Enterprise Startup Scheme (SESS)[18] provides mentorship programmes and financial support to CUHK students and young alumni to transform their creative business ideas into enterprises with social missions, and most importantly to offer mentorship to them from experts in the business sectors. As shown in Figure 2.3.3, by 2022, a total of 18 social enterprises had been supported by SESS. These social enterprises operated in sectors such as Professional Services, Healthcare, Education, Chinese Medicine, Biotechnology, and Arts, with Professional Services being the sector with the highest number of social enterprises supported.

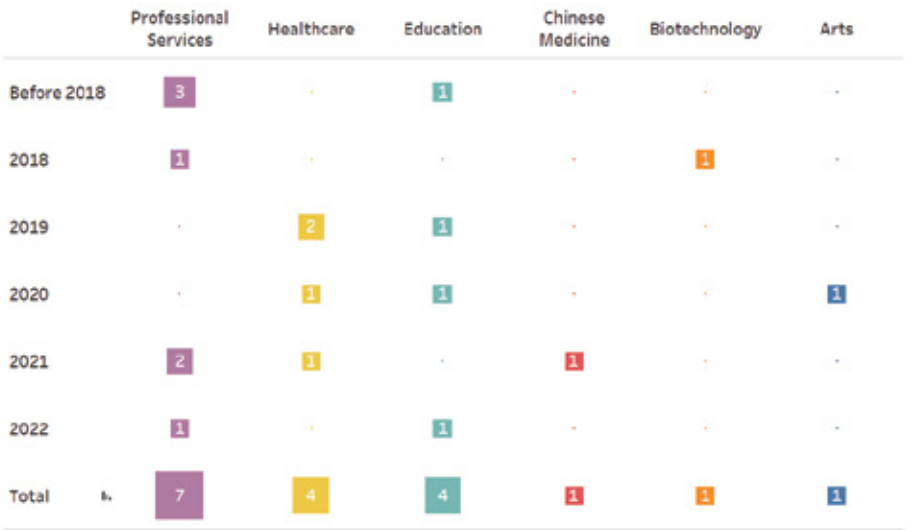


Figure 2.3.3 Number of enterprises per industry supported by CUHK Social Enterprise Startup Scheme, 2018–2022.
Source: Students Experience and Development Section Office of Students Affairs of CUHK

[18] Launched in 2015–16, the Social Enterprise Startup Scheme (SESS) has encouraged CUHK students and graduates to make good use of their expertise to establish or expand their social enterprises. Participants may receive from the 'CUSE Fund' a maximum of HK$100,000 as seed money to set up an enterprise with a social mission.

Patent activities and IP licensing

Utilising internal and external resources such as the Office of Research and Knowledge Transfer Services (ORKTS), Office of Innovation and Enterprise (OIE), Patent Application Fund (PAF) and TSSSU, CUHK has achieved fruitful results in patent application and licensing. As shown in Figure 2.3.4, the annual count of patents filed by CUHK continues to increase, reaching 481 in 2023 from 315 in 2018. There is also an upward trend in the number of granted patents by CUHK, increasing from 202 to 260, with an average of 240 patents granted every 12 months. CUHK's ratio of granted patents to filed patents (not necessarily the same patent) is about 60% every 12 months, a ratio in line with the average patent grant rate of the United States Patent and Trademark Office (USPTO), considering that the entire examination process of a standard patent application from filing to granting is usually expected to take at least 2–3 years.

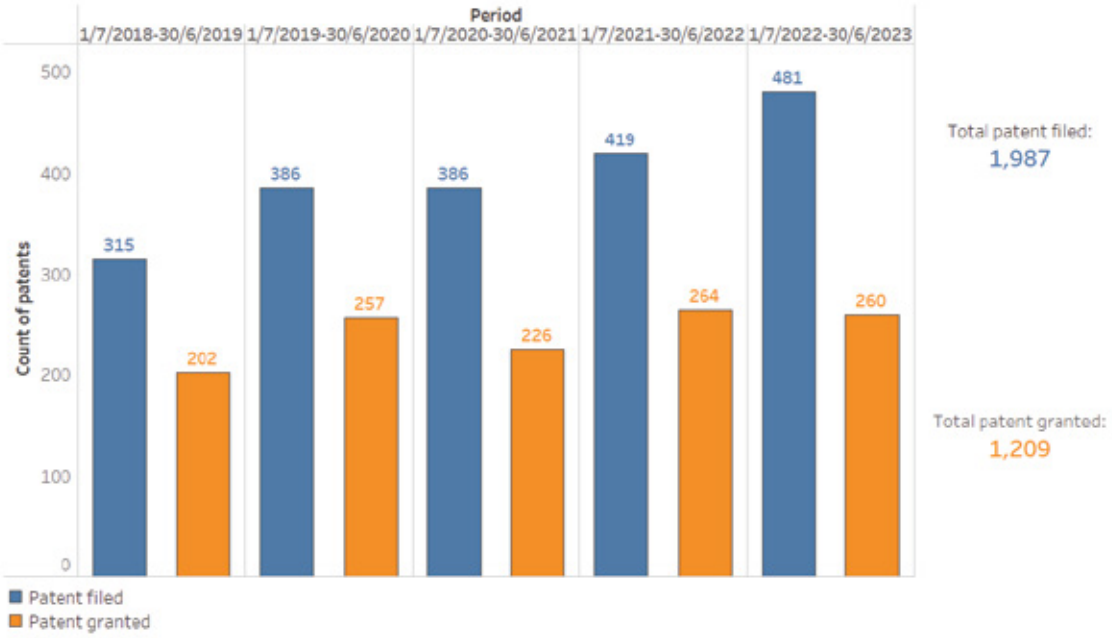


Figure 2.3.4 Number of patents filed and granted at CUHK, 2018–2023.
Source: Office of Research and Knowledge Transfer Services of CUHK

Figure 2.3.5 shows the number of IP licences (including patents and other forms of IPRs such as trademarks, copyrights and know-how) and the corresponding IP income between 2018 and 2023 for CUHK. Since 2018, there has been an uninterrupted growth in IP income reported by CUHK, increasing from HK$53 million to HK$71 million in 2023. On average, approximately 70 IPs were licensed every 12 months, with an average income of HK$ 895,368 per IP licence.

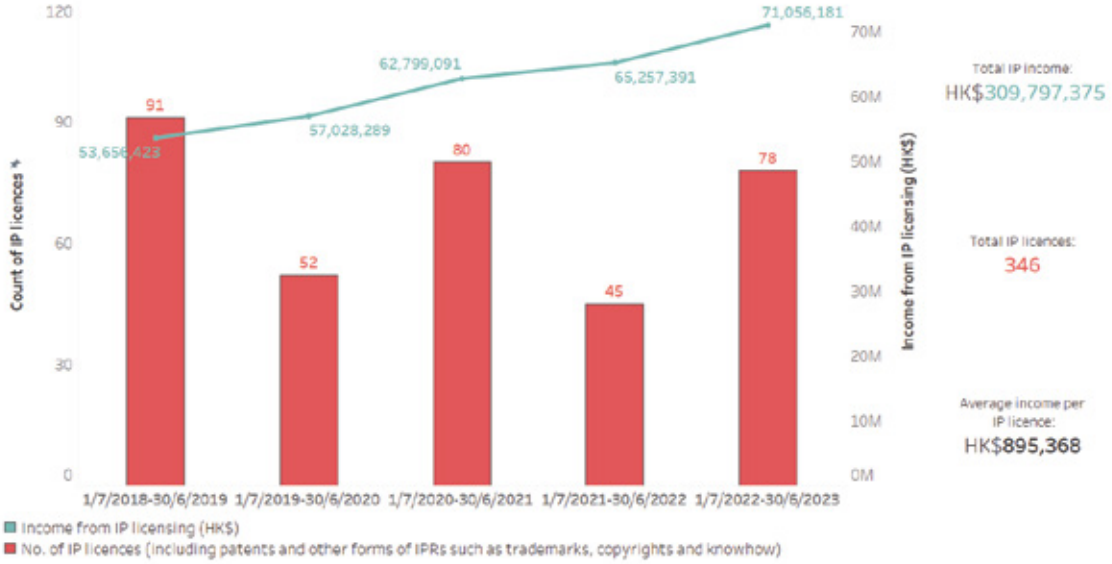


Figure 2.3.5 Number of IP licences, total income of IP licensing, and income per IP licensing of CUHK, 2018–2023.
Source: Office of Research and Knowledge Transfer Services of CUHK

2.4 Research collaboration at CUHK

CUHK has a strong global outlook in research collaboration, with 43% of CUHK publications stemming from international collaboration. CUHK's contribution to promoting research networks within and beyond the GBA is substantial. Around 40% of CUHK's research involves GBA institutions.

CUHK strives to deepen and expand its research collaboration partnerships with Chinese mainland and international institutions to further the goals of research and innovation. This section examines the performance of CUHK in international collaboration, and its important role in bridging the research network within and beyond the GBA. Furthermore, important institutional partners of CUHK will be identified to assist with CUHK's planning to further strengthen its research partnerships.

International collaboration

International collaboration is a distinctive feature of CUHK publications when compared with the research of Chinese mainland institutions. Over the five years between 2018 and 2022, 42.9% of CUHK publications were co-authored with international institutions, a rate substantially higher than other types of inter-institutional collaboration (Figure 2.4.1). Notably, CUHK's share of internationally collaborative publications surpassed that of the GBA (30.2%) and even Hong Kong (41.1%), highlighting CUHK's extensive international engagement. The scholarly impact of these international publications, as measured by FWCI, was 3.1, respectively 1.3 and 1.5 times the FWCI of Hong Kong and the GBA.

Besides international collaboration, CUHK's other forms of research collaboration also yielded higher scholarly impact than those of Hong Kong and the GBA. This underscores CUHK's robust research competitiveness across various types of inter-institution collaboration.

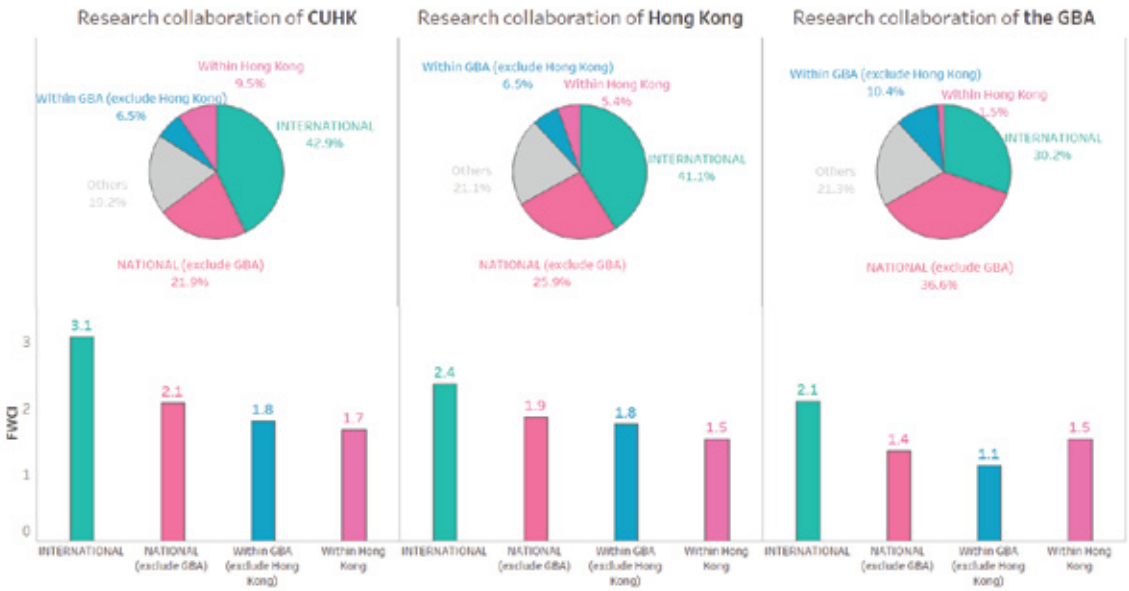


Figure 2.4.1 The share and FWCI of different types of research collaborations for CUHK, Hong Kong, and the GBA, 2018–2022.
Source: Scopus

Connecting the GBA and beyond

Just as Hong Kong is often seen as a gateway connecting China to the rest of the world, CUHK serves as a bridge connecting the GBA and the other international cities through its research collaboration network. A regional perspective on the research collaboration of CUHK provides an in–depth look into CUHK's impact and contribution to extending the research network of the GBA. As seen in Figure 2.4.2, nearly 40% of CUHK publications in the period 2018–2022 involved the participation of GBA institutions. Out of these, around 60% were co-authored with GBA institutions as well as institutions beyond the region, accounting for 24% of CUHK's overall research output. This indicates the proactive engagement of CUHK in expanding the regional network in the GBA and fostering connections on a broader scale. The remaining 40% were collaborations only with GBA institutions, accounting for 16% of CUHK's total publications in the period (9.5% from Hong Kong and 6.5% from other GBA cities), underlining CUHK's commitment to strengthening local research ties.

While 41% of CUHK publications were exclusively co-authored with institutions outside the GBA, these represent an opportunity for CUHK to leverage its network resources to bring new collaborative opportunities to the GBA.

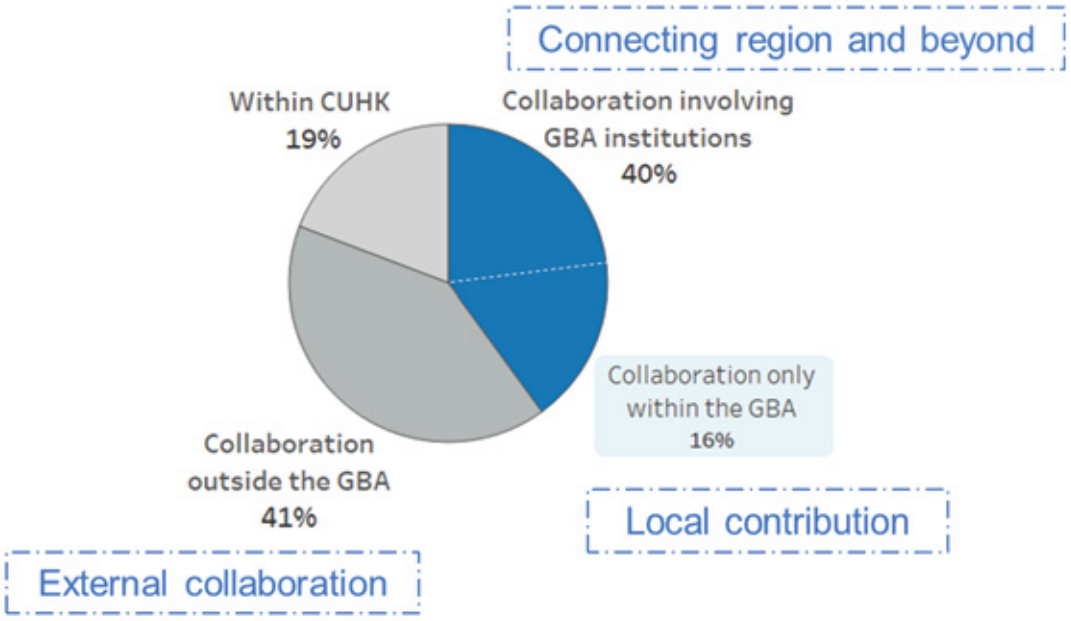


Figure 2.4.2 A regional perspective on the share of CUHK's different types of collaborative publications, 2018–2022.
'Publications within CUHK' is defined as any article that was published by authors only affiliated with CUHK, including single author publications and collaborative publications within CUHK.
'Collaboration involving GBA institutions' is defined as any article that was co-published by at least one author from a GBA institution (other than CUHK) and one from CUHK.
'Collaboration only within the GBA' is defined as any article that was co-published by at least one author from CUHK and others only from GBA institutions, with no co-authors from institutions outside the GBA.
'Collaboration outside the GBA' is defined as any article that was co-published by authors from CUHK and institutions that were only outside the GBA (e.g. institutions in other parts of Chinese mainland, or international institutions), with no co-authors from GBA institutions.
Source: Scopus

Institutional partners

CUHK partners with the major research contributors in the GBA region and in China. Figure 2.4.3 displays CUHK's top five institutional partners worldwide by collaborative output. It is not surprising that CUHK's top three research partners are all GBA universities, underscoring CUHK's close research ties with the local region. The University of Hong Kong (HKU) is the largest research partner of CUHK in terms of collaborative publications. The two parties co-authored over 2,400 publications in the past five years. Sun Yat-Sen University, the largest institutional research contributor in the GBA, follows as the second largest collaborator for CUHK. Other than GBA institutions, CUHK's major research collaborators also include Shanghai Jiao Tong University and Tsinghua University, both of which are prestigious universities in China contributing significantly to the country's research output.

Collaboration with these strong research partners yielded a high level of scholarly impact. Notably, publications co-authored with Tsinghua University, Shanghai Jiao Tong University, and Sun Yat-sen University achieved an FWCI as high as or above 5, indicating the high-impact research resulting from the research collaboration.

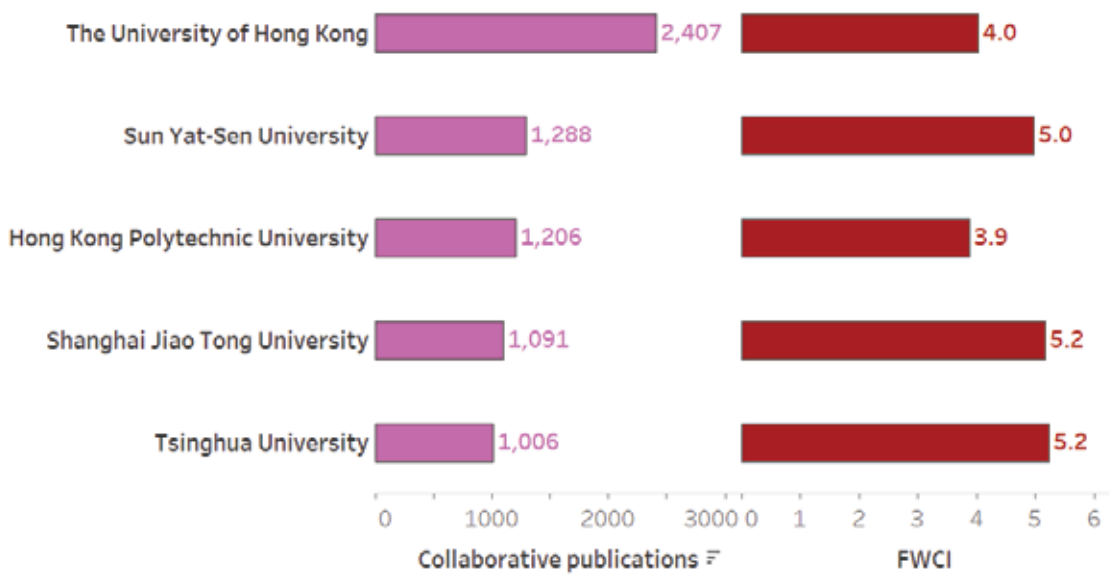


Figure 2.4.3 The count and FWCI of collaborative publications of CUHK's five most published research partners worldwide, 2018–2022.
Source: Scopus

High-quality research collaboration helps enhance the research impact of both CUHK and its collaborators. Figure 2.2.4 shows CHUK's top 10 GBA partners in Chinese mainland and illustrates the extent to which the scholarly impact of CUHK and its collaborators has been enhanced through research collaboration.

Representing CUHK's benefit from the collaboration (vertical axis), the ratio of FWCI for CUHK's collaborative publications with eight of the GBA institutions to FWCI for CUHK's overall publications reached a value above 1, meaning that the FWCI of collaborative publications with these institutions is higher than the average FWCI of CUHK's overall research output. Namely, CUHK benefited from research collaboration with these institutions from the perspective that these collaborations enhanced the overall scholarly impact of CUHK. Notably, CUHK's collaborative publications with Guangzhou Medical College had an FWCI 4.6 times that of CUHK's FWCI for overall research, the highest increase among CUHK's top 10 GBA research collaborators in Chinese mainland. It should be noted that a number of these highly cited collaborative publications are related to COVID-19 research, which boosted the FWCI of the overall collaborative publications with Guangzhou Medical College, and nearly one-fifth of the collaboration also involved a third party: Sun Yat-Sen University.

The horizontal axis shows the increase in the FWCI of CUHK's collaborators, suggesting the benefit gained by the institutions collaborating with CUHK. Nine out of 10 collaborating institutions achieved an FWCI ratio higher than 1, meaning that these institutions' collaborative publications with CUHK have achieved higher FWCI, namely higher scholarly impact, than that of their overall research. This indicates that these institutions are benefiting from the collaboration with CUHK. Furthermore, the increased FWCI for most collaborator institutions was higher than that for CUHK, implying that the collaboration helps boost the research impact of the collaborators more than it would for CUHK. For instance, Guangzhou Medical College has the largest FWCI increase among the 10 collaborators, with the FWCI of its collaborative publications with CUHK more than 6.5 times the average FWCI of its overall research. This again highlights the key role of CUHK in fostering high-impact research collaborations.[19]

[19] Note that the collaborations analysed above usually involved multiple parties; therefore, the benefits of collaboration for each institution may also come from other parties not mentioned here.

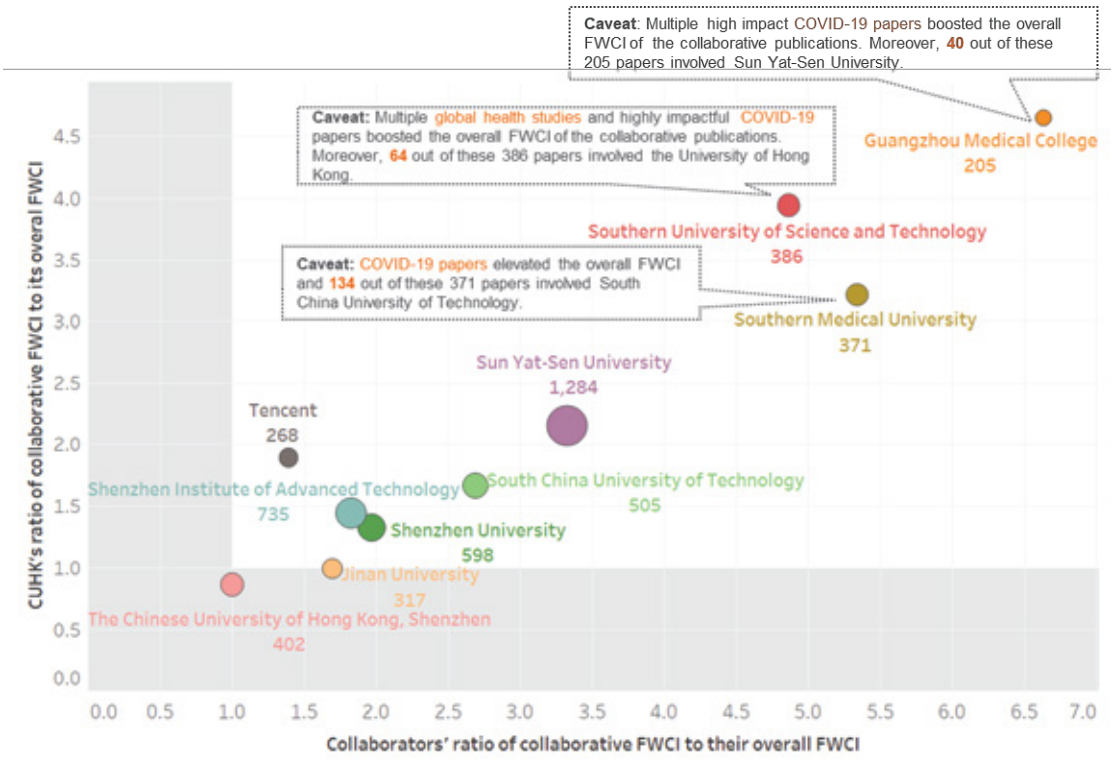


Figure 2.4.4 The increased FWCI for CUHK and its top 10 GBA partners in Chinese mainland for collaborative publications, 2018–2022. The number under the institution name denotes the number of collaborative publications, and the size of the dot represents the volume of collaborative output.
Source: Scopus

Chapter 3

Socioeconomic impact of CUHK's research: a qualitative view

3.1 Novel liquid biopsy technologies: Transforming early cancer detection

CUHK's innovative medical research introduces a new way to screen for cancer, particularly for nasopharyngeal cancer (NPC). Groundbreaking work on plasma EBV DNA testing may create a paradigm shift in early cancer detection, bringing important health and social benefits to the GBA and beyond.

Hong Kong only has two comprehensive medical faculties offering a range of medical courses (such as Nursing and Dentistry), as well as six-year Medicine programmes in public universities, and one of them is the Faculty of Medicine, The Chinese University of Hong Kong (CUHK). In the previous analysis, Hong Kong as a whole has an RAI of 0.8 for Medicine, while CUHK's RAI for Medicine is 1.25, suggesting CUHK's greater specialisation in Medicine as compared with Hong Kong. More remarkably, the FWCI of Medicine in CUHK is 2.83, the highest among the top 10 most publishing universities in the GBA, corroborating that CUHK makes notable contributions to advance medical development in Hong Kong and the GBA. Importantly, this contribution extends beyond academia, exerting notable impact on the population and society. One prominent example of how medical research at CUHK benefits the welfare of people in the GBA and across the world is its research breakthroughs in liquid biopsy, which enable effective cancer screening and allow for early detection of cancer.

A deep dive into medical research at CUHK shows it as a world leader in genetics, genomics and precision medicine, setting a strong foundation for cancer research. Particularly, the research team led by Professor Yuk Ming Dennis Lo, the Director of the State Key Laboratory of Translational Oncology at CUHK, is a global leader and pioneer in the field of circulating nucleic acids, specialised in DNA testing and identification of cancer biomarkers. Seeing that many cancers can be cured if detected early, Lo's team focuses on developing effective screening tests with the use of liquid biopsy.

Liquid biopsy refers to the analysis of cancer-derived DNA in blood and is seen as an important tool for cancer diagnostics. Using nasopharyngeal cancer (NPC) as the model, in 2017, Lo's team demonstrated the clinical benefits of NPC screening through plasma Epstein-Barr virus (EBV) DNA testing by polymerase chain reaction (PCR). This landmark study showed that liquid biopsy is a feasible concept that could bring about a clinical impact when applied to the detection of early cancer, with promising prospects for effective early cures for other types of cancer and increased likelihood of survival. Given its potential clinical impact, the work was selected as one of the ten most notable articles of the *New England Journal of Medicine* in 2017.[20]

[20] Chan et al. New England Journal of Medicine, 2017; 377:513-522

Prof. Dennis Lo and Prof. Allen Chan of the State Key Laboratory of Translational Oncology reported results of the use of plasma EBV DNA for the screening of nasopharyngeal carcinoma published in the *New England Journal of Medicine* in 2017.

The team subsequently discovered differentiating molecular characteristics of plasma EBV DNA (including quantitation, size and methylation) in NPC patients. Based on the discovery, they have developed novel diagnostic approaches that allow better differentiation of NPC and non-NPC samples in the context of screening. These new approaches could achieve a substantially higher positive predictive value for NPC and are available for clinical use now.[21]

Aiming to evaluate the implication of cancer-associated DNA change in subjects with no immediate cancer identified, the team also carried out the second-round screening of a whole 20,000-subject cohort. They found that subjects positive for plasma EBV DNA would have a higher risk of developing NPC in the future, implying that the presence of cancer-associated DNA changes (i.e. a positive liquid biopsy test result) not only can detect a current concealed cancer but also reflect the risk of future cancer development.[22] This would impact the clinical interpretation of liquid biopsy test results in the screening setting.

Moreover, novel liquid biopsy technologies developed at CUHK have generated significant application value in the industrial sector. This is demonstrated by the large number of granted patents awarded to Professor Lo, the leader of the team. More importantly, based on the CUHK technology, Grail, the largest multi-cancer early detection (MCED) company by market value, has launched the first clinically available MCED test, Galleri. The value of this technology can also be seen by the acquisition of Grail by Illumina at the end of 2021 at a price of USD 8 billion. In addition, this test has been named as one of the best inventions in 2022 by *Time* magazine.[23] Apart from developing strategic collaboration with industrial partners to explore the translational value of the technologies that are also applicable for other cancer types in addition to NPC, Professor Dennis Lo and his team have also co-founded their own biotechnology start-up, Take2 Technologies. The company aims to provide NPC diagnostics services in the GBA based on the novel technologies, and their NPC diagnostics products[24] are already available for clinical use in Hong Kong.

[21] Lam et al. PNAS 2018; 115(22): E5115-E5124
[22] Chan et al. NEJM Evid 2023;2(7)
[23] https://time.com/collection/best-inventions-2022/6225228/grail-galleri-cancer-test/
[24] Take2 Prophecy™ (https://take2health.net/health-platform/zh-HK/product-prophecy) and monitoring (Take2 Clarity™) (https://take2health.net/en/products-and-services/take2-clarity/)

At a broader level of social significance, the NPC screening model might create in a paradigm shift in cancer screening and impact cancer management, bringing important health benefits. Screening with plasma EBV DNA could profoundly impact on the natural history of NPC, which ranks among the 10 most common types of male cancer in southern parts of China and Southeast Asia. It is demonstrated that plasma EBV DNA testing could identify early-stage NPC, and such early detection could bring about a reduction of mortality by 90%, a significant survival benefit. This screening strategy is also cost-effective. It is estimated that if a mass NPC screening program were launched for all men aged between 40 and 65 years old (~20 million men) in Guangdong, one of the Chinese provinces with the highest incidence rates of NPC, the now clinically available second-generation NPC screening test would reduce the number of false positives by 10-fold, that is, 1.8 million subjects, compared to screening with the existing screening tool of EBV antibody. This is a huge impact from the public health point of view.

Under the leadership and guidance of Professor Lo, the research team also led the development of the first international recommendation document on the use of EBV-based biomarkers for screening of NPC, European Society for Medical Oncology (ESMO) 2020 treatment guidelines and the UptoDate™ guideline for NPC, which are useful to guide public health programmes to translate the research findings and enhance NPC screening adoption in Hong Kong and the GBA. Professor Lo and his team have made significant advancement in terms of research, economic and social impact, strengthening CUHK's impact of medical research, and leading the development of biomedicine in Hong Kong and the GBA.

3.2 Greater Bay Area Research Initiative: Innovating policy for smart integration

To promote the development of Smart Integration in the GBA, the wide-ranging Great Bay Area Research Initiative, led by CUHK's Centre for China Studies, has made high-impact contributions to policy innovation in the service of building a modern, efficient, and developed region.

As shown in Chapter 2, Social Sciences stands out as one of CUHK's top five pillars of research in terms of publication share, while at the same time having high impact (an FWCI as high as 1.82). As a specialised research strength of CUHK, Social Sciences research at CUHK has exerted an impact not only in the academic community, but also in broader society. This is exemplified by CUHK's China Studies programmes.

Hong Kong is a vibrant and cosmopolitan city where Chinese culture and other cultures meet, exchange and merge. Located in Hong Kong and in close proximity to Shenzhen, CUHK provides an ideal geographic location and learning environment for China Studies, attracting scholars and students from home and abroad to explore the richness and complexity of Chinese society.

CUHK's Centre for China Studies (CCS), an interdisciplinary science department within the Faculty of Arts, is dedicated to promoting academic research and learning in all areas related to China. With the aspiration to foster development of the GBA, CCS has launched the Greater Bay Area Research Initiative as part of its wide-ranging research on contemporary China, which brings together scholars and practitioners who work on different aspects of the GBA. Led by Professor Li Chen and Professor Tim Summers, the research initiative and work of CCS have been widely recognised by the policy and business communities, gaining substantial media exposure to reach the wider public.

One representative high-impact research activity of the research initiative is a major symposium entitled 'Policy Innovation in the Greater Bay Area: Smart Integration under China's "Dual Circulation" Strategy' in November 2022. It was successfully co-organised by CCS and the Institute for International Affairs (IIA) of CUHK (Shenzhen), with support from other internal partners of CUHK, as well as external partners including Hua Jing Society and Hong Kong Institution for International Finance.

The symposium was held in a challenging context. In 2019, China's central government issued the Outline Plan[25] for the GBA, envisaging an important role for the GBA as a region that could help enhance China's global competitiveness and innovation strengths. But soon after, the outbreak of the COVID-19 pandemic, combined with the changing international geopolitical trends challenged globalisation. Integration and connectivity remain constrained within the GBA, also challenging the development of the region. The need for 'smart'

[25] The official goals of the plan are expansive: to build an open, economically vibrant and internationalised region, enhancing its international competitiveness; to place innovation at the heart of developing a 'leading economy'; to promote green development and a good living environment; and to encourage better coordination between the administrative jurisdictions in the GBA (Guangdong province, the nine cities and two SARs) with the role for different cities based on their comparative advantages.

integration in the GBA calls for policy innovation which responds to the global, national, and local context, so as to achieve the goal of building a modern, innovative and developed region.

At the symposium, keynotes on governance, talent, and regional integration, as well as finance and dual circulation, were followed by in-depth panel discussions on policy innovation in the GBA, featuring leading experts from the academic, policy and business communities. This symposium also brought together high-profile speakers and audience from the Legislative Council, business, local think tanks and academia, engaging with the key policy and public debates across the range of issues facing the GBA development.

The research findings of this symposium have comprehensively covered the key themes of GBA development in terms of governance, talent, regional integration, finance, innovation, and dual circulation, with innovative ideas on how to remove barriers, mitigate gaps and enhance connectivity organisationally and institutionally in the development of the GBA. It finds that the GBA development need to combine top-down development planning more effectively, and bottom-up policy entrepreneurship and experimentation. 'Smart integration' in the GBA requires not only effective 'hardware' physical infrastructure, but also, more fundamentally, an adaptive institutional and policy system to enhance cross-border connectivity. Given that the inter-city competition within the GBA has led to substantial inefficiency in multiple areas such as education, R&D investment, transportation infrastructure, the region needs to place a stronger emphasis on inter-city collaboration. The symposium also shows that smart integration in the GBA is predicated on the complementary roles of the government and market, with a framework of public action that encourages economic integration, connectivity, diversification, and innovation. Experts at the symposium agreed that a new approach of regional industrial policy and financial policy is needed to support GBA development, supporting the region to explore new development strategies that more proactively shape its industrial structural transformation.

CCS Interdisciplinary Symposium on Policy Innovation in the Greater Bay Area.

Apart from the major symposium, the research initiative has organised a series of policy-oriented seminars and strengthened network development with partners in the policy, business and academic communities. The research initiative has built, together with the Institute for International Affairs at CUHK (Shenzhen), a prominent WeChat public account, The GBA Review, which as a leading digital policy journal on the GBA has gained over 62,000 followers by January 2024. As leaders of the research initiative, Prof LI Chen and Prof Tim Summers have contributed numerous articles on financial policy and governance, regularly served as speakers on the public policy forum, and hosted policy-oriented seminars.

As the highlight of the Social Science area of CUHK, The Greater Bay Area Research Initiative not only spurred the socioeconomic impact of CUHK and Hong Kong as a whole, but generated far-reaching influence on policymaking of integration and development of the GBA.

3.3 PSPNet: Revolutionising the computer vision

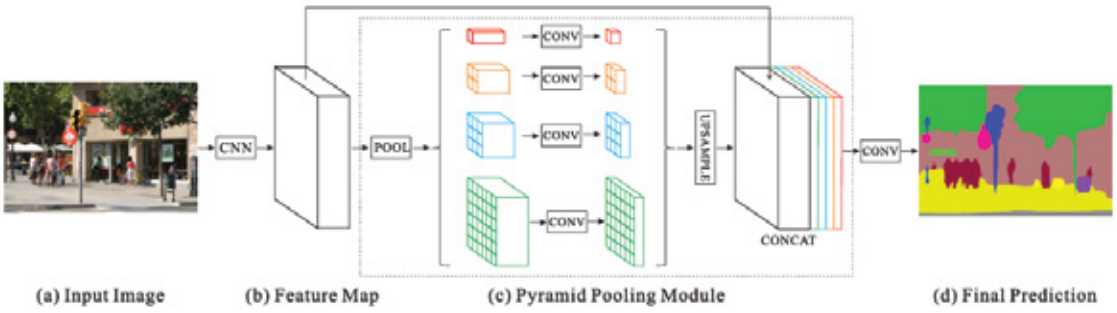
CUHK's high-impact research in Computer Science and Artificial Intelligence, exemplified by the pioneering development of the Pyramid Scene Parsing Network (PSPNet), is revolutionising the realm of computer vision, with far-reaching implications for industry, education, and societal development.

In the fast-paced technological landscape of the GBA, the strategic significance of computer science and artificial intelligence (AI) cannot be overstated. CUHK has firmly established itself as one of the leading institutions in these critical domains, evident through its prolific research output and high-impact research contribution.

Over the past five years, Computer Science has been the second most published subject area at CUHK, only exceeded by Medicine. The prolific research output is also accompanied by a high quality of research. The scholarly impact of CUHK in Computer Science surpasses those of other top 10 most published institutions in the GBA, underscoring its leading position in producing academically impactful research in the field. CUHK's contribution to the GBA's AI research is substantial. Representing 5.8% of GBA's research output in AI, CUHK's output share in AI is the largest among the five strategic industry fields studied in this report. CUHK's scholarly impact in AI, as measured by FWCI, is 1.6 times that of the GBA. As a leading institution in Computer Science and AI, CUHK stands at the forefront of groundbreaking research, driving innovation and economic growth in the field.

Led by Professor Jiaya Jia, the Department of Computer Science and Engineering at CUHK has made significant contributions to the advancement of AI, particularly in the realm of computer vision. One of the most notable research endeavours led by Professor Jia and his team is the development of the Pyramid Scene Parsing Network (PSPNet)[26]. This revolutionary project focuses on scene parsing, a fundamental topic of computer vision. Scene parsing involves assigning a category label to each pixel in an image, enabling pixel-level understanding of complex visual scenes. Traditionally, scene parsing algorithms struggled with diverse scenes and unrestricted vocabularies, limiting their practical utility. PSPNet addresses the challenges of scene parsing by introducing innovative context modelling techniques, significantly enhancing accuracy and performance in diverse real-world scenarios.

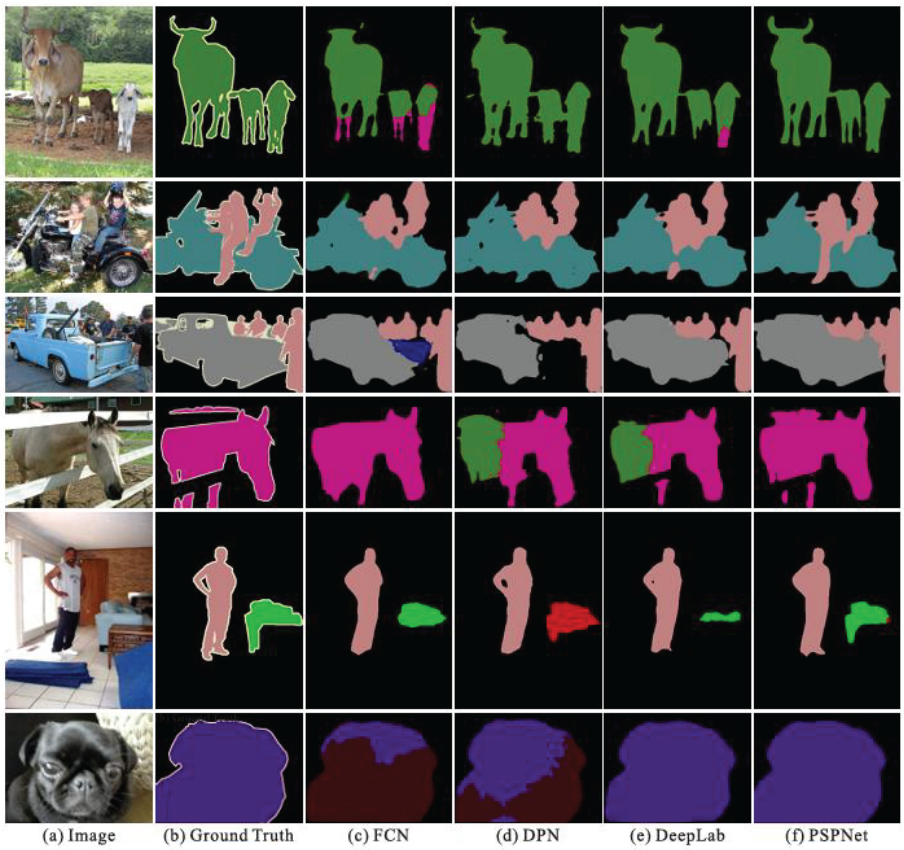
[26] Zhao, Hengshuang, Jianping Shi, Xiaojuan Qi, Xiaogang Wang, and Jiaya Jia. 'Pyramid scene parsing network.' In Proceedings of the IEEE conference on computer vision and pattern recognition, pp. 2881-2890. 2017.



Overview of our proposed PSPNet. Given an input image (a), we first use CNN to get the feature map of the last convolutional layer (b), then a pyramid parsing module is applied to harvest different sub-region representations, followed by up-sampling and concatenation layers to form the final feature representation, which carries both local and global context information in (c). Finally, the representation is fed into a convolution layer to get the final per-pixel prediction (d).

PSPNet's state-of-the-art performance has been validated across various benchmarks, including the ImageNet Scene Parsing Challenge, an annual computer vision competition developed upon the computer vision data set called ImageNet, where it ranked among the top submissions globally. Its remarkable accuracy and versatility extend beyond scene parsing, demonstrating promise in tasks like stereo matching, optical flow, and depth estimation. By pushing the boundaries of deep learning in computer vision, PSPNet has established itself as a landmark achievement in the field, earning recognition as one of the twenty most cited papers at the prestigious conference on Computer Vision and Pattern Recognition (CVPR) in the past five years.

The impact of PSPNet extends beyond academia, with profound implications for AI industry and influence for AI education. PSPNet methodologies have been adopted by leading companies like SenseTime for applications in autonomous driving systems, underscoring the practical relevance and commercial viability. Moreover, PSPNet's influence extends to educational resources, with its principles enshrined in seminal texts on computer vision and AI. The PSPNet algorithm's source code has been embraced by the open-source community, evidenced by over 10,000 stars on GitHub, a popular open-source platform for software development and collaboration, indicating its widespread approval and utility. Additionally, its visual results have engaged a broad audience with more than 100,000 views on YouTube, fostering collaboration and innovation on a global scale.



Visual comparison on PASCAL VOC 2012 data. (a) Image. (b) Ground Truth. (c) FCN. (d) DPN. (e) DeepLab. (f) PSPNet.

PSPNet's advanced scene parsing capabilities unlock new opportunities for entrepreneurship and product development. By leveraging PSPNet, startups and established companies can create innovative products in areas like autonomous vehicles, surveillance systems, and augmented reality, gaining a competitive edge in the market. Furthermore, the integration into AI systems facilitates the development of smarter solutions for various industries, driving economic growth and innovation.

The social impact of PSPNet is far-reaching, from enhancing public safety and security to advancing urban planning and environmental monitoring. By enhancing surveillance systems and aiding in autonomous vehicle technology, PSPNet contributes to safer roads and improved transportation efficiency. Additionally, its application in environmental monitoring and urban planning promotes sustainable development and informed decision-making, benefitting policymakers and communities alike. CUHK's research impact in computer science and AI, exemplified by Professor Jia and his team's work on PSPNet, underscores its pivotal role in driving innovation and societal progress in the GBA and beyond. As PSPNet continues to revolutionise various industries and address pressing societal challenges, CUHK will live up to its commitment to advance the frontiers of AI research and translate groundbreaking discoveries into tangible solutions with real-world impact.

Appendix A

Description of indicators

Altmetrics

Altmetrics (derived from the term 'alternative metrics') is a set of methods to measure the visibility of peer-reviewed scientific publications in traditional news outlets and policy documents and on social media. These mentions are usually tracked through document identifiers such as DOI, PMID and the URL of the article.

This report presents findings on citations and mentions of publications outside of Scopus—for example, in repositories of policy-related literature (such as the UK Parliamentary Office of Science and Technology), online news portals (such as *The Conversation* or the *New York Times*), or social media platforms (e.g., Wikipedia). Our analysis captures discussion of research findings outside the academic community, among policymakers or government scientists, scientific educators, and a broad audience of the science-news-reading public. When we refer to news or journalistic mentions, we define this as content generated by journalists, or scientific news aggregators with editorial oversight. Policy-related documents made up of technical advice and evidence syntheses are known as synoptic science documents. We use the PlumX and Overton databases (see Appendix B for details) to produce our altmetrics indicators. Both databases mix automated coding and parsing methods with some manual curation to link peer-reviewed publication records to those from selected online repositories and aggregators.

Author

Author refers to any individual listed in the author byline of a Scopus-indexed publication.

Bibliometrics

The quantitative data used in Chapter 1 of this report are analysed using bibliometric techniques. Bibliometrics is a set of methods that use data from databases indexing records of scientific publications and patents, as well as other R&I outputs of growing interest, such as designs and trademarks, to derive new insights into these outputs' corresponding funding and performance. Within bibliometrics, the branch of scientometrics examines the records of research publications to measure scientific activity. Increasingly, it also examines related types of outputs such as research data sets and protocols. The branch of technometrics focuses on patent records as a proxy measure for innovation. It is being actively expanded to cover other forms of innovation that are not well captured by patents, such as those covered by designs and trademarks.

Citation

A citation is a formal reference in a research journal publication to earlier work. Citations are used to credit the published source of an idea or finding. The number of citations received by a publication from subsequently published articles in the scientific literature is used as a proxy for the influence or impact that publication has had. In this report, 'citations' refer to citations by any Scopus-indexed publications, whereas citations made by other types of documents (e.g., policy documents) specifically reference the type of document that the citation was made in (e.g., as 'policy citations' or citations in policy documents).

Compound annual growth rate

The compound annual growth rate (CAGR) is defined as the year-over-year constant growth rate over a specified period of time. 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.

Collaboration

Research collaboration is measured by counting publications resulting from the efforts of two or more authors. Such publications are referred to as co-publications throughout the report. Collaboration can be categorised into various types; in this report, we focus on the following two:

- International collaboration—co-publication in which the affiliations listed by the authors of a publication include institutions from two or more countries or regions.
- Academic–corporate collaboration—co-publication in which the affiliations listed by the authors of a publication include institutions or organisations from both academia and the corporate sector; this is a type of intersectoral collaboration.

Field-weighted citation impact

Field-weighted citation impact (FWCI) is an indicator of the citation impact of a publication. It is calculated by comparing the number of citations actually received by a publication with the number of citations expected for a publication of the same document type, publication year and subject. 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 means the entity's publications have been cited 111% more than the world average. An FWCI of less than 1.00 indicates that the entity's publications have been cited less than would be expected based on the global average for similar publications; for example, an FWCI score of 0.87 means the publications have been cited 13% less than the world average. The FWCI is 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 ages (e.g., older documents are expected to have accrued more citations than recently published documents), document types (e.g., reviews typically attract more citations than research articles), as well as subjects (e.g., publications in Medicine accrue citations more quickly than publications in Mathematics). The FWCI uses an unweighted variable 5-year window. The mean FWCI value for 2012 publications, for example, is calculated for documents published in 2012 using their citations from 2012 to 2017. For recent output with less than five years since publication, all citations available at the date of data extraction are used in the calculation. For instance, if an article is published in 2016, and the data are extracted in 2018, the article's FWCI is calculated using the article's 2016–2018 citations.

Interdisciplinarity (knowledge integration)

Interdisciplinary research is that which combines two or more academic disciplines into one activity (e.g., a research project). In this report, research interdisciplinarity is measured using disciplinary diversity of authors (DDA) and disciplinary diversity of references (DDR).

- Disciplinary diversity of authors (DDA)

The DDA reflects the diversity of the prior disciplinary backgrounds of a paper's co-authors. This indicator was developed to account for the number of distinct disciplines, the cognitive distance that separates them, and the balance between them. A paper co-authored by authors whose previous papers were distributed across subfields of science in a similar pattern (i.e., having similar relative frequency across subfields) would score lower than papers bringing together authors with different backgrounds (as measured by the subfields from their prior publications), even if those authors, individually, have published in a less diverse set of subfields. In other words, it is having differences between the backgrounds of each co-author that increases multi-disciplinary integration and not having individual authors with more diverse backgrounds. Nevertheless, authors having diverse backgrounds may be more likely to increase the multi-

disciplinary integration of one paper, but only if this diversity is sufficiently different from the subfields of the remaining authors. As a result of this approach, a single-author publication, no matter the diversity of its author's background, will always receive the minimum score, because the indicator is intended to capture diversity across different authors. In this report, the share of an entity's papers with a DDA score in the top 10% is measured and normalised to the average of all papers worldwide published in the same subfield and same year.

- Disciplinary diversity of references (DDR)

The DDR of a publication is computed based on the material cited by the publication and reflects the diversity of knowledge that is being integrated into the publication. The indicator considers (a) the number of different subfields that are being cited, (b) the distribution of those citations across the cited subfields, and (c) the intellectual proximity of those subfields to one another. For example, a paper that draws on knowledge from four different subfields would have a higher DDR score than a paper that draws on only three. Similarly, a paper that cites one subfield 90% of the time and the other subfields only 10% of the time would have a lower score than a paper that cites its various subfields in roughly equal measure. Finally, a paper that integrates knowledge from biology and from chemistry would have a lower score than a paper that integrates knowledge from biology and the performing arts, because the former pair is more intellectually proximate than the latter pair. In this report, the share of an entity's papers among the top 10% with the highest DDR in the world is computed and the DDR score is adjusted to the average of all papers worldwide published in the same subfield and same year.

Keyphrase

SciVal uses the Elsevier Fingerprint Engine to extract distinctive keyphrases within a given research area. Text mining is done through applying a variety of Natural Language Processing techniques to the titles and abstracts of the documents in the research area in order to identify important concepts. These concepts are matched against a set of thesauri spanning all major disciplines. For each document the distinctive keyphrases are selected based on Inverse Document Frequency (IDF), by incorporating a factor that diminishes the weight of words that occur frequently in the document set and that increases the importance of words that occur rarely. Each keyphrase is given a relevance between 0 and 1, with 1 given to the most frequently occurring keyphrase. Remaining keyphrases are given a value based on their relative frequency.

Publication

Publication (unless otherwise indicated) denotes the main types of peer-reviewed documents published in journals: articles, reviews, and conference papers.

Publications in top 1% high impact journals

are those publications published in journals ranked among the world's top 1% by CiteScore Percentile in the studied period, normalised by subject field (CiteScore is a metric measuring citation impact of journals indexed in Scopus). An entity's number or share of publications in a high impact journal is treated as indicative of the excellence of the research.

Relative activity index (RAI)

The RAI of an entity against the world for a subject area (subfield) is defined as the share of an entity's article output for a subject area (subfield) relative to the global share of articles for the same subject (subfield). For example, CUHK published 31.8% of its publications in Medicine, while for the world 25.4% of all articles were published in Medicine. The RAI for CUHK against the world in Medicine is calculated as 31.8%/25.4% = 1.25. A value of 1.0 indicates that an entity's research activity in a subject area (subfield) corresponds exactly with the global activity in that subject (subfield); a value higher than 1.0 implies a greater emphasis; and a value lower than 1.0 suggests a lesser focus.

Scholarly output

In this report the terms *output*, *articles* and *publications* refer to peer-reviewed articles, reviews and conference papers published in journals and conference proceedings and indexed in the Scopus database.

Appendix B

Data sources and analytical platforms

Elsevier Fingerprint Engine®

Based on state-of-the-art Natural Language Processing (NLP) techniques, the Elsevier Fingerprint Engine is a back-end software system that extracts information from the unstructured text of scientific documents. It applies a domain-relevant thesaurus to each scientific publication to map text to semantic 'fingerprints' or collections of weighted key concepts. By identifying and extracting new concepts, the Elsevier Fingerprint Engine can enrich each thesaurus and generate new vocabularies, so it continuously improves the insights it delivers to researchers and funding bodies. It can be used as a back-office processing component of applications or as a stand-alone service.

See https://www.elsevier.com/solutions/elsevierfingerprint-engine

Overton

Overton is the world's largest searchable index of policy documents, guidelines, think-tank publications and working papers. Its database consists of more than 1.65 million policy documents, with data collected from 182 countries and over a thousand sources worldwide. These policy documents include white papers from international multilateral organisations, as well as guidelines from city councils, parliamentary transcripts and other classes of the so-called 'grey literature'. Around half of these documents make citations to academic or scholarly publications. More than 2 million distinct journal-based publications are cited by at least one policy document in the database.

See https://www.overton.io/

PlumX

PlumX Metrics provide insights into the ways people interact with individual pieces of research output in the online environment. Examples include research being mentioned in the news or Wikipedia. These metrics are divided into five categories (citations, usage, captures, mentions, social media) to help make sense of the huge amounts of data involved and to enable analysis by comparing like with like.

See https://plumanalytics.com/learn/about-metrics/

SciVal

SciVal is a web-based analytics solution with unparalleled flexibility that provides access to the research performance of over 20,000 academic, industry and government research institutions and their associated researchers, output and metrics. SciVal allows users to visualise research performance, benchmark relative to peers, develop strategic partnerships, identify and analyse emerging research trends, and create uniquely tailored reports.

See www.scival.com

Scopus

Scopus is Elsevier's expertly curated abstract and citation database with content from over 7,000 publishers to help track and enhance researcher and institutional data and discover global research in all fields. Scopus covers over 84 million items from more than 26,000 serial titles, 240,000+ books and 10.4 million+ conference papers connected through a robust data model including over 94,000 affiliation and 17 million author profiles. 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 countries across Europe, Latin America, Africa and the Asia-Pacific region.

See www.elsevier.com

Appendix C

Data set creation for the five industry fields of national strategic importance

Data set construction

The data sets for the five industry fields of national strategic importance were built primarily using Scopus All Science Journal Classification (ASJC), research fields curated by SciVal, and relevant Elsevier reports. The ASJC were used in Scopus to classify published research by its subject area. This was done by in-house experts at the moment the serial title was set up for Scopus coverage. The classification is based on the aims and scope of the title, and on the content it publishes. There are in total 27 subject areas and 334 sub-areas. The complete list of Scopus ASJC subject areas is available from

https://service.elsevier.com/app/answers/detail/a_id/15181/supporthub/scopus/

- Artificial intelligence

is defined using publications categorised in Scopus ASJC subject '1702. Artificial Intelligence', a sub-area under ASJC first-level subject '17. Computer Science'.

- Biomedicine

is a multidisciplinary research field that lies at the intersection of biology and medicine. Focusing on the interdisciplinary nature of the research field, the field of biomedicine is defined using a combined publication set resulting from intersecting publications of five ASJC first-level subjects and of seven ASJC second-level subjects. See below for the detailed list of subjects.

The intersections of five ASJC first-level subjects are:

No.	The intersection of five ASJC first-level subjects
1	"27.Medicine" **and** "24.Immunology and Microbiology"
2	"27.Medicine" **and** "13.Biochemistry, Genetics and Molecular Biology"
3	"22.Engineering" **and** "13.Biochemistry, Genetics and Molecular Biology"
4	"22.Engineering" **and** "24.Immunology and Microbiology"
5	"30.Pharmacology, Toxicology and Pharmaceutics" **and** "13. Biochemistry, Genetics and Molecular Biology"

The seven ASJC334 second-level subjects are:

No.	ASJC second-level subject	Corresponding ASJC first-level subject
1	1305.Biotechnology	13. Biochemistry, Genetics and Molecular Biology
2	1313.Molecular Medicine	13. Biochemistry, Genetics and Molecular Biology
3	2704.Biochemistry, medical	27. Medicine
4	2726.Microbiology (medical)	27. Medicine
5	2204.Biomedical Engineering	22. Engineering
6	2802.Behavioral Neuroscience	28. Neuroscience
7	2803.Biological Psychiatry	28. Neuroscience
8	2804.Cellular and Molecular Neuroscience	28. Neuroscience
9	2805.Biological Psychiatry	28. Neuroscience
10	2808.Neurology	28. Neuroscience

- Quantum technology

is defined using the 'Quantum Technologies' publication set available in SciVal. This research field encompasses publications related to Quantum Computing, Quantum Simulation, Quantum Metrology, Quantum Sensing, and Quantum Communications based on a series of search queries.

- Clean Energy/Net Zero

is defined using the publication set of Elsevier report 'Pathways to Net Zero: The Impact of Clean Energy Research'. The 'Net Zero' data set is a combination of publications from SDG 7 and energy related publications from SDG 13, looking at science and innovation trends in clean energy and carbon removal. The SDG research areas are defined using search queries, augmented with a machine learning (ML) model.

The 'Net Zero' report is available from https://www.elsevier.com/connect/net-zero-report

- Environmental Science

is defined using publications categorised in Scopus ASJC subject '23. Environmental Science'.

About

This report was prepared by Elsevier's Analytical Services in collaboration with The Chinese University of Hong Kong, who funded this project.

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