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Strategic Planning of Global Innovation and Industry Highland in Guangdong–Hong Kong–Macao Greater Bay Area from a Medium- and Long-Term Perspective

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Abstract: As the construction of the Guangdong–Hong Kong–Macao Greater Bay Area (GBA) enters a new stage, it is necessary to further improve technological innovation and emerging industries in this area and promote their global influence to support the high-quality development of China's industries. In this study, we analyze the role of the GBA in national economic development and explore the development status of technological innovation and emerging industries therein. Moreover, we propose strategic goals and key tasks for medium- and long-term development under the unique institutional framework of "one country, two systems." The GBA can be built as a global innovation and industry highland that is open, integrated, and sustainable by 2050, through four steps, and a borderless GBA can be constructed in an orderly manner through integrated technological innovation. The key tasks that we propose include: (1) strengthening the construction of an international technological innovation center; (2) improving the ability of science and technology to support industrial development; (3) cultivating world-class clusters of emerging industries; (4) creating a gathering place for outstanding professionals in China and abroad; (5) deepening the integration of finance and technology; (6) establishing a diversified investment coordination mechanism for scientific innovation; and (7) exploring an innovation and industrial factor flow mechanism.
Keywords: Guangdong–Hong Kong–Macao Greater Bay Area; technological innovation; emerging industries; global innovation and industry highland; bay area economy

1 Introduction

World-class city clusters are essential spatial carriers that participate in global competitions. The Guangdong–Hong Kong–Macao Greater Bay Area (GBA), which covers nine cities in the Pearl River Delta (PRD), Hong Kong, and Macao, strives to accelerate the building of a world-class city cluster. The *Outline Development Plan for the Greater Bay Area* (2019) emphasizes the essential strategic position of the GBA in national development. Building the GBA is an attempt by China to form a new pattern of overall opening up and a new practice to promote the

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development of "one country, two systems."

A new round of the science and technology (S&T) and industrial revolution is reshaping the global economic landscape, accompanied by accelerating S&T innovation and the emergence of new industries and business forms. As a new member of the Bay Area Economy, the GBA has made remarkable achievements in new fields, such as next-generation information technology (NGIT), biomedicine, unmanned aerial vehicles, and robotics. However, compared with other international bay areas, there is still room for S&T innovation and emerging industries, which will be an essential orientation for future breakthroughs. In the context of unprecedented changes in the world, how the GBA achieves self-reliance in terms of S&T innovation and emerging industries has become a major mission for regional development and a strategic problem for building a modernized country, and coping with global transformations and challenges [1].

S&T innovation herein contains basic research, application research, and experimental development of universities, research institutions, enterprises, and other innovation subjects. Emerging industries refer to the new industries and business forms that emerge with the invention and application of new technologies, featuring intensive knowledge technologies, less consumption of material resources, great growth potential, comprehensively prosperous benefits, and far-reaching influence on socio-economic development. Existing literature has extensively discussed how to promote S&T innovation and the development of emerging industries in the GBA. In terms of S&T innovation research, based on the analysis of the current status of S&T innovation and its coordination with economic development in the GBA [2–4], scholars have explored the development path [5–7] from the dimensions of building an innovation ecosystem and strengthening the Guangdong–Hong Kong–Macao innovation cooperation. By contrast, there has been little research on emerging industries in the GBA. For example, some scholars have discussed the integrated development of the industrial chain and the innovation chain [8] and suggested industrial policies and the construction of the digital bay area [9,10]. Combined with the existing literature, this study needs to conduct in-depth research in two aspects: systematically conceive key development tasks considering S&T innovation and the development of emerging industries in the GBA, and research the medium- and long-term development goals of S&T innovation and emerging industries in the GBA.

Observed from the *Overall Plan for the Construction of the Hengqin–Guangdong–Macao In-depth Cooperation Zone* and *Comprehensively Deepen the Reform and Opening-up Plan of Qianhai–Shenzhen–Hong Kong Modern Service Industry Cooperation Zone*, the Chinese government requires that the "one country, two systems" path be explored for the integrated development of the GBA with pilot projects in some regions. S&T innovation is an essential breakthrough in the promotion of this process. Therefore, this study examines how the GBA comprehensively accelerates the construction of an open, integrated, and sustainable global innovation and industrial highland to promote the construction of a "borderless" GBA through integrated S&T innovation and development. Targeting the strategic goals of medium- and long-term development, this study will take S&T innovation and the development of emerging industries into consideration to build systematic key development tasks. The medium- and long-term periods will differ in different situations—for example, more than ten years, as required in the national strategic planning documents; 30 years for population planning. Given the long-term importance and complexity of S&T innovation and emerging industries in the GBA, medium- and long-term strategic planning mainly aims at 2035 and looks forward to 2050.

2 The value of the Bay Area economy for the national economic development

Regional clusters serve as ideal spatial carriers for S&T innovation and emerging industries in the global economy and are an effective approach for constructing a national innovation system. The bay area city cluster can form an urban division system with highly open characteristics and shape a cluster innovation culture that opens up to the outside world with complementary advantages, interest sharing, risk-sharing, and the pursuit of excellence. It is believed that the bay area city cluster is the birthplace of global S&T innovation and emerging industries.

The San Francisco Bay Area and New York Bay Area in the United States, the Tokyo Bay Area in Japan, and the GBA are the world's four largest bay areas, whose economic volumes are irreplaceable for the economic development of the corresponding countries—they accounted for 4%, 9%, 31%, and 12% of their 2019 national GDP, respectively. They developed emerging industrial clusters with the following characteristics: (1) The formation of the San Francisco Bay Area is driven by innovation in universities, mainly in emerging industrial clusters, such as NGIT, new energy, and biomedicine. (2) In the New York Bay Area, the service industry is dominated by the financial and information service industries, while the manufacturing industry is dominated by the pharmaceutical and electronic information manufacturing industries; the added value of the service industry accounts for more than 90%

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of the GDP. (3) The Tokyo Bay Area has formed emerging industrial clusters, represented by robots, biomedicine, and new energy sources around the Tokyo Prefecture, Kanagawa Prefecture, Chiba Prefecture, and Saitama Prefecture. (4) The number of enterprises in emerging industries in the GBA accounts for 15.3% of that in the country (as per the statistics and calculations in this study). The GBA has become an essential force leading to the development of China's emerging industries and forms the main gathering venue for NGIT, high-end equipment manufacturing, new materials, biomedicine, and other emerging industries.

In promoting the development of emerging industries, the San Francisco Bay Area, New York Bay Area, and Tokyo Bay Area cultivated emerging industrial clusters with global influence, leading to global trends in S&T innovation. The San Francisco Bay Area has formed an emerging industrial cluster marked by NGIT and has gathered a large number of well-known multinational information technology enterprises (e.g., Google, Apple, Oracle, Facebook, Cisco, Intel, Yahoo, and HP). The New York Bay Area, with strong financial resources, has driven the development of biomedicine. New Jersey in the northwestern New York Bay Area has a particularly developed pharmaceutical industry with more than 20 world-class pharmaceutical companies (e.g., Johnson & Johnson and Merck), with sales accounting for 50% of global sales [11]. Relying on NGIT, the Tokyo Bay Area supports the transformation and upgrade of the traditional competitive manufacturing industry, and aims to develop a modern and advanced manufacturing cluster. The digital industry has become a global benchmark for development, with its market share exceeding one-third of the global digital industry.

Emerging industries, such as NGIT, high-end equipment manufacturing, and new materials in the GBA are still at risk of limited independent development because of the lack of original innovation capacity. Without having yet established a global influence, the GBA is still far from becoming a global S&T innovation highland and an essential cradle of emerging industries. Different from the international bay areas (i.e., San Francisco, New York City, and Tokyo) and the domestic city clusters (e.g., Yangtze River delta and Beijing–Tianjin–Hebei Region), the GBA has institutional advantages for development and faces unique structural challenges under the unique institutional framework of "one country, two systems, and three tariff zones." Therefore, under the institutional framework of "one country, two systems," an in-depth discussion of the medium- and long-term goals and key tasks of S&T innovation and emerging industries in the GBA is of strategic significance for promoting China's S&T innovation and high-quality development of emerging industries.

3 Current Status of S&T Innovation and Emerging Industries in the GBA

3.1 Current status of S&T innovation

3.1.1 Development foundation

The research and development intensity (RDIN) in the GBA is approaching the levels of innovative countries. In 2018 and 2019, the GBA invested RMB 279.42 billion and RMB 318.73 billion in research and development (R&D), respectively, up 14.1% year-on-year. In 2019, the RDIN was 2.75%, which was 0.35% higher than the national average in the same year. This was close to that of the United States (2.83%) and Finland (2.76%), and higher than that of France (2.19%), the United Kingdom (1.73%), Singapore (1.84%), and Canada (1.56%) for the same year.

Innovative cooperation in the region has ushered in a new situation. In 2020, Guangdong province made available more than 10 000 large-scale scientific instruments and allocated approximately RMB 150 million in scientific research funds to Hong Kong and Macao, to jointly fund the building of 20 new laboratories. This attracted nearly 200 academicians of the Chinese Academy of Sciences and the Chinese Academy of Engineering, and more than 40 scientists from Hong Kong and Macao to work in Guangdong province [12]. Hong Kong, Macao, and Guangdong province are also strengthening their active cooperation. According to the *Statistics of Hong Kong Innovation Activities 2019*, nearly 30% of the innovation partners of Hong Kong enterprises came from the GBA (excluding Hong Kong), indicating that Hong Kong enterprises have established close innovation cooperation relations with the GBA.

The scale of innovation output continues to expand. Taking Science Citation Index (SCI) papers as an example, the number of papers published in the GBA increased from 57 100 in 2016 to 91 300 in 2019, but decreased slightly due to the COVID-19 epidemic in 2020—the unit of statistics applied in this study is times rather than papers, since each city involved in a cooperative publication is counted. Overall, the number of SCI papers published in the GBA maintained a double-digit growth rate between 2016 and 2020 (the compound annual growth rate was 11.7%). There is a greater probability of S&T innovation in areas with a large population. To eliminate the impact of the urban population scale, this study calculated the number of SCI papers per 10 000 people in the GBA (excluding the number

of permanent residents at the end of the year), which increased from 8.39 in 2016 to 11.97 in 2020 (with a compound annual growth rate of 2.2%).

Shenzhen–Hong Kong–Guangzhou has become an essential S&T innovation cluster worldwide. According to the *2020 Global Innovation Index*, Shenzhen–Hong Kong–Guangzhou has become a scientific and technological cluster ranking second only to Tokyo–Yokohama (Japan), with indicators such as the number of international patent applications under the Patent Cooperation Treaty (accounting for 6.9% of the world total) and scientific publications (accounting for 1.37% of the world total), thus, performing well.

3.1.2 Problems

First, there is an imbalance in internal R&D funding. The large difference in the distribution of innovation resources restricts regional S&T innovation to a certain extent. In 2019, Shenzhen's R&D expenditure reached RMB 132.8 billion (41.7% of the GBA's), but Guangzhou's corresponding investment was only one-half that of Shenzhen's, and that of other cities was significantly lower. Notably, the RDIN was 0.92% in Hong Kong but only 0.22% in Macao. If data from Hong Kong and Macao were included, the RDIN in the GBA would drop from 3.4% to 2.75%, or even 0.01 percentage points lower than in the Yangtze River Delta region. Therefore, the growing investment in S&T innovation in Hong Kong and Macao is significant in supporting the construction of the GBA into an international S&T innovation center.

Second, the investment in fundamental research is insufficient. The scale of R&D investment in Hong Kong, Macao, and cities in Guangdong province, excluding the Pearl River Delta, is relatively small, and so is the relevant basic research investment. Thus, the basic research investment data from Guangdong province was used in studying the GBA. Of the R&D funds in 2019, the basic research funds of the GBA accounted for only 4.6%, which was lower than that of the world's major innovative countries, national first-tier cities, and the average national level. From the perspective of the two core cities of the GBA (Guangzhou and Shenzhen), the basic research funds of Guangzhou accounted for 13.9% of the total R&D funds in 2020, which was close to the level of major innovative countries. The basic research funds of Shenzhen accounted for 3.3%, far below the average level of the GBA (4.6%). Thus, the GBA needs to strengthen its basic research investment further to meet the innovative needs of future economic development.

Third, there is a weakness in the high-level scientific research institutions and innovation platforms. S&T innovation platforms are core carriers for gathering innovation elements, implementing innovation activities, and transforming innovation achievements. Guangdong, Hong Kong, and Macao, characterized by fewer high-level scientific research institutions, are less attractive for high-end S&T talent, have incomplete R&D systems and low continuity and scale benefits of R&D activities. The number of national key laboratories in the GBA is significantly less than in the Beijing–Tianjin–Hebei region and the Yangtze River Delta region (accounting for about 2/3 of that of China), which is not commensurate with the level of regional economic development. Compared with the innovation platforms of Beijing, Jiangsu, Zhejiang, and other provinces, the national-level platforms in Guangdong province are fewer and have less variety. Most are R&D platforms rather than technical consulting and trading platforms. Thus, the corresponding operational mechanisms of these platforms need to be improved owing to the lack of public service capacities.

3.2 Current development of emerging industries

3.2.1 Development foundation

Emerging industries have become indispensable pillar industries in the GBA. Based on the proportion of emerging industry enterprises in the total number of enterprises—national industrial and commercial registration data by March 2021 were identified by referring to the strategic emerging industry classification standards issued by the National Bureau of Statistics of China and applying the big data research method—the emerging industry enterprises in the GBA accounted for 23.2% of the total number of enterprises, implying that they formed a gathering pattern of a certain scale. The corresponding proportion of Guangzhou was the highest (33.5%), 10.3% higher than the overall level of the GBA. The corresponding proportion of Shenzhen was 22.3%, slightly lower than the overall regional level, while that of other cities outside Guangzhou and Shenzhen was at the average level (from 13% to 17%). The following can be said about the development status of emerging industries in Hong Kong and Macao: There being no specialized statistics in Hong Kong, professional services, cultural and creative industries, and innovation and technology industries can be classified into emerging industries. In 2019, the added value of these three industries was 17% of Hong Kong's GDP, indicating that the industries related to emerging industries occupied a certain

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position in Hong Kong's economic development. Although the financial, exhibition, cultural, traditional Chinese medicine, and other industries related to emerging industries were not leading industries in Macao, the added value of these industries accounted for 8.23% of Macao's GDP in 2019, implying an upward trend year by year.

The emerging industries in the GBA show a "1323" hierarchical structure, indicating an obvious hierarchy. The first echelon comprises NGIT; the second echelon consists of high-end equipment manufacturing, new materials, and biology; the third echelon comprises services related to energy conservation and environmental protection; and the fourth echelon comprises new energy vehicles, new energy, and digital creativity. The number of NGIT enterprises in the GBA has reached 477 000, accounting for approximately 34% of the total enterprises in emerging industries. The three industries in the second echelon have comparable numbers of enterprises—with 180 000; 188 000; and 219 000, respectively—accounting for 12.8%, 13.4%, and 15.6%, respectively, of the total number of emerging industry enterprises in the GBA. The enterprises of the two industries in the third echelon accounted for 9% and 10.6%, respectively, of the GBA's total emerging enterprises. These figures indicate that there is a coordinated development in the emerging industries in innovation, manufacturing, and services. The enterprises of the three industries in the fourth echelon accounted for less than 3% of the total emerging enterprises in the GBA.

The emerging industries in the GBA also showed an obvious urban concentration trend. Most emerging industries are distributed in Guangzhou and Shenzhen in varying degrees: 86.5%, 81.8%, 87%, and 89.2% of enterprises of NGIT, high-end equipment manufacturing, new energy, and digital creative industries, respectively, are distributed in Guangzhou and Shenzhen; NGIT enterprises are concentrated in Shenzhen; new energy and digital creativity enterprises are concentrated in Guangzhou; and high-end equipment manufacturing enterprises are evenly distributed between Guangzhou and Shenzhen; 72.2%, 80%, 72.1%, and 75.1% of enterprises of new materials, biology, new energy vehicles, and related service industries, respectively, are distributed in Guangzhou and Shenzhen; new materials and related services gather in Guangzhou, while biological and new energy vehicles do so in Shenzhen; 63.3% of the enterprises in the energy conservation and environmental protection industry are distributed in Guangzhou and Shenzhen, most of which are in Guangzhou. Additionally, there is a concentration of NGIT, high-end equipment manufacturing, new materials, biology, new energy vehicles, new energy, energy conservation, environmental protection, and related services enterprises in Dongguan City; new materials, new energy, energy conservation, environmental protection, and related services in Foshan City; new energy vehicles, energy conservation, and environmental protection in Huizhou City; and digital creativity in Zhuhai City.

3.2.2 Problems

There is a lack of emerging industry clusters with global influence. The San Francisco, New York, and Tokyo Bay Areas have cultivated emerging industry clusters with global influence, specifically, the NGIT industry cluster in the San Francisco Bay Area, biomedicine industry cluster in the New York Bay Area, and advanced manufacturing industry cluster in the Tokyo Bay Area. Although the GBA initially built an NGIT industrial belt on the east bank of the Pearl River and a high-end equipment manufacturing industrial belt on its west bank, these emerging industrial clusters still lack global influence and their strengths have not been fully leveraged. Because of the lack of guidance for world-class enterprises, the leading effect of the industrial cluster in the GBA is not obvious, and the coordinated development trend of emerging industries in Guangdong, Hong Kong, and Macao has not been fully demonstrated.

There is a lack of S&T innovation in the emerging industries. Apart from importing core technologies, such as chips and operating systems, in the GBA, some high-end components, parts, equipment, materials, and basic software also rely on international supply. Thus, high-quality development faces the problem of insufficient independent controls. For example, high-end capacitance and resistance commonly applied to electronic products, large indium tin oxide target materials of LCD displays, and tactile sensors, which are the core components of industrial robots, are rarely manufactured in domestic enterprises. The complexity and uncertainties in the current international environment pose a challenge to the industrial chain security of the GBA.

Companies have failed to lead emerging industry clusters to impose a global influence. In the field of emerging industries with comparative advantages, the number and proportion of the world's top 500 enterprises in the GBA are lower than those in the other three international bay areas. As an advantageous emerging industry in the Tokyo Bay Area, advanced manufacturing counts ten enterprises among the Fortune Global 500 enterprises, 3.3 times that of the GBA. In the San Francisco Bay Area, NGIT gathers 72.7% of Fortune Global 500 enterprises, which is 57.7% higher than those of the GBA. The lack of world-class enterprise clusters is not conducive to forming competitive emerging industries in the GBA around the industrial chain.

The advantages of the coordinated development of emerging industries in Guangdong, Hong Kong, and Macao have not yet been fully leveraged. Since the Bay Area development strategy was put forward, industrial cooperation

among Guangdong, Hong Kong, and Macao has continuously strengthened. The lack of a joint development force for emerging industries in these three regions hinders the formation and cultivation of emerging industry clusters. The industrial planning of Guangdong, Hong Kong, and Macao has been relatively independent for a long time because of historical reasons and the differences in planning systems, technical standards, and management systems. This seems to be particularly prominent under the new collaborative development requirements. For example, as a major strategic platform, the Hetao–Shenzhen–Hong Kong S&T Innovation Cooperation Zone was established to promote the cooperative development of Shenzhen and Hong Kong in S&T innovation and emerging industries. However, there is a lack of coordination between the Shenzhen Science Park and Hong Kong Science Park. Many development platforms in the Shenzhen Science Park have been implemented or are being implemented, demonstrating the apparent advantages of the emerging industry cluster. Because of the slow construction of the Hong Kong Science Park, eight buildings of the phase I planning will be completed in stages between 2024 and 2027. In the future, under the framework of the overall development of the GBA, the problems of uncoordinated industrial planning, unscientific space utilization, and misplaced niche planning of the three regions must be addressed as soon as possible.

4 Target planning and index calculation of S&T innovation and emerging industries in the GBA for medium and long-term development

4.1 Planning basis

Following the *Outline Development Plan for the GBA* and *The Outline of the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and Long-range Objectives for 2035*, we will support the GBA in forming an international S&T innovation center, a global highland for S&T innovation, and an essential cradle of emerging industries. To achieve strategic positioning for S&T innovation and the development of emerging industries in the GBA, Guangdong, Hong Kong, and Macao must form a coordinated development pattern. Guangdong Province took the lead in promoting unilateral opening in the field of S&T innovation, thus supporting Hong Kong and Macao in setting up R&D institutions, sharing scientific and technological facilities and instruments among Guangdong, Hong Kong, and Macao, and implementing the policy of directly allocating financial research funds to institutions in Hong Kong and Macao [12].

As proposed in the *Overall Plan for the Construction of the Hengqin–Guangdong–Macao In-depth Cooperation Zone*, the Hengqin–Macao integrated development system and mechanism will be further improved by 2035. As mentioned in the *Comprehensively Deepen the Reform and Opening-up Plan of the Qianhai–Shenzhen–Hong Kong Modern Service Industry Cooperation Zone*, developing and building the Qianhai–Shenzhen–Hong Kong Modern Service Industry Cooperation Zone is significant in supporting Hong Kong's economic and social development and improving the cooperation level of Guangdong–Hong Kong–Macao. Notably, the Chinese government expects to explore the road of "one country, two systems" for the integrated development of the GBA, with some regions as a pilot.

Based on the existing cooperation between Guangdong, Hong Kong, and Macao, S&T innovation is an essential breakthrough in realizing the integrated development of the GBA within a certain period. The medium- and long-term development goals of S&T innovation and emerging industries in the GBA could be summarized as promoting the construction of a borderless GBA through the orderly integration of S&T innovation and development. The research factors of this construction goal, characterized by openness, integration, and sustainability, mainly include the following three aspects.

First, the global division of labor and the integrated innovation model guided by developed countries cannot form a core innovation ecology in the GBA. A more open, innovative organizational model is needed to reshape the innovation network and industrial market, and break the constraints of the current industrial chain. The primary feature of the GBA in building global innovation and industrial highlands is opening up, which is manifested in the following aspects: (1) Opening the technological innovation network to promote the orderly spreading and absorption of knowledge, which is reflected not only in that the GBA should give full play to its role as a regional highland and spread its advanced production knowledge to other regions through the technological innovation network, but also in that the GBA should make use of the existing technological innovation network to attract and gather global knowledge with a more open attitude. (2)Opening up the market environment and integrating it deeply into the global market. This not only needs to break the market boundary of traditional industries to promote high-quality enterprises to go global, but also faces new competition from new enterprises that enter into China.

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Second, S&T innovation and the development of emerging industries are indispensable from a stable social environment. The social atmosphere in Hong Kong is not harmonious enough, which will hinder the flow of innovation resources and collaborative innovation development within the GBA for quite a long time. Hong Kong's economic and social order has been gradually on the right track, conducive to developing local scientific research and coordinating with mainland China's S&T industry. The construction of integrated innovation and industrial ecology is an essential prerequisite for S&T innovation and emerging industries in the GBA to march toward a global highland. In the future, integration will become the second feature of building the GBA into a global innovation and industrial highland.

Third, S&T innovation and emerging industries in the GBA will ultimately achieve sustainable development through either open or integrated development. Only by cultivating endogenous growth drivers can global S&T innovation and emerging industries continue to play a leading role. Therefore, sustainability is the third feature of building the GBA into a global innovation and industrial highland. Currently, there is still a gap between the modernization capacity of the GBA government, the market, and technological governance, and the requirements of a global innovation and industrial highland. The government should promote a long-term strategy of cultivating a sustainable innovation ecology and carry out innovation in policy tools to support the high-quality development of industries.

4.2 Development objectives

By 2050, the GBA will have driven the construction of a borderless GBA through integrated S&T innovation and development in four steps and become an international S&T innovation center, a global highland for S&T innovation, and an essential cradle of emerging industries.

Step 1: By 2025, Guangdong Province will promote the effective connection of innovation in GBA with industrial resources. Institutional restrictions on Hong Kong and Macao in the fields of S&T innovation and industrial development will be removed, to constantly improve the convenience for Hong Kong and Macao residents to travel to mainland China. Meanwhile, in-depth innovation and cooperation among Guangdong province, Hong Kong, and Macao will be promoted, so that professionals and enterprises from Hong Kong and Macao could enjoy national investment and commercial treatment in mainland China.

Step 2: By 2030, multilateral opening up of S&T innovation and industrial development in Guangdong, Hong Kong, and Macao will be realized. The integration of Guangdong Province with Hong Kong and Macao in scientific research rules, market access, financial and fiscal policies, and other aspects will be promoted to form a collaborative mechanism between S&T innovation and industrial planning and implementation. A more coordinated and free business environment and accelerated building of an open and integrated bay area market will be created.

Step 3: By 2035, the economic integration of the GBA under the guidance of integrated S&T innovation and industrial development will be promoted. Institutional restrictions on Guangdong, Hong Kong, and Macao in the economic field will be removed to achieve a high level of market connectivity and promote a gradual shift from a regional community to an economic community, thus, driving innovation and sustainable industrial development in the GBA with opening up and integration and making it a benchmark for global development.

Step 4: By 2050, the integrated economic and social development of the GBA will be comprehensively promoted. The governance of the bay under the law will be achieved and standardized, and applicable operating rules and systems will be created, with more attention being given to the sharing of resources, connection of multiple systems, and social integration in various areas. While sharing the development achievements among the residents of Guangdong, Hong Kong, and Macao, the social boundaries will be removed, to develop the GBA into a world-class bay area that integrates work, tourism, and life.

4.3 Index calculation

It is believed that the premise of the integrated development of S&T innovation in the GBA is to build an open, integrated, and sustainable global innovation and industrial highland, which gathers global innovation and industrial elements. The internationalization level of enterprises in the GBA will rank among the top leaders. With the orderly flow of regional personnel, materials, funds, and information, as well as improved and solid innovation ability, emerging industry clusters could exert global influence and participate in international economic cooperation and competition at a higher level.

To provide referable quantitative guidance and facilitate the realization of the development goals, the indicators of S&T innovation and emerging industries in the GBA are calculated at the levels of openness, integration, and

sustainable development, based on the status of regional development and the benchmark of the international leading level, looking forward to 2050 (Table 1). Referring to relevant documents and research reports, such as the *Outline of the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of the Long-term Objective for 2035*, *Outline Development Plan for the Greater Bay Area*, *Outline of the Regional Integrated Development Plan of the Yangtze River Delta*, *The Outline of the 14th Five-Year Plan for National Economic and Social Development of Guangdong Province and the Outline of the Long-term Objective for 2035*, O*pinions on Financial Support for the Construction of the Greater Bay Area*, China Innovation Index Research (prepared by National Bureau of Statistics), and the research data and methods in the references [12–14], the basis and reasons for the selection of the indicators are expounded. The expert interview method, regression analysis, and standard method were applied to calculate the target value of relevant indicators at different stages (the index selection and measurement process are omitted because of the word limitation in this paper).

Table 1. Indicators for the opening up, integration, and sustainable development in GBA.

Dimension	Indicator	2025	2030	2035	2050
Open development	Proportion of foreign talents in permanent resident population (%)	3.3	4.9	6.5	10
	Number of unicorn companies	46	100	250	400
	Proportion of exports of high-tech products in exports of goods (%)	40	50	60	70
Integrative development	Population of Hong Kong and Macao living in the GBA (10 000)	35	40	45	60
	Number of the GBA enterprises listed in Hong Kong	420	570	720	1170
Sustainable development	Proportion of basic research investment in R&D investment (%)	10	15	20	40
	RDIN (%)	3.2	3.5	3.8	5
	Contribution rate of scientific and technological progress (%)	70	75	80	90
	Proportion of added value of strategic emerging industries in regional GDP (%)	20	30	38	50
	Number of strategic emerging industries with global influence	1	2	3	5

5 Key tasks for S&T innovation and the development of emerging industries in the GBA

5.1 Strengthening the development of international S&T innovation centers

The GBA has achieved remarkable achievements in S&T innovation in multiple fields, but there is a gap between basic research and original innovation capacity, when compared with powerful S&T nations. The issue of core technologies being controlled by foreign countries has not yet been fundamentally solved. Therefore, the GBA should face the world frontiers, strengthen innovative cooperation, make more efforts to promote basic R&D, concentrate on tackling problems in key and core technologies of emerging industries, and improve the internationalization level of S&T innovation to reach the first-class ranks.

The first task the GBA should undertake is to promote the differentiated and coordinated development of basic research in Guangdong, Hong Kong, and Macao. The same efforts should be made to construct a comprehensive national science center in Shenzhen to support the innovation and development of Hong Kong and Guangzhou, facilitate the construction of state key laboratories of particle physics and nuclear physics, medical materials, space, and astronomy in Hong Kong and Guangzhou, and state key laboratories of biological genes and antivirus, intelligent manufacturing, and ocean engineering in Shenzhen, as well as provincial and ministerial laboratories in Macao, Zhuhai, Dongguan, and Foshan.

Second, major global scientific installations and plans should be implemented. International cooperation on large scientific devices should be promoted in the GBA to help it become a gathering place for cutting-edge large scientific devices worldwide. Then, relying on the construction of large international scientific devices, the GBA should lead and implement a series of global planning projects by cooperating with various countries.

Third, key projects should be conducted to tackle the problems in key and core technologies of emerging industries in batches. Priority directions include electronic design automation software, additive manufacturing bone/high-bone active powder materials, hydrogen fuel cells, ultra-large precision electron beam equipment, and high-end special alloy powder materials for additive manufacturing for national defense needs.

Fourth, an open-source innovation platform for S&T frontiers should be built, relying on well-known S&T enterprises in the GBA. Emerging technologies such as AI, big data, cloud computing, and Internet of Things (IoT) will be applied to build high-tech enterprises and innovative technology communities supported by the open-source innovation platform in the GBA.

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5.2 Improving the support of science and technology in industrial development

Although outstanding achievements have been made in S&T innovation and development in the GBA, the problem of insufficient connections between S&T and the economy remains unsolved. The reform, innovation, and breaking of bottlenecks during the transformation of scientific and technological achievements should be deepened. All parties should work together to promote the industrialization of scientific and technological achievements and provide innovation support for the high-quality development of emerging industries in the GBA.

First, innovative entities should be supported in setting up technical transfer agencies for the GBA. Support should be given to universities and scientific research institutions in the Bay Area in setting up technology transfer institutions. Universities, scientific research institutions, enterprises, and public institutions outside the Bay Area should be encouraged to establish technology transfer institutions within the region. Furthermore, the rapid development of emerging industries in the GBA should be supported through the large-scale industrial transformation of cutting-edge scientific research achievements.

Second, an international pilot service platform base should be built. It should be planed and built centered on scientific research achievements in circuits, new materials, medical devices, and so on. It is necessary to gather service resources from authoritative inspection and testing institutions, certification and accreditation institutions, standardization organizations, and other services in China and abroad; provide public services, such as inspection and testing, certification, qualification, and measurement and calibration, for emerging industries in the GBA; and accelerate the industrialization, promotion, and application of scientific research achievements.

Third, talent teams of technical managers should be strengthened. Educational authorities should encourage universities in the GBA to set up professional master's degrees to train professional and technical managers. Based on universities in the GBA, large amounts of technical manager training bases will be built through school–enterprise cooperation. Researchers from universities and research institutions should be encouraged to engage in brokerage and intermediary work for the industrialization of scientific and technological achievements, thus, gradually enlarging the talent team in the technology market.

Fourth, an achievement transformation pattern of "Hong Kong and Macao incubation + Guangdong industrialization" should be formed. Hong Kong and Macao have taken leading positions in basic R&D and industrial application technologies in multiple fields. With a broad market and a complete industrial chain, the PRD could form a new pattern of "Hong Kong and Macao incubation + Guangdong industrialization," which will effectively promote not only the manufacturing industry of the PRD from the middle-low level to the mid-to-high end in the global industrial and value chain, but also the optimization of the economic structure of Hong Kong and Macao.

5.3 Fostering world-class emerging industry clusters

The GBA has formed an NGIT industrial cluster on the east bank of the Pearl River as the core and high-end equipment manufacturing industrial cluster on its west bank, but the advantageous emerging industries are still "choked." The leading effect of these clusters has not been manifested because of the lack of guidance from world-class enterprises. Therefore, the GBA should accelerate the cultivation of world-class emerging industry clusters and help build an essential source of global emerging industries.

To achieve this, the GBA must first consolidate and enhance the global influence of competitive emerging industries. Focusing on competitive emerging industries, such as NGIT, high-end equipment manufacturing, new materials, biomedicine, and new energy, the GBA should endeavor to increase the supply of resources and form world-class emerging industry clusters with complete industry and supply chains, in stages (Table 2).

Second, classified measures should be taken to build a unicorn company cultivation platform. According to different industrial types, unicorn company cultivation policies should be formulated in line with the development laws of emerging industries, and competitive enterprises should be supported to go global with high quality and participate in the division of labor and standards formulation for global emerging industries at a higher level to reflect their internationalization, influence, and communication level.

Third, focusing on competitive emerging industries, state-owned S&T, enterprise groups should be set up. Based on the existing classified management framework of commercial state-owned enterprises and public welfare state-owned enterprises, a new state-owned asset management system should be established to support the development of state-owned S&T enterprises, and new paths should be sought in asset pricing and exit mechanisms, assessment and evaluation mechanisms, and incentive and restraint mechanisms. It is imperative to implement the due diligence and compliance exemption mechanism and encourage state-owned S&T enterprises to build long-term and patient

capital to implement medium- and long-term national strategies. State-owned S&T enterprises should take the lead in tackling the problems in key and core technologies, such as AI, biomedicine, high-end chips, new materials, and new energy vehicles, and shoulder the responsibility as the master of the industrial chain, to strengthen the coordination of upstream and downstream industries and drive the coordinated development of small, medium, and micro enterprises.

Fourth, the construction path of a Greater China Economic Zone in the GBA should be explored. The industrial linkage with the Hainan Free Trade Port, Beibu Gulf City Cluster, the Economic Zone on the west coast of the Taiwan Straits, and Taiwan should be strengthened. The GBA should be developed into a modern hub that integrates goods, services, digital, offshore, and green trade development, and an exploring path developed for the Greater China Economic Zone, as proposed in the *Regional Comprehensive Economic Partnership*.

Table 2. Key development directions of emerging industries in GBA.

Emerging industries	Key development directions
AI	AI algorithms, machine learning, quantum computers, autonomous driving cars, virtual reality, soft motor control devices, automatic detection and estimation systems, brain-like learning, virtual reality simulation, etc.
Communication	The fifth-generation mobile communication technology, Blockchain, high-speed data services, digital finance, optical fiber technology, flash memory chip technology, unified payment, etc.
Advanced manufacturing	IoT, additive manufacturing, quantum computing, Industry 4.0, Digital rail transit, smart factory, fuel cell technology, carbon fiber, graphene, etc.
New materials	High-precision rapid laser imaging, thermoplastic elastomer materials, perovskite thin film, perovskite solar cell, optical fiber patch technology, industrial water corrosion prevention technology, particle size measurement technology, atomic layer deposition thin film, silicon-based material technology, etc.
Biomedicine and health	Digital medical treatment, chimeric antigen receptor T-cell immunotherapy, gene editing, biopharmaceutical, immune cell therapy, gene therapy, artificial pancreas, antibody imaging technology, heart monitor, compound preparations, tumor immunotherapy, etc.
Environment and energy	Solar farms, Powerpack systems, fusion technology, crustal plate, green biosphere, advanced hydroponic systems, thermal energy, energy-saving buildings, carbon capture technology, wind turbines, clean energy, renewable technology, offshore oilfield development, lithium battery technology, etc.

5.4 Building a gathering venue for outstanding talents in China and abroad

Talents are the subjects and support for building the GBA into an international S&T innovation center. Building an S&T innovation highland is key to attracting outstanding talent in China and abroad, focusing on basic research, and tackling key technologies. Therefore, we should innovate the development of higher education, improve the system of S&T innovation talents, create an environment conducive to the training and gathering of outstanding global talent, and construct the GBA into a prominent talent highland with global influence and attraction, an international talent-free port, an international first-class education demonstration zone, and a benchmark for higher education innovation clusters.

First, the formation of world-class higher-education innovation clusters must be promoted. According to the development characteristics and differentiated function orientation of universities in Guangdong, Hong Kong, and Macao, mainland China will serve as a strategic hinterland and industry–university cooperation base for universities in Hong Kong and Macao, while Hong Kong and Macao will be built into a hub and medium for mainland China to introduce international first-class intelligence and resources.

Second, talents can be recruited with the help of international headhunting enterprises. It is necessary to gradually establish an international talent information database, formulate a “database of potential employees for China,” contact and cultivate overseas headhunters, and improve the efficiency of precise and efficient talent introduction in the GBA.

Third, an integrated talent operation system should be established for Guangdong, Hong Kong, and Macao. The GBA Talent Card and GBA Talents Plan should be implemented to form an international free port for talent in the GBA. A talent-bonded zone should be built to eliminate barriers in tax, entry, and exit, and practice qualification in the bay area.

Fourth, international blocks should be built. It is suggested to select large amounts of regional pilots for constructing international blocks in batches and form a one-stop management and service platform for overseas talent to provide convenient and efficient foreign-related public management and services. It is necessary to explore

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new mechanisms for the diversified supply of public services, improve the internationalization of public services, and create a suitable working and living environment.

Fifth, a new team-oriented evaluation mechanism for scientific and technological talent should be established. It is difficult to make breakthroughs in rapidly evolving emerging technologies. Carrying out key and core technologies and breakthroughs through teamwork and better gathering the wisdom of researchers conforms to the objective law. Thus, talent evaluation should shift from being individual-oriented to team-oriented. Pilot work could be carried out in universities and scientific research institutions in the GBA to reform the talent evaluation mechanism, highlight the actual contribution of talent in the scientific research team, and recognize and respect the performance appraisal conducted by the team leaders of the team members. Relevant restraint measures should be implemented simultaneously to ensure the steady implementation of the evaluation reform.

5.5 Promoting the deep integration of finance and technology

With abundant innovative resources, such as finance, enterprise, social culture, scientific and technological talents, a dynamic private economy, a complete industrial chain, and rich financing and innovative conditions, the GBA could create beneficial conditions for R&D, production, and marketing, and facilitate the coupling effects of finance and S&T. Nowadays, finance in the GBA is insufficient for the S&T industry; hence, a solid financial system must be built to firmly support the development of the clusters of the S&T industry.

To do this, an S&T and financial ecosystem must first be constructed for the GBA. Based on a diversified S&T financing market, the S&T and financial ecosystem should integrate venture capital with the S&T innovation cooperation center and actively apply venture capital to leverage the transformation of S&T innovation achievements. Focusing on the gathering trend of global venture capital, the GBA should capture the venture capital trend of leading technology enterprises and the unicorn companies, and promote the sound and efficient development of venture capital venture networks. Drawing on the professional advantages of Hong Kong, the business platforms represented by the Shenzhen Qianhai Equity Exchange Center should be gathered to establish a unified private equity over-the-counter (OTC) market based on professional certification and hierarchical operation in the GBA. A board transfer association mechanism should be established between the Bay Area private equity OTC market and the domestic new OTC, growth enterprise market (GEM), small- and medium-sized board market, and GEM and mainboard market in Hong Kong.

Second, S&T banks in the GBA should be set up. The governments of Guangdong, Hong Kong, and Macao can invite policy banks, commercial banks, state-owned enterprises, and private enterprises to jointly establish and invest in the GBA Science and Technology Bank. Targeting start-up and high-growth tech enterprises, the GBA should establish business processes and audit standards that meet the needs of S&T enterprises, expand the scope of intellectual property pledge financing, and strengthen the supply of S&T credit.

Third, the unique advantages of Hong Kong's financial system should be fully exploited by making use of the low cost and high efficiency of the Hong Kong International Financial Center in cross-border financing, eliminating regulatory constraints, and making new reasonable institutional arrangements in compliance with relative regulations within the GBA. Current national foreign exchange controls should be broke to realize the free flow of cross-border trade funds and facilitate the smooth flow of overseas capital into the GBA.

Fourth, a hybrid investment fund system should be built for small, medium, and micro technology enterprises. Relying on the resources and experience of the existing equity investment platform in the GBA, we should optimize the geographical advantages of Guangzhou and Shenzhen as regional financial centers, attract overseas funds in Hong Kong and Macao by encouraging state-owned enterprises to invest first, build a dynamic fund system, and support the full life cycle development of small, medium, and micro technology enterprises. In particular, at the "death valley" stage and high-risk stage of small, medium, and micro enterprises, other social capitals are unwilling to invest. The marketing-oriented support and assistance led by state-owned capital (when appropriate, exit from the relevant enterprises after further development and expansion) will help overcome this and create a virtuous cycle of S&T and industrial innovation in the GBA.

5.6 Establishing a diversified collaborative mechanism for science and technology innovation investments

S&T innovation and emerging industries entail capital-intensive industrial activities. Thus, high-quality development inevitably requires a large amount of capital investment. Government investment should play a leading role, but the GBA cannot rely solely on it when its funds are limited. Therefore, it is essential to improve the diversified investment mechanism of S&T innovation and the development of emerging industries, and stimulate the

enthusiasm of social subjects to participate in the construction of S&T innovation undertakings in the GBA.

Hence, the GBA must first implement a R&D framework plan. Projects in Guangdong, Hong Kong, and Macao that have been discussed and need to be researched and developed will be submitted to the R&D framework plan. The world's top talents and teams will be attracted to participate in their R&D through public bidding and targeted entrusted research. Meanwhile, scientific research achievements can be shared to different degrees according to the investment situation [15].

Second, the GBA should encourage enterprises to increase their independent scientific research investment with the government–enterprise linkage system. Enterprises in the GBA will be encouraged to jointly set up technology R&D funds and apply the benefits generated by the funds to fund scientific research institutes or enterprises through market-oriented operations. For scientific research institutes or enterprises, the GBA could apply the government guidance fund in the R&D framework plan to invest in varying proportions according to the importance, frontiers, and return rate of technology R&D projects to reasonably reduce the cost of S&T innovation of market entities.

Third, conditions need to be created for the third distribution to play a greater role. The practice of China's social donations to support S&T innovation has just begun. Therefore, the GBA should further improve tax incentives and supporting policies, mobilize the enthusiasm of all parties, and encourage society to inject funds into the GBA R&D framework plan through donations.

5.7 Exploring a mechanism for innovation and the flow of industrial factors

The flow of people, funds, equipment, information, and technology among Guangdong, Hong Kong, and Macao is blocked because of differences in economic and cultural backgrounds and social systems, and their high coordination costs. Deepening the construction of the GBA is key to removing the barriers of industrial factors in the GBA and tackling the problem of the free circulation of industrial factors [16].

To achieve this, first, it is important to create a more coordinated, open, and free business environment. Other cities in Guangdong Province in the bay area should follow the business environment of Guangzhou and Shenzhen and strive to form an undifferentiated and unified inland urban business environment in the GBA. Guangdong province should take the initiative to enhance synergy with the business environment of Hong Kong and Macao, and break the mechanism mode that restricts the circulation of factors.

Second, the GBA should facilitate the upgrading of the Guangdong Free Trade Zone. This could be incorporated into the Dongguan Binhai Bay New Area and Zhongshan Cuiheng New Area to connect the Nansha, Qianhai (Shekou), and Hengqin free trade zones, forming the core area of the GBA. We should further expand the scope of market access to foreign investment, open financial institutions to the outside world, and create an international, convenient, and equitable environment for development.

Third, business endorsement-facilitation policies based on credit supervision should be promoted. It is necessary to build a public credit platform for the GBA and improve the credit data of scientific research institutions, enterprises, and individuals in the GBA to provide convenient business filing services for institutions, enterprises, and talent. Referring to the filing conditions of Shenzhen for vehicles, people should apply according to their demand, without a limitation on their number, and business filing and registration consistent with the time limit for qualification recognition should be implemented (up to three years).

Fourth, a "double Y" scheme should be explored and implemented for Shenzhen to cross the Hong Kong–Zhuhai–Macao Bridge. It is suggested to explore and implement the channel from Shenzhen to Zhuhai and Macao via the Hong Kong–Zhuhai–Macao Bridge and give full play to the connecting role of the Hong Kong–Zhuhai–Macao Bridge. If the Hong Kong–Zhuhai–Macao Bridge changes from "single Y" to "double Y," the corresponding lines will pass through the Northern Metropolitan Area under construction in Hong Kong, which could connect to the west bank of the PRD. This will promote the integration of Shenzhen and Hong Kong into a super metropolis and provide greater possibilities and better development conditions for constructing the GBA into a global Silicon Valley.

Fifth, the GBA should optimize and innovate the policy of hierarchical management by piloting it in the Hetao–Shenzhen–Hong Kong S&T innovation Cooperation Zone and the Hengqin–Guangdong–Macao In-depth Cooperation Zone. It should boldly take the lead in exploring innovative policies and measures for coordinated S&T innovation, emerging industry clusters, global talent gathering, fintech, and a unified digital market to promote a convenient and effective flow of innovation factors. These measures should be promoted when conditions are favorable to create a model for developing the GBA into an open, integrated, and sustainable global innovation center and industrial highland.

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6 Conclusions

Based on the development foundation and strategic positioning of the GBA, the S&T innovation and emerging industry target for the medium- and long-term development of the GBA is to construct a borderless GBA with integrated and orderly S&T innovation development. To promote the integrated development of S&T innovation, the GBA should comprehensively accelerate the construction of an open, integrated, and sustainable global innovation and industry highlands. This study advances key tasks and suggestions for S&T innovation, achievement transformation, emerging industries, innovative talents, S&T finance, S&T innovation investment, and the flow of factors, to provide a basic reference for the implementation of the medium- and long-term development strategies of S&T innovation and emerging industries in the GBA.

With the implementation of major national strategies, S&T innovation and emerging industries in the GBA are facing a new development situation. For example, the two-city economy of "Hong Kong + Shenzhen" and "Macao + Zhuhai" has emerged; the establishment of the Beijing Stock Exchange will have a multi-level and complex impact on the GBA; the common prosperity goal of China will further stimulate the innovative vitality of social capital in the Bay Area. Meanwhile, there is a strong demand for the distinctive development of the GBA. The free flow of resource factors must break the barriers of the "two systems" in the field of S&T innovation. National major projects/equipment R&D and "bottleneck" technologies need to be constantly vitalized, and the further expansion of global opening-up and pilot projects should be empowered. In the face of the new development situation and unique strategic needs, theoretical research on S&T innovation and emerging industries in the GBA must be continuously followed up and improved to provide basic support for the development of national S&T innovation and enhance global industrial competitiveness.

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