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ORIGINAL ARTICLE

Study on the Diffusion Characteristics of Science and Technology Innovation Policies in Guangdong-Hong Kong -Macao Greater Bay Area Based on the Policy Quantification Perspective

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Abstract

Amidst escalating global competition in science and technology and China's economic transformation, it is crucial to quantify the effectiveness of science, technology, and innovation (STI) policies in the Guangdong, Hong Kong, and Macao Greater Bay Area (GBA). This region plays a strategic national role and significantly contributes to China's economic growth. This study investigates the evolution of STI policies administered by central and local governments in the GBA from 2016 to 2022, employing text mining technologies in Python and Latent Dirichlet Allocation (LDA) modeling for policy quantification and diffusion analysis. The findings indicate a predominant top-down diffusion pattern of STI policies, with an increasing responsiveness of lower-level governments to higher-level directives. Although these policies are progressively refined through the diffusion process and exhibit distinct temporal characteristics, there is a notable lack of bottom-up policy feedback. This research offers a novel perspective on STI policy analysis in the GBA and provides valuable insights for future policy formulation, aiming to enhance the overall STI policy framework in the region.

Introduction

With the intensification of global competition in science and technology, science, technology, and innovation (STI) have become the principal drivers of national economic growth, essential for industrial transformation, productivity enhancement, and product quality improvement[1, 2]. Regional STI not only underpins regional economic growth and core competitiveness, but also secures a country's leading position in the global STI landscape[3, 4]. The emergence of "innovation corridors"—regions characterized by abundant innovation resources and vibrant economic activities—exemplifies this global innovation trend and underscores their pivotal role in boosting regional and national economic development. Therefore, strengthening regional STI is a widely adopted strategic response to global competition and escalating uncertainty [5]. In this context, quantifying the diffusion effects of STI policies is critical to providing a scientific foundation for future policy enhancement.

The scholarly investigation into STI policies traces its roots to Schumpeter's (1934) theory of innovation[6]. However, the absence of quantifiable data in policy texts has impeded the development of structured frameworks for policy text analysis. Rothwell and Zegveld introduced a policy-based approach to evaluate policy performance [7], and in 1989, the General Accounting Office (GAO) of the United States pioneered content analysis, standardizing information collection to describe and quantify profiles[8]. Policy diffusion theory, initially proposed by American scholar Walker[9] and later refined by British researcher Rogers, highlights the role of communication and idea

exchange in promoting policy innovation[10]. As research in policy innovation and diffusion has advanced, various models have emerged, including the national interaction model, regional diffusion model, leader-laggard model, and vertical influence model[11, 12]. However, existing studies primarily focus on evaluating the performance of STI [13, 14], analyzing influencing factors[15-17], and examining spatial pattern differentiation[18, 19]. For example, Cai's 2018 study utilized patent technology transaction data to analyze the agglomeration characteristics and spatial polarization of innovation factors in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA), identifying a "two-tiered and two-strong" pattern and proximity advantage[20]. In addition, other researchers have also explored the impact of STI on regional green economies[21, 22]. For example, Cao used a Data Envelopment Analysis (DEA) model to quantify the intensity of innovation investment and green efficiency of cities within the GBA between 2000 and 2017. The findings indicated that an increase in the intensity of innovation investment correspondingly enhanced the green economic efficiency of these cities[23]. Nonetheless, most studies on STI in urban economies have centered on performance assessment, utilizing innovation indicators to gauge the extent of STI. These indicators often relate to unobservable factors potentially correlated with the explanatory variables of the model, introducing endogeneity issues and resulting in biased measurements. Policy remains the fundamental driver of scientific and technological innovation.

Amid rapid advancements in information technology, traditional event history analysis methods are merging with computer simulation, econometric models, and big data tools to develop new approaches for studying policy diffusion[24, 25]. The topic model, a pivotal text mining tool, effectively organizes, comprehends, and summarizes vast quantities of text data, a feat challenging to achieve manually[26]. Among the various topic models, the latent Dirichlet allocation (LDA) is the most prevalent. The LDA-based topic modeling technique is extensively applied across multiple fields, including natural language processing, text mining, and information retrieval. The LDA model can distill a set of topics pertinent to an entire document corpus and is particularly useful for multi-topic documents[27]. Given the multifaceted nature of science and technology innovation policies, the LDA model can adeptly explore the thematic characteristics of such policies.

The advancement of regional scientific and technological innovation is largely contingent on policy support, particularly in countries like China, which embraces a dual-track resource allocation system involving government and market co-governance[28]. Government interventions significantly influence regional scientific and technological innovation activities. Measures such as financial subsidies[29], fostering an innovative environment[30], and talent attraction[31] can enhance the innovation capabilities of specific regions. In recent years, the Chinese government has enacted numerous policies to foster the scientific and technological innovation sector, significantly elevating the contribution of these innovations to economic growth. By 2022, scientific and technological innovation contributed 60% to China's economic expansion[32].

Current research on the science and technology innovation policies of the Guangdong-Hong Kong-Macao GBA remains inadequate, particularly regarding the text-driven quantitative analysis of policy diffusion characteristics at central and local levels. To elucidate the diffusion effects of central and local science and technology policies, this study adopts a policy-oriented approach to conduct an in-depth analysis of policy texts in the GBA, aiming to enhance effective evaluation and prediction. The main objectives of this study are as follows: (1) Assess the current state of STI policies in the GBA, applying text mining techniques to analyze policy content; (2) Employ the unsupervised learning LDA model for the first time to extract themes from STI policies in the GBA, integrating this with policy diffusion theory to enrich the body of research in this domain; (3) Examine the characteristics of STI policy diffusion between the central and local governments within the Guangdong-Hong Kong-Macao GBA, particularly in the context of "one country, two systems," and identify discrepancies between the policies of the Hong Kong and Macao governments and those of the mainland; (4) Condense and compare the concerns and focuses of STI policies in the GBA, providing a reference for future policy formulation. This

analysis will aid in delineating the thematic distribution of scientific and technological innovation policies, tracing their evolutionary trajectory, and objectively assessing the alignment between policy and practice. Consequently, it will offer crucial insights for crafting a new round of STI policies in the GBA.

Materials and Methods

Study Area

Recent restructuring of urban clusters has been a significant component of China's regional development strategy. The Guangdong-Hong Kong-Macao GBA, ranking as the fourth global bay area after the Los Angeles Bay Area, New York Bay Area, and Tokyo Bay Area, includes nine cities in the Pearl River Delta along with the two Special Administrative Regions of Hong Kong and Macao. Situated on the southern coast of China (longitude 111°21′–114°53′ E, latitude 21°28′–24°29′ N), it spans 56,100 square kilometers and boasts a population exceeding 80 million. Characterized by a robust industrial system, prominent innovation resources, and a superior economic stature, the GBA stands as one of the most dynamic zones for innovation activities in China. In 2021, the total R&D spending in the Pearl River Delta's nine cities reached $53.154 billion, surpassing that of 30 provinces, with an R&D expenditure intensity of 3.8%, trailing only behind Beijing and Shanghai among the 31 provinces. Additionally, the Guangdong-Hong Kong-Macao GBA, as the first bay area globally developed under the “one country, two systems, three customs territories, and three currencies” framework, uniquely explores new mechanisms for regional STI development, continuously pushing forward as a beacon of institutional innovation, reform, and openness.

Data Sources

This study gathers data on STI policies relevant to the Guangdong-Hong Kong-Macao GBA from various sources including the official websites of Peking University Fabulous (https://pkulaw.com), and the Ministry of Science and Technology of the People’s Republic of China (https://www.most.gov.cn/satp/). By analyzing policies issued by the central government, provincial and municipal authorities, as well as Hong Kong and Macao from 2016 to 2022, a selection was made of 15 national-level policies from the central government and ministries, 53 provincial policies, 194 municipal policies, and 30 legislative acts from Hong Kong and Macao. The selection process involved excluding returns, policy interpretations, and duplicate categories while also considering the timeliness and relevance of policy content.

Methodology for Quantifying Policy Texts

The LDA model, introduced by Blei et al. in 2003[41] serves as a quantitative analytical method for content analysis. This topic modeling technique views topics as probability distributions over lexical items and documents as compositions of these topics, each characterized by distinct probabilities. The LDA model, which merges Bayesian theory with the Dirichlet distribution, is recognized as an effective tool for natural language processing. This methodology facilitates highly automated text analysis through machine learning and text mining techniques, excelling in processing large-scale policy datasets and conducting quantitative policy research[33] [**Error! Reference source not found.**].

Consequently, this study employs the unsupervised learning LDA model to extract themes from science and technology innovation policy texts at both the central and local levels within the Guangdong-Hong Kong-Macao GBA. By segmenting the texts and organizing key terms, the study elucidates the distinctive characteristics of central and local policy documents. However, because unsupervised learning models rely solely on automatic computer analysis, issues such as model overfitting and data misinterpretation may arise [40]. To address these challenges, this paper introduces a ‘confusion index’ to determine the optimal number of topics, thereby enhancing the accuracy and reliability of the analytical results. The document generation process includes: (i) For each document d, select the topic probability distribution θ, and $\theta \sim P(\theta|\alpha)$; (ii) From θ, draw a topic z, and $z \sim P(z|\theta)$; (iii) Draw a word w from the topic’s distribution ϕ of the topic z, and $w \sim P(w|z, \beta)$; (iv) Repeat (iii) and (iv) for each word in the document. In this model, θ and ϕ have Dirichlet prior with hyper-parameters α and β, respectively, where w is the observed variable, z and θ are hidden variable. The document representation in lexical space is transformed into a topic space representation

through the selected parameter estimation algorithm.

The specific process of topic identification by the LDA model is shown in Fig. 1:

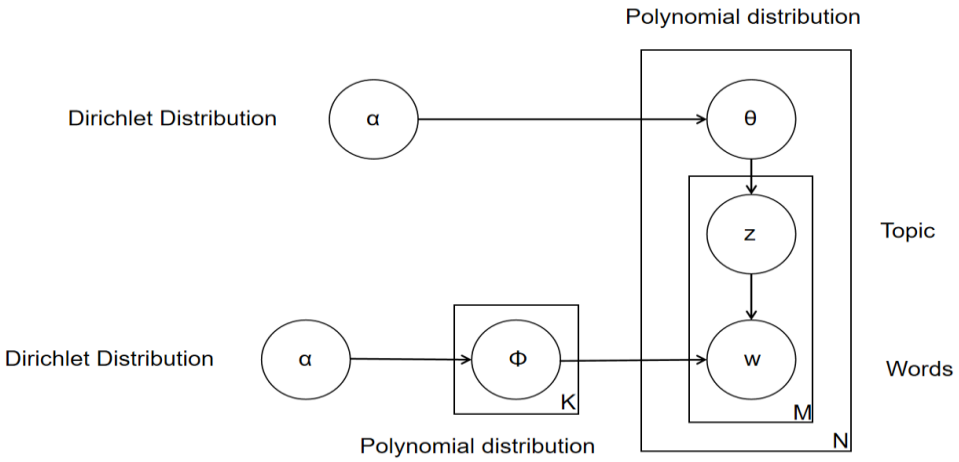

Figure 1 LDA Model Process (α and β represent the prior distribution parameters for topic distribution ϕ and word distribution β, respectively, z and w denote the topics and words generated by the model, N represents the number of documents, and M the number of words in the documents, respectively).

In operating the model, it is necessary to preset the number of topics to determine the optimal number. This study employs a perplexity-solving model developed in Python to ascertain the optimal number of topics, with the perplexity formula presented as follows:

$$\text{Perplexity}(D)=\frac{-\sum_{i=1}^{N}\ln(P(w_i))}{\sum_{i=1}^{N}M_i}$$

Perplexity indicates the uncertainty of the topic to which the document belongs; the smaller the perplexity, the better the identification of the optimal number of topics. However, if the number of topics is too large, the model will be overfitted. Generally, if Q is the point where the perplexity reaches its minimum, then Q is the optimal number of topics k. If the difference in perplexity between this point and the previous point is significant, and the difference between this point and the next is minimal, or if the perplexity remains relatively stable after Q, then k corresponds to the optimal number of topics.

Meanwhile, this study employs the pyLDAvis package in Python for clustering and visualizing the recognition results of the LDA topic model. The clustering and visualization results are beneficial for mining and analyzing topics and Validating the effectiveness of the optimal number of topics determined by the perplexity model. In addition, this study extracts high-frequency words from policy texts issued by the central government, Guangdong Province, the cities within the province, as well as Hong Kong and Macao, and counts their frequencies by writing Python programs in the data preprocessing stage. Furthermore, this study utilizes the word cloud library (wordcloud) in Python to create word cloud maps, which provide more intuitive mining and analysis of policy text information.

In summary, the study in this study can be divided into three steps: The first step involves organizing and summarizing the policy texts with statistics, formatting and editing the text, using Python for word segmentation and regular expressions to clean the text, adopting a Chinese deactivation word list and HITC deactivation word list for word deactivation processing, extracting high-frequency vocabulary, and generating word cloud diagrams; The second step involves constructing the lexicon vector matrix for the finished text, constructing the LDA model, determining the parameters, and executing the LDA model through Python to generate the topic data; The third step uses the data model, summarizes the text themes, mines theme information, visualizes the LDA theme model using Python, and interprets the results of the text analysis (Fig. 2).

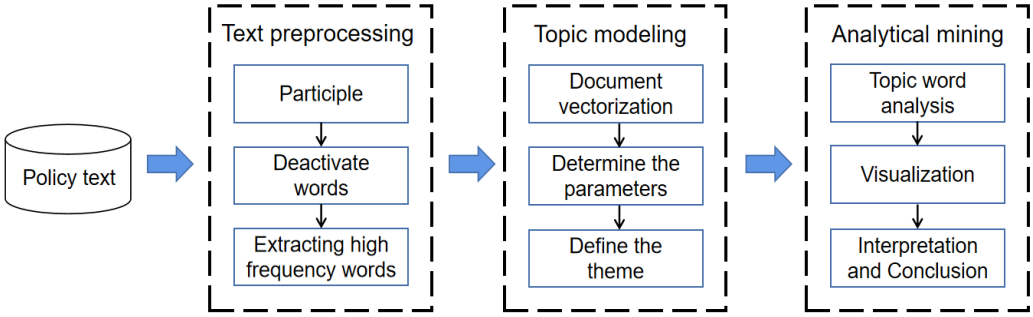

Figure 2 LDA Thematic Modeling Analysis Framework

Results and Analysis

Status of STI Policies in Guangdong-Hong Kong-Macao GBA

STI policies within the Guangdong-Hong Kong-Macao GBA play a pivotal role in driving and enhancing STI development. Both central and local governments place significant emphasis on STI initiatives within the GBA, contributing to its emergence as a leading STI hub.

From a hierarchical perspective, the central authorities involved in policy introduction range from the Communist Party of China Central Committee to the State Council, Ministry of Science and Technology, Ministry of Finance, and six additional departments. Meanwhile, provincial-level contributors include the Guangdong Provincial People's Congress, the Provincial Government, the Department of Science and Technology, the Department of Finance, the Development and Reform Commission, and the Department of Human Resources and Social Security. This collective, comprising scientific, technical, and financial sectors, operates interdependently to facilitate STI policy synergy. As illustrated in Fig 3, provincial STI policy introducers reflect a dual hub-and-spoke network, with the Guangdong Provincial Department of Science and Technology serving as the primary core and the Guangdong Provincial Department of Finance as the secondary core. To accurately gauge the impact of the Guangdong Provincial Department of Science and Technology and the Guangdong Provincial Department of Finance within the network system, we employ degree centrality and proximity centrality as key indicators. Degree centrality measures the number of direct connections to the node, with a higher value indicating more extensive connections. Conversely, proximity centrality assesses a node's ability to control relationships among other nodes in the network. A higher proximity centrality value suggests greater influence over and control of sectoral relationships[34]. As shown in Table 1, both departments are leaders in degree centrality and proximity centrality, underscoring their pivotal role in STI policy synergy in the GBA and their substantial capacity to shape STI policies.

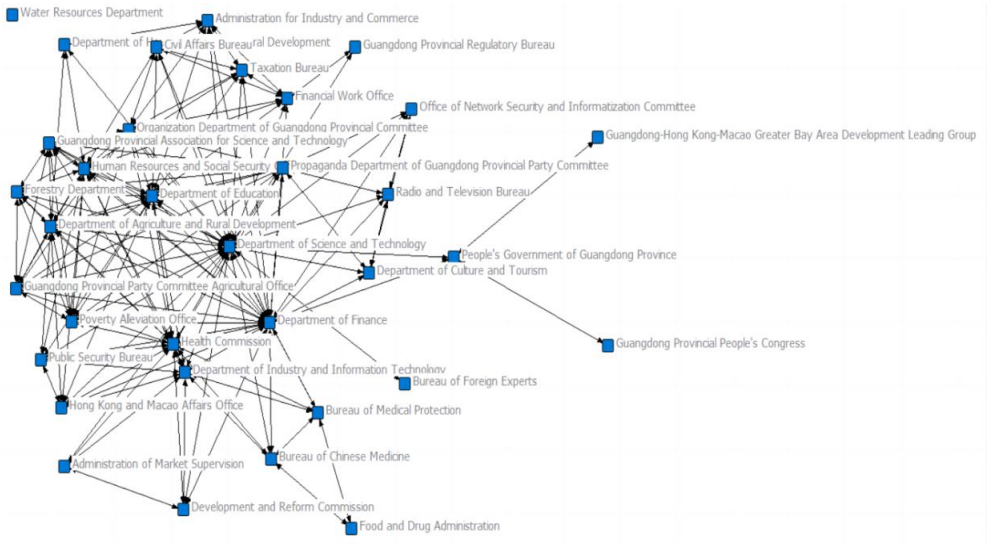

Fig. 3. Social network map of provincial STI policy introduction departments

Table 1 Degree centricity and tight centricity in each sector

Department	degree centrality	closeness centrality
Department of Science and Technology	70	47.826
Department of Finance	54	45.205
Human Resources and Social Security Office	32	39.759
Health Commission	28	40.244
Department of Education	27	39.759
Department of Agriculture and Rural Development	21	37.931
Organization Department of Guangdong Provincial Committee	19	38.372
Department of Industry and Information Technology	18	37.079
Propaganda Department of Guangdong Provincial Party Committee	16	37.931
Guangdong Provincial Party Committee Agricultural Office	14	36.667
Poverty Alleviation Office	14	36.667
Forestry Department	13	36.667
Financial Work Office	12	35.87
Guangdong Provincial Association for Science and Technology	11	36.667
Development and Reform Commission	9	36.667
Public Security Bureau	8	35.484
Civil Affairs Bureau	8	35.484
Hong Kong and Macao Affairs Office	8	35.484
Taxation Bureau	8	35.484
Administration for Industry and Commerce	8	35.484
People's Government of Guangdong Province	8	34.737
Bureau of Chinese Medicine	6	35.106
Bureau of Medical Protection	6	35.106
Department of Housing and Urban-Rural Development	5	34.021
Office of Network Security and Informatization Committee	5	34.375
Department of Culture and Tourism	5	34.375
Radio and Television Bureau	5	34.375
Administration of Market Supervision	4	34.021
Food and Drug Administration	2	26.613
Guangdong Provincial People's Congress	2	26.19
Guangdong Provincial Regulatory Bureau	2	33.333
Bureau of Foreign Experts	1	33
Guangdong-Hong Kong-Macao GBA Development Leading Group	1	26.19
Water Resources Department	0	0

During the data collection stage, we attempted to categorize the policy texts manually. It was determined that the contents of STI policies from the central government, Guangdong Province, and the municipalities including Hong Kong and Macao, could be broadly categorized as follows: regional cooperation, scientific and technological achievement transformation, scientific personnel development, STI, support for science and technology enterprises, innovation within scientific and technological systems, primary research, and safeguarding services for scientific and STI activities (Table 2). The scope of STI policies has continuously expanded over time, enriching its inherent meaning. Current STI policies in the Guangdong, Hong Kong, and Macao GBA adopt a balanced approach. Supply-oriented policies encompass areas such as science and technology infrastructure development, funding for science xand technology, technological research, development of scientific and technological talents, and the conversion of achievements. Meanwhile, environmental policies focus on tax benefits for science and technology enterprises, intellectual property rights protection, and innovation within science and technology systems. Conversely, demand-oriented policies include the declaration of science and technology projects and scientific and technological cooperation. Notably, the majority of the GBA's STI policies are supply-oriented.

Table 2 Highlights and key elements of STI policies across sectors (provinces and municipalities)

Policy main-points	**Main content**
Regional cooperation	"One core, one belt and one district" for innovative and coordinated development, the flow of STI elements in the GBA, the Hengqin Guangdong-Macao Deep Cooperation Zone; Guangzhou- Shenzhen "two city linkage," the Guangzhou-Shenzhen-Hong Kong-Macao Joint Innovation, the "Guangzhou-Shenzhen-Hong Kong-Macao," "Guangzhou-Shenzhen-Hong Kong," "Guangzhou-Zhuhai-Macao" STI Corridor Construction, the promotion of the Nansha Guangdong-Hong Kong-Macao Comprehensive Cooperation Demonstration Zone, the Guangzhou-Foshan STI Cooperation, and the Foshan-Shunde Collaborative Development Cooperation Zone.
Transformation of scientific and technological achievements	Intellectual property protection, Scientific research achievements property rights system, Improve the evaluation mechanism of scientific and technological achievements, National scientific and technological achievements incubation base, the formation of the technical standard alliance, Guangdong-Hong Kong-Macao youth entrepreneurship and employment base; international technology transfer, technology promotion, technology trading market, scientific and technological achievements disposal right denationalization, Optimization of the distribution of scientific research rights and interests.
Construction of scientific and technological talents team	The reform of technical personnel title, the introduction of "high-precision and short-sighted" talents, incentive system for scientific research personnel, optimization of scientific research funding system, training system for scientific research personnel, improvement of foreign talent system, exchange and cooperation of talents, optimization of talent treatment, STI correspondent.
STI	Strong core engineering, core software research, a new generation of artificial intelligence, high-end equipment, intelligent manufacturing, agricultural modernization digitization, modernization of traditional Chinese medicine, high-end medical equipment, new energy, new materials, big data, cultural and STI, green and low carbon.

Basic research	Major scientific research laboratory construction, national super computing center construction, national gene bank phase II construction, human cell lineage device, intelligent dynamic wide-area hypersonic wind tunnel construction, Jiangmen neutrino experimental station construction, essential research fund management.
Industrialization of technology	University Science Park, Technology Business Incubation System, Technology Collaborative Innovation Alliance, High-tech Industry Demonstration Zone, Industry-University-Research Collaborative Innovation Mechanism Optimization, Industrial Cluster Transformation and Upgrading.
STI guarantee service	STI reward system reform, STI development special fund, scientific research personnel burden reduction measures, STI land management measures, STI enterprise tax relief, STI enterprise special support fund, STI investment and financing system, STI project application optimization, scientific research integrity, STI plan supervision and evaluation system.

Analysis of high-frequency vocabulary in policy texts

Following the segmentation and removal of superfluous words from the aggregated policy texts, high-frequency words are identified based on their occurrence count. Word cloud visuals of STI policies at the national, provincial, municipal, and Hong Kong and Macao levels are created (Fig. 4), accompanied by a ranking of the top 20 most frequent terms (Table 3). A comparative analysis shows that, excluding specific policy attribute words such as "STI," there is a high recurrence of terms like "construction," "development," "enterprise," "project," "research and development," and "talent" across all four levels. The frequent appearance of these terms indicates notable similarities and shared themes in how STI policies are articulated across different levels.

Figure 4 The text WordCloud map of STI policy in GBA

Table 3 A high-frequency vocabulary of STI policy texts in the GBA

Number	National level		Provincial level		Municipal		HK & Macao	
	Word	**Frequency**	**Word**	**Frequency**	**Word**	**Frequency**	**Word**	**Frequency**
1	Innovation	177	Innovation	2218	S&T	9755	Plan	953
2	S&T	124	Program	1849	Innovation	9430	S&T	849
3	Construction	117	Construction	1455	Enterprise	6963	Funding	825
4	Support	84	Development	1406	Project	6748	R & D	730
5	Development	70	Enterprise	1376	Development	5028	Enterprise	607
6	Shenzhen	53	Technology	1179	Construction	4085	Project	510
7	Guangdong Hong Kong - Macao	43	Research	979	Technology	3894	Technology Entrepreneurship	450
8	Technology	43	Project	860	Industry	3649	Fund	442
9	International	42	Industry	811	Service	2854	Innovation	431
10	Transformation of results	41	R & D	732	R & D	2776	Development	422
11	Institution	41	Institution	704	Support	2759	STI Park	420
12	Hong Kong and Macao	41	Talents	645	Institution	2442	University	317
13	Artificial intelligence	40	Service	616	Talents	2254	Technology	292
14	Industry	39	Entrepreneurship	569	Platform	1992	Investment	278
15	Cooperation	38	Platform	532	Industry	1817	Institution	262
16	Talents	36	Artificial intelligence	529	Funds	1777	Support	256
17	S&T achievements	34	Basic Applications	521	S&T achievements	1683	Science	219
18	Intellectual property rights	31	STI Center	502	Cooperation	1630	Research	215
19	Mechanism	31	S&T	450	Declare	1568	Cultivation	205
20	Enterprise	29	Transformation of results	447	STI Fund	1516	Cooperation	185

An in-depth analysis of the 20 most recurring terms at all policy levels reveals a distinct pattern: these terms, while consistent in objectives, emphasize different aspects in their respective policy contexts. The prominence of terms such as "Guangdong-Hong Kong-Macao", "Shenzhen", "international", and "mechanism" at the central level highlights the strategic focus on transforming the Guangdong-Hong Kong-Macao GBA into a global STI hub and positions Shenzhen as a key player within the GBA STI ecosystem. This reflects the national-level emphasis on broad strategic design and macro-control. Conversely, terms like "enterprise", "artificial intelligence", "talent", "research and development", and "fruit transformation" are more prevalent at the provincial and municipal levels, reflecting these governments' efforts to implement and advance national macro policies. Specialized funds, distinct from direct top-down diffusion, foster STI development in Hong Kong and Macao due to unique institutional factors.

Upon examining the nature of these high-frequency words, verbs predominantly feature in central and provincial policies, while municipal policies favor nouns. This distinction suggests that central and provincial policies outline broader work deployment strategies, whereas municipal policies convert these strategies into specific, actionable tasks. Thus, a top-down diffusion approach is evident in the GBA's STI policies. Furthermore, STI policies within the GBA demonstrate a higher degree of adaptability, reflecting strong central government support for STI development in the Guangdong-Hong Kong-Macao corridor.

Thematic Analysis of Policy Texts

Topic modeling, including techniques such as latent semantic analysis (LSA)[35], probabilistic latent semantic analysis (PLSA)[36], and LDA[37], is employed as a probabilistic generative model of text content. These methods simulate the human cognitive process to identify optimal topics and vocabulary for text generation, maximizing the representation of embedded meanings with minimal information loss. They also effectively address the semantic associations among words, topics, and texts[38], making them the most widely used methods for text topic extraction[39].

The LDA topic model posits that each document can be represented as a mixture of various topics, each with a specific probability[40]. Each topic is characterized by a set of words that follow a particular probability distribution, defining the weights or probabilities associated with topics on different words. Therefore, by employing the LDA model, it is possible to extract the core content and features of each topic from the text data[41].

This study utilizes Python's LDA model for topic analysis to establish a mapping relationship of text-topic vocabulary. Through this analysis of policy themes, the study discerns shifts in policy focus across the central, provincial, and municipal levels, as well as in Hong Kong and Macao. The ranking of policy themes also reveals the level of attention and research intensity associated with the policies.

Prior to mining policy text topics, this study determines the number of topics by selecting the optimal level of topic confusion. The variation of perplexity with the number of topics is shown in Fig. 5. When the point corresponding to k=8 forms an "elbow shape," it exhibits a more significant difference in the degree of confusion compared to k=7, and a minor difference compared to k=9. Beyond k=9, the degree of confusion stabilizes, leading to the determination that k=8 is optimal. Due to the small sample size of central policies, it is impractical to ascertain the optimal number of topics using perplexity alone. Therefore, after testing the LDA model for the central tier at k=8, this paper finds that the results are optimal, thus setting the number of central policy topics at 8. From the vocabulary-theme matrix of the LDA model, 32 policy themes across four levels were identified (Table 3).

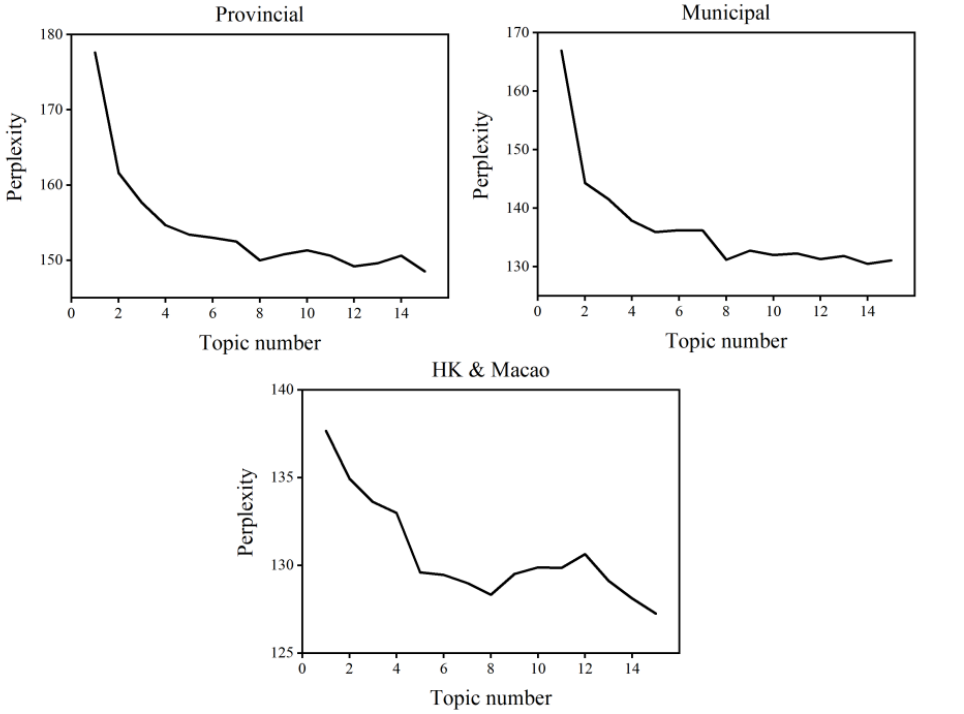

Figure 5 Perplexity at all levels

Table 4 The theme of STI policy in the Guangdong-Hong Kong-Macao GBA

Number	Nation level	Provincial level	Municipal	HK & Macao
	Topic	**Topic**	**Topic**	**Topic**
1	STI intellectual property rights	Support enterprise innovation	Development of the STI industry	STI Funding Program
2	Shenzhen STI Construction	STI project declaration	Special funds for S&T	Development of STI enterprises
3	Transformation of S&T achievements	Artificial intelligence development	STI enterprise innovation	Technology R & D
4	Nansha construction	Science, technology and innovation	Transformation of S&T achievements	Development of Traditional Chinese Medicine
5	Hong Kong and Macao STI Development	STI and entrepreneurship	Artificial intelligence research	Laboratory funding
6	Artificial intelligence	Culture, agricultural STI and development	Technology Business Incubation	STI safeguard measures
7	Exploration of STI system	Basic research	STI Services	STI Fund
8	Scientific research equipment investment	STI Commissioner	Science and Innovation Fund	Small enterprise funding

In strategic policy across STI, the Guangdong-Hong Kong-Macao GBA focuses primarily on intellectual property rights within science and technology, the transformation of STI advancements, exploration of STI systems, and developmental initiatives in Shenzhen and Nansha. This strategy reflects the central government's directive for STI development within the GBA, with key activities centered in the cities of Guangzhou, Shenzhen, Hong Kong,

and Macao. The establishment of the Guangzhou-Shenzhen-Hong Kong-Macao STI Corridor aims to enhance both the internal and international flow of STI factors, thereby elevating the overall STI quality in the region. Dominant themes such as "Science and Technology Intellectual Property" "Shenzhen Science and Technology Construction" and "Transformation of Science and Technology Achievements" are prevalent across all topics. Key terms associated with these themes include "science and technology," "innovation," "intellectual property," "transformation," "technology," an "application," (Fig. 6). Their collective presence underscores the central government's emphasis on transforming STI achievements and protecting intellectual property. As pivotal elements in the STI process, these themes facilitate project realization and productivity advancement, thus being crucial for driving STI development within the GBA. In 2018 and 2019, significant policy initiatives were undertaken when the Ministry of Science and Technology (MOST) released supportive documents for the construction of the Pearl River Delta National Science and Technology Achievement Transfer Demonstration Zone, and the State Council of the CPC issued the development plan for the Guangdong, Hong Kong, and Macao Bay Area. These policies highlight the priority given to transforming STI achievements and strengthening intellectual property rights, thereby optimizing the GBA's innovative environment. The theme "Shenzhen Science and Technology Construction" encompasses impactful terms such as "innovation," "science and technology," "technology," "industry," and "center". This reflects the central government's focus on Shenzhen as a key entity in the GBA's STI strategy, emphasizing its role in advancing STI within the region. To position Shenzhen as the core of STI in the GBA, the central government has successively issued various action plans and a pilot implementation plan for STI activities.

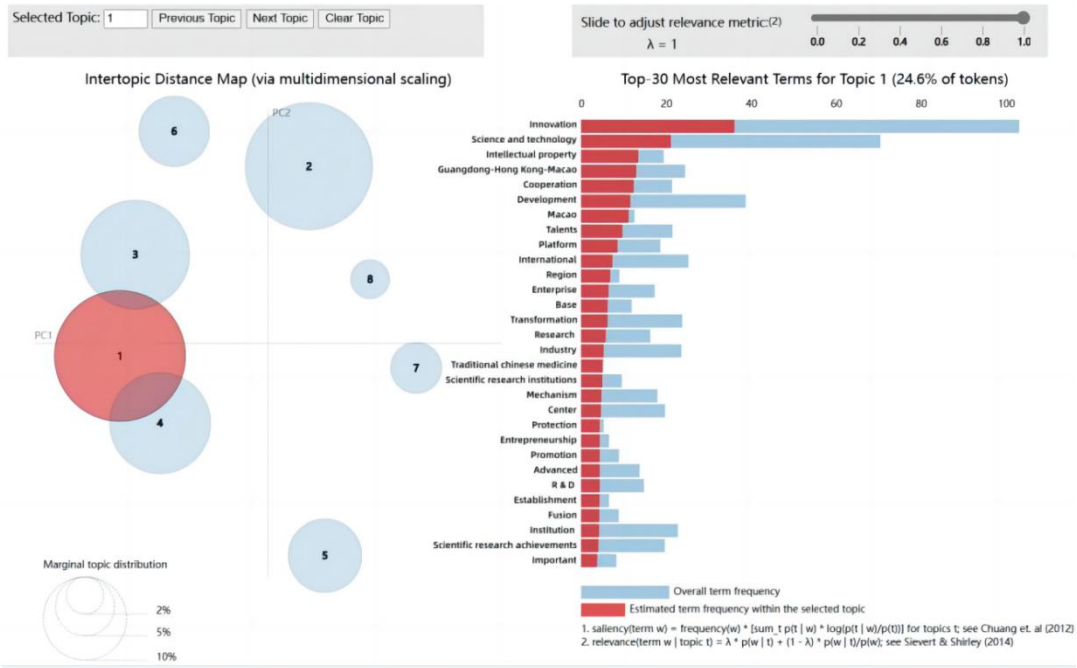

Figure 6 Visualization results of the Central policy

At the provincial level, the Guangdong-Hong Kong-Macao GBA's STI policies focus primarily on STI, artificial intelligence, enterprise development, and basic research. Provincial governments are tasked not only with implementing the macro policies introduced by higher levels of government but also with developing policies that guide lower levels of government in the direction of science and technology, resulting in considerable variation in the content of provincial-level policies. The three most prominent themes at the provincial level are "support for enterprise innovation," "declaration of science and technology projects," and "development of artificial intelligence." The theme "Supporting enterprise innovation" ranks first, showing the greatest prominence within

policy discussions, with associated high-frequency terms including “enterprise,” “science and technology,” “industry,” “innovation,” and “research and development,” (Fig. 8). This underscores the Guangdong Provincial Government’s recognition of enterprises as the cornerstone of scientific and STI endeavors, viewing them as a critical force in advancing science and STI in the GBA. The report of the 20th CPC National Congress specifically highlights “strengthening the status of enterprises as the mainstay of scientific and STI and maximizing the leading and supporting roles of key science and technology enterprises,” reflecting the implementation of central macro-policies in Guangdong Province. The theme “Artificial Intelligence Development” has emerged as a significant focus, directly aligning with the central government’s mandate to accelerate the development of artificial intelligence. During this period, Guangdong Province issued the “Guangdong Province New Generation Artificial Intelligence Innovation and Development Action Plan (2022-2025)” and the “Guangdong Province New Generation Artificial Intelligence Development Plan,”aiming to advance artificial intelligence technology and position Guangdong Province at the forefront of international AI industry development. The theme of “science and technology project declaration” remains a critical component of STI policies, with nearly every policy incorporating aspects of project declaration as an essential element in promoting the development of STI.

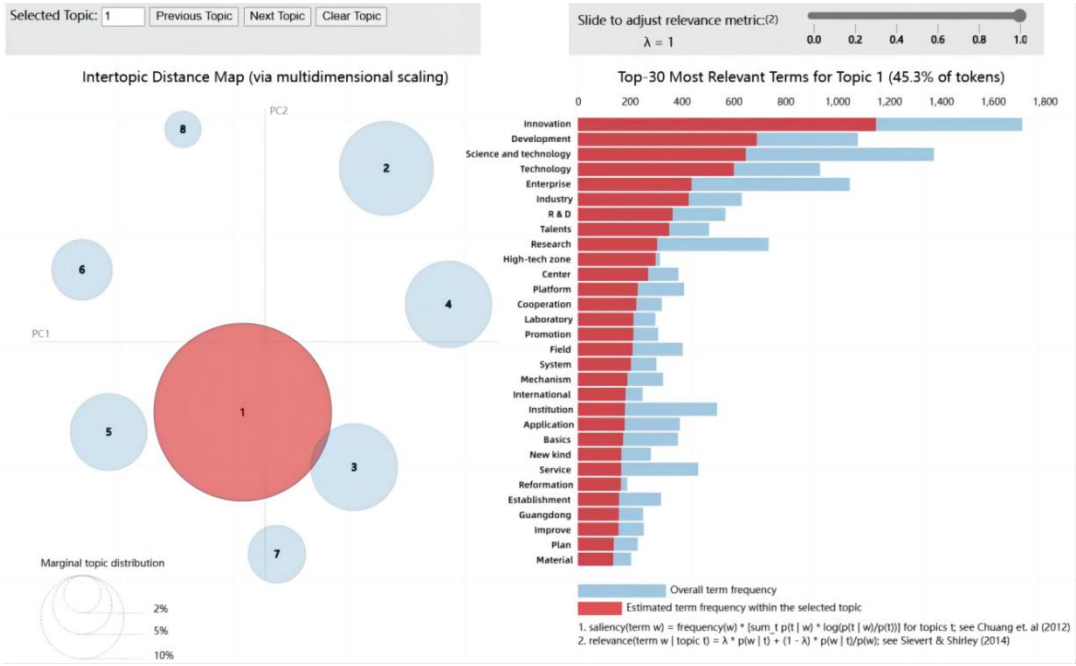

Figure 8 Visualization results of provincial policy

At the municipal level, STI policies emphasize industrial development, transformation of scientific and technological achievements, business incubation, and scientific and technological services. Municipal governments, serving as the final implementers of STI, develop themes that reflect the detailed execution of policies issued by higher levels of government, thus crafting more targeted policies that facilitate specific tasks. “Industry” has emerged as a frequent term within this policy level, illustrating local governments’ commitment to advancing the science and technology industry as a key area to promote STI. Associated terms such as “enterprise,” “technology,” “high-tech zone,” and “talent” also appear regularly in the policy texts across provinces, underscoring the significance of policy application in achieving practical outcomes (Fig. 9). At the municipal level, the "development of the science and technology industry," “special fund for science and technology,” and “innovation of science and technology enterprises” rank as the top three themes. These themes reveal that municipal governments are dedicated to executing STI policies, particularly in guiding grassroots initiatives, and tend to focus on well-defined tasks for implementation. Moreover, local governments actively enforce central government policies. A

pre-policy review identified 2019 as a pivotal year for the introduction of STI policies by local governments (Fig. 10). Thissurge in activity corresponds with the State Council's 2019 issuance of the "Outline of the Development Plan for the Guangdong-Hong Kong-Macao GBA," which explicitly aimed to establish the GBA as an international STI hub. Following this directive, local governments extensively introduced a range of STI policies in line with central instructions.

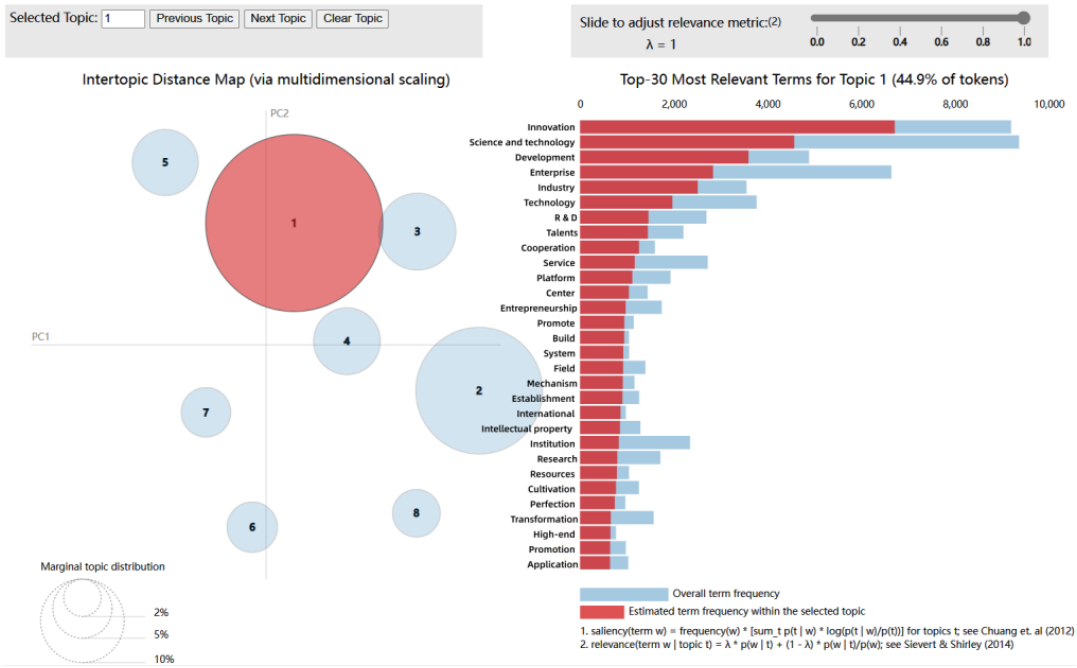

Figure 9 Visualization results of municipal policy

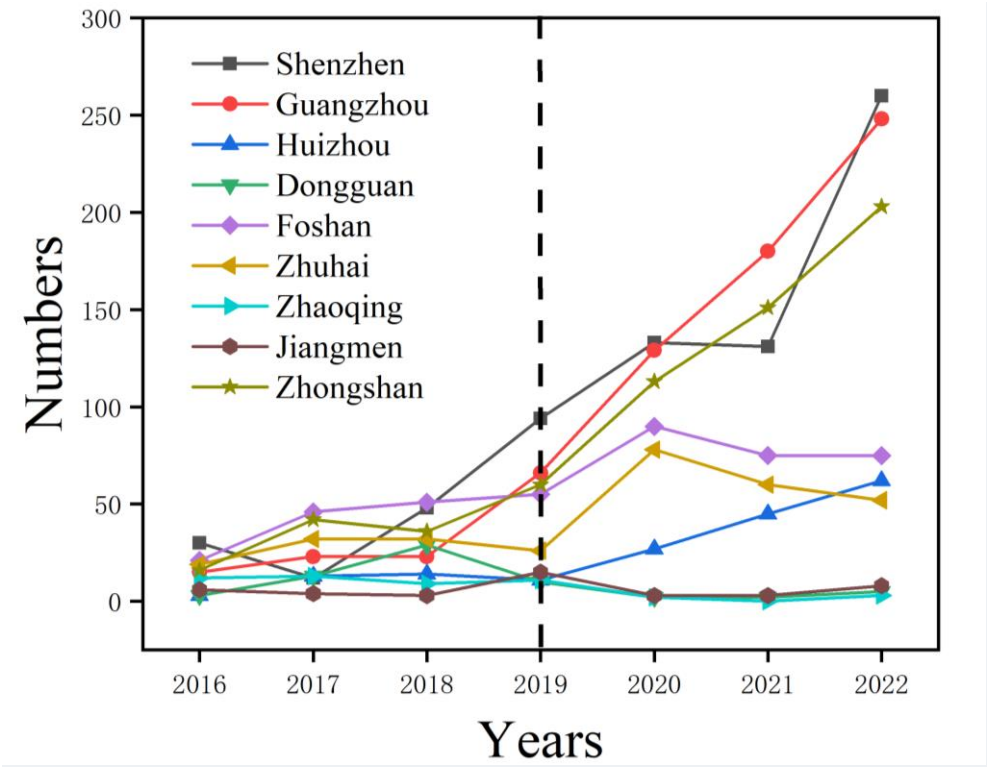

Figure 10 Number of STI policies in each city

Hong Kong and Macao, as Special Administrative Regions, possess relatively independent political and administrative systems, granting them a degree of autonomy in formulating and implementing science and technology policies, which are somewhat distinct from those in

mainland regions. Their STI policies are primarily finance-oriented, as evidenced by initiatives such as the "Science and Technology Funding Scheme," "Laboratory Funding," and "Microenterprise Funding," (Fig. 11). For example, Hong Kong enacted the "Provision of Additional Tax Deduction for R&D Expenditures" and "Capital Injection into the Innovation and Technology Fund" in 2018, while Macao introduced the "Tax Incentive System for Enterprises Engaged in Science, Technology and Innovation Businesses" in 2021. Similar to the mainland, the "development of science and technology enterprises" remains a prevalent theme in Hong Kong and Macao, underscoring the critical role of supporting science and technology enterprises in enhancing S&T innovation.

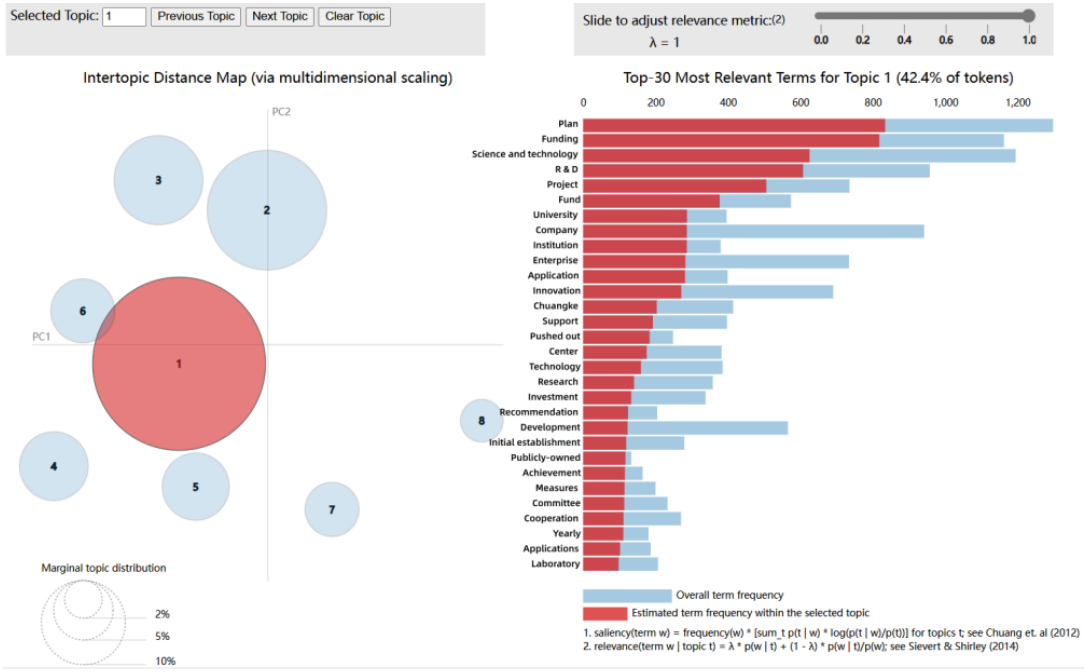

Figure 11 Visualization results of HK & Macao policy

Conclusion

Based on a quantitative analysis of policy texts, this study examines the characteristics of STI policies in the GBA, introduced across four levels from 2016 to 2022 through word frequency statistics and cloud map visualization. The LDA model is employed to extract themes from the STI policies at these levels, yielding the following conclusions:

STI policy themes in the GBA display distinct temporal characteristics. From 2016 to 2018, central-level policies were relatively scarce, while provincial and municipal-level policies experienced marginal growth. However, the 2019 introduction of the Outline of the Plan for the Development of the Guangdong-Hong Kong-Macao GBA catalyzed a significant increase in central-level STI policies. This period also saw a marked increase in provincial and municipal policies, indicating a robust trend in policy diffusion.

The content of STI policies in the GBA has become increasingly refined during its proliferation, although Hong Kong and Macao policies show non-convergence. From a thematic perspective, central, provincial, and municipal policies are closely aligned, primarily focusing on "enterprise innovation," "development of the science and technology industry," and "science and technology projects". However, the themes of Hong Kong and Macao policies differ significantly, dominated by funding-oriented themes. Provincial governments typically adopt a strategic planning approach to policy development, whereas municipal governments tailor their policymaking to local conditions, often resulting in more detailed themes and a pervasive trend of "policy content reproduction" across all levels of governance.

The exploration of policy innovation by each municipal government is limited, and a reciprocal interaction of STI policy in the GBA has not yet materialized. While the themes of provincial and

municipal policies often exhibit general consistency and high relevance, this alignment primarily results from top-down policy execution rather than grassroots innovation. Consequently, a mutual discourse surrounding the GBA's STI policies has yet to be fully established. Many municipalities have initiated pragmatic STI projects, yet higher-level policies rarely incorporate practical models such as technological specialists and technological enclaves. This slow process, combined with insufficient support from higher governmental levels, hampers execution at the municipal level. This discrepancy may lead to a "top hot, bottom cold" dynamic, potentially undermining the effectiveness of local governments in implementing higher-level policies.

Discussion

Central and local policy diffusion processes

This paper examines the diffusion characteristics of STI policies across various levels of governance – central, provincial, municipal, and those of Hong Kong and Macao within the context of the Guangdong-Hong Kong-Macao GBA, with a particular focus on the endogenous factors influencing STI development across the region. By exploring the thematic content of these numerous STI policies, the research reveals that central policies are highly directive, primarily setting the developmental trajectory for STI and establishing innovation institutions within the GBA. Amidst policy diffusion, provincial governments draw inspiration from and subsequently extend central themes, such as developmental initiatives for science and technology enterprises, advancement of artificial intelligence, and broader STI strategies. However, municipal policies, which act as the operative enforcers of these directives, often reflect themes established at the provincial level, including the promotion of technological business development and artificial intelligence. The interaction between Hong Kong, Macao, and the mainland is less pronounced due to structural differences in governance, resulting in comparatively weaker policy dissemination, characterized mainly by financial support.

The design of the STI framework within the Guangdong-Hong Kong-Macao GBA epitomizes China's national strategy. This top-down policy diffusion mechanism aligns the construction of the GBA's STI with the nation's broader objectives. The central government typically orchestrates STI policies by devising strategic plans, regulations, and related policies. In contrast, local governments develop complementary policies tailored to their unique economic structures, scientific capacities, and innovation demands, all within the confines of this overarching strategy[42]. Local authorities are noted for innovating upon and refining these central mandates, crafting more specialized and adaptive policies. While centralized policy objectives guide overarching governmental decisions, local governments are encouraged to infuse their perspectives and adapt these central principles to their specific contexts for implementation [43]. Consequently, an interconnected and symbiotic relationship evolves between central and local governments concerning STI policies within the GBA, fostering a dynamic of both upward and downward synergy. This interaction is expected to enhance the synergy within the GBA's STI landscape, boosting innovation and elevating international competitiveness.

Suggestions

In alignment with the national strategy for developing the Guangdong-Hong Kong-Macao GBA, this study recommends accelerating its scientific and technological autonomy by establishing a robust STI policy framework and enhancing the GBA's STI support system. The first step involves improving the efficacy of the existing STI policy framework. This could be achieved by introducing policies that redefine departmental responsibilities within the GBA and enhance inter-departmental cooperation, thereby achieving sectoral synergies and enhancing the relevance and effectiveness of the policy framework. The second initiative focuses on refining the feedback mechanism for STI policies within the GBA. This entails streamlining policy exchange channels with sub-national governments, optimizing the collaboration across different offices, initiating joint meetings across offices and cities, reinforcing the policy experimentation process, facilitating policy innovation, creating a competitive yet incentivizing atmosphere among governments, and encouraging local governments to innovate policies. Lastly, the policy framework should

concentrate on increasing the capacity of local governments to adapt and modify policy content. In the context of the GBA STI, while top-down policy diffusion channels are efficient, there is a need to better motivate sub-national governments to replicate policies. Departments and local governments should lead policy introduction while top-down policy diffusion channels are efficient, there is a need to better motivate sub-national governments to replicate policies targeted and improved policies.

Limitations and Future Research

The limitation of this study lies in the absence of an evaluation system for the STI policies in the GBA, which hinders the objective assessment of these policies' effectiveness. Therefore, the next step involves quantitatively assessing STI policies across different topics to evaluate their effectiveness, thereby providing data support and scientific references for the development of a new round of STI policy frameworks in the GBA.

Data Availability Statement

All data in this article is publicly available and not in dispute. And the data URLs as follows: BYU's magic bullet: https://pkulaw.com, the Ministry of Science and Technology of the People's Republic of China: https://www.most.gov.cn/satp/. All of the above are public websites and can be downloaded directly without registration.

Author Contributions

C.F. supervised and guided the writing of the article. Y.X.L. wrote the paper. S.C.Z. modified the chart and adjust format. All the authors reviewed the manuscript.

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Competing Interests

The authors declare no conflict of interest.

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