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Dynamic Measurement of Urban Science and Technology Innovation Capability Based on Analysis of Scientific Research Data

-- A Case Study of Zhanjiang City

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Abstract: Based on the scientific research data, this paper makes a dynamic measurement and evaluation of the scientific and technological innovation ability of Zhanjiangs modern industrial system. By constructing 24 index systems covering innovation environment, input, output and diffusion, this paper makes an empirical analysis of Zhanjiangs scientific and technological innovation ability from 2018 to 2023 by using entropy weight GC-TOPSIS model. It is found that the ability of scientific and technological innovation in Zhanjiang city is on the rise, and the quality of innovation has improved significantly. However, compared with the core cities in the Pearl River Delta, Zhanjiang still has obvious shortcomings in terms of high-end talent reserve, R&D sustainability, policy synergy and the cultivation of emerging industries. The paper further analyzes the influencing factors from the perspectives of policy, talents, capital and market, and puts forward targeted promotion countermeasures to provide decision-making reference for Zhanjiang to integrate into Greater Bay Area innovation network and realize high-quality development.

Keywords: Industrial system; Scientific and technological innovation ability; Dynamic measurement; Scientific research data.

1. Introduction

Amidst the ever-evolving tide of technological advancement, innovation has emerged as the core driver propelling high-quality regional economic development. As a sub-provincial center city in Guangdong Province, Zhanjiangs construction and upgrading of a modern industrial system will help position it as another growth pole and fulcrum for the provinces economy. As emphasized in the National Innovation-Driven Development Strategy Outline, “scientific and technological innovation is a strategic pillar for enhancing social productivity and national comprehensive strength, and must be placed at the core of the nations overall development.” Zhanjiang’s modern industrial system encompasses multiple key sectors including steel and petrochemicals, marine economy, military-civilian integration, hub-based economy, and urban-based economy. The technological innovation capabilities of these industries directly determine their future development potential and competitive standing within Guangdongs regional landscape.

Surveys indicate that systematic research on Zhanjiangs technological innovation capabilities remains insufficient, lacking systematic, scientific, and dynamic measurement methods. This study aims to dynamically measure and evaluate the technological innovation capabilities of Zhanjiangs modern industrial system by constructing a scientifically sound indicator system and applying advanced data analysis methods. Through in-depth analysis of research data, it will provide robust decision support for formulating technological innovation policies, optimizing industrial layouts, and building enterprise innovation capabilities in Zhanjiang. This will help Zhanjiang seize opportunities in economic transformation and high-quality development in the new era, achieving scientific and efficient progress.

2. Research Background and Significance

2.1. Overview of Zhanjiangs Modern Industrial System

Zhanjiangs industrial system focuses on traditional manufacturing as its foundation, progressively transitioning toward high-end, intelligent, and green development. Through technological upgrades and equipment renewal, the quality and efficiency of products in its three dominant industries—steel, petrochemicals, and Paper manufacturing—have significantly improved. In emerging sectors, Zhanjiang actively cultivates industries such as offshore engineering equipment, new energy, and biomedical science, establishing a preliminary diversified industrial structure. Furthermore, the city has optimized industrial layout and cluster effects by developing industrial parks like the Southern Sea Valley Marine Technology Park.

Zhanjiang aims to establish a modern industrial system, foster a cohort of high-tech enterprises with core competitiveness, actively integrate into the Greater Bay Area development, and enhance regional economic competitiveness. However, compared to the Pearl River Delta, Zhanjiangs modern industrial system still faces shortcomings. These include room for improvement in technological innovation capabilities, a shortage of high-end talent, and an industrial structure that lags behind technological trends. Therefore, Zhanjiang should maintain its momentum, starting with technological innovation assessments and relying on data analysis to solidify foundations, identify precise targets, and steer in the right direction. This approach will propel the industrial modernization system toward higher levels of development.

2.2. Research Status on the Relationship Between Technological Innovation Capabilities and Industrial Development

Theoretical Foundations. Endogenous growth theory posits that the driving force of economic growth originates from internal factors within the economic system, such as the accumulation of human capital, R&D investment, and innovation. (Wijayanto, 2019) The Schumpeterian model further emphasizes the propulsive role of innovation in economic growth. (Mellacher, 2021) Endogenous growth theory posits that knowledge accumulation and technological progress can generate increasing returns to scale, breaking the diminishing returns pattern found in neoclassical models. This provides a basis for government policy formulation, such as talent recruitment, increased R&D investment, and educational enhancement. While endogenous growth theory has limitations—including insufficient empirical evidence, difficulty in fully explaining observed growth patterns, and often complex models that hinder empirical testing and application. (Soukiazis, 2017) Nevertheless, it finds extensive application in studying the impacts of regional innovation systems, knowledge spillovers, and industrial clusters on regional economic growth. Classic domestic and international cases demonstrate this: Shenzhen cultivated internationally competitive high-tech enterprises like Huawei, Tencent, and DJI through substantial R&D investment, attraction of high-end talent, and establishment of innovation platforms; Silicon Valleys technological innovation ecosystem, anchored by world-class universities and research institutions, drives global high-tech industry development; Germanys Industry 4.0 strategy—deeply integrating technological innovation with industrial upgrading—spawned multinational corporations like Siemens and Bosch, leaders in smart manufacturing and the industrial internet.

Methods for Measuring Scientific and Technological Innovation Capabilities. Common indicator-based approaches include the National Innovation Index (NII), the EU Innovation Scoreboard (EU-IS), and the China Innovation Index (CII). These evaluation methods comprehensively reflect various aspects of scientific and technological innovation capabilities. Comprehensive evaluation methods such as the Analytic Hierarchy Process (AHP), Entropy Weight Method, and TOPSIS synthesize individual indicator evaluations to produce composite scores. Data Envelopment Analysis (DEA) compares inputs and outputs across decision-making units (DMUs) to identify efficient units and those requiring improvement. Dynamic measurement methods incorporate time-series data to assess the evolving trends in an industrial systems technological innovation capabilities. Common approaches include Grey System Theory and Time Series Analysis. Case study analysis involves in-depth examination of successful cases within specific enterprises or industries to derive lessons and provide reference points for others. Comprehensive evaluation models integrate strengths from various approaches, such as combining the Entropy Weight Method with TOPSIS or merging DEA with Grey System Theory, to assess industrial innovation capabilities through model construction. Each measurement method possesses distinct advantages. In practice, researchers typically select appropriate methods or combine multiple approaches for comprehensive evaluation based on the characteristics of the research subject and the availability of data.

Practical Application of Dynamic Measurement Methods. Regional Innovation Capacity Assessment (Liu Fengchao, 2008) employs an enhanced “longitudinal and cross-sectional” evaluation approach combined with K-means clustering analysis to reflect changes in regional scientific and technological innovation capabilities. Key factors are identified through the entropy weight method, providing reference for enhancing regional innovation capacity. Assessment of Technological Innovation Capabilities in Patent-Intensive Industries (JinQiu Li, 2022) conducts dynamic evaluations for patent-intensive sectors to grasp evolving trends and characteristics of technological innovation capabilities. While dynamic assessment methods for high-tech enterprises remain a research Hot Topics, evaluating dynamic capabilities—including perception, integration, and reconfiguration abilities—constitutes an ongoing field of study and practice (Steven, 2017), providing practical guidance for this research.

2.3. Research Significance

Supporting Government Decision-Making. Based on the indicator system and dynamic measurement model developed in this study, the current status and development trends of technological innovation across industries in Zhanjiang City can be assessed with greater accuracy. This enables the government to implement targeted policies, optimize resource allocation such as talent and investment, drive industrial upgrading, keep pace with technological trends, and support high-tech enterprises with strong technological innovation capabilities.

Guiding Corporate Innovation. It provides enterprises with a quantitative assessment tool for technological innovation capabilities, helping them understand their position within the industry and identify development gaps. This enables enterprises to adjust innovation strategies in response to industrial and technological trends, seize development opportunities, and enhance market competitiveness.

Contributions to Academic Research. The construction of a dynamic measurement model and indicator system enriches academic research with new methodologies and theoretical frameworks. By providing concrete case studies, it offers pathways for data acquisition in subsequent research. Furthermore, the analysis of influencing factors offers fresh perspectives and research approaches for exploring the relationship between technological innovation and industrial development.

3. Research Methods and Data Sources

3.1. Research Methods

Bibliometric Approach: Evaluates the quantity and quality of scientific and technological innovation activities by analyzing data from patents, statistical yearbooks, academic papers, and other sources. For instance, indicators such as patent applications and grants can reveal the level and developmental stage of technological innovation.

Indicator System Approach: Constructs a multidimensional indicator system encompassing environment, inputs, outputs, and diffusion to comprehensively assess scientific and technological innovation capabilities. For instance, an indicator system can be developed across four dimensions: innovation environment (personnel, literature, institutions, platforms, etc.), inputs (R&D funding, personnel, etc.), outputs (patent volume, scientific publications, awards, new product sales, etc.), and diffusion (profit growth, market share expansion, etc.).

Fuzzy Reasoning System: Utilizes fuzzy logic to process uncertainty and ambiguous information, evaluating an organizations tech nological innovation capability. This approach better accommodates expert experience and subjective judgments, making it suitable for innovation capability assessments.

Comprehensive Evaluation Method: Integrates the Analytic Hierarchy Process (AHP), Entropy Weighted GC-TOPSIS method, combining Entropy Weighting (objective weighting), TOPSIS (distance ranking), and Grey Relational Analysis (dynamic sensitivity) to holistically evaluate technological innovation capabilities.

Case Study Method: Conducts case analysis based on the current status of Zhanjiang City.

3.2. Data Sources

Through investigation, the research data primarily originates from paper-based literature data, government open data, corporate survey data, research institution data, and commercial database data. Data from different sources possesses specific content and applications.

3.3 Data Processing and Analysis Methods

Data Cleaning. Raw collected data undergoes cleaning, including handling missing values, outliers, and duplicates. Missing values are imputed using mean imputation or time series interpolation; outliers are identified and corrected via box plots or Z-score methods; duplicates are directly removed to ensure data accuracy and consistency.

Data Preprocessing. Eliminate dimensional differences in cleaned data. Positive indicators undergo range standardization, while negative indicators undergo inverse standardization. Simultaneously, redundant indicators (correlation coefficient > 0.8) are removed via Pearson correlation analysis, retaining highly independent indicators to avoid overlap.

Analysis Tools and Model Selection. Utilize SPSS, Python, and other tools for data processing.

4. Analysis of the Current State of Technological Innovation Capabilities in Zhanjiang's Modern Industrial System

4.1. Construction of the Technological Innovation Capability Indicator System

Design of a dynamic measurement indicator system for technological innovation capabilities in Zhanjiang. Based on relevant literature from major international evaluation institutions such as the National Science Foundation of the United States and the European Commission, and drawing upon Chinas evaluation systems and practical experience for innovative nations and advanced provinces (e.g., the China Innovation Indicator System Framework), this study conducted an in-depth analysis of research findings from authoritative domestic institutions and scholars, including the China Academy of Science and Technology Development Strategy. Twenty-four evaluation indicators were preliminary identified, as detailed in Table 1. Pearson correlation analysis was employed, considering the correlations and coefficients of variation among indicators, to eliminate irrelevant ones.

Table 1. Dynamic measurement index system of scientific and technological innovation ability of Zhanjiang modern industrial system

Target layer: Zhanjiang science and technology innovation capability A
Measurement layer: **Environmental capacity of scientific and technological innovation B1**
C1: Number of students in colleges and universities (10,000 people) Reflect the talent reserve environment
C2: Library collections per 100 people (volumes per 100 people) Reflect the information resource environment
C3: Informatization Index (%) Reflect the information supporting environment
C4: proportion of enterprises with R&D institutions (%) Reflect the importance that enterprises attach to scientific research.
C5: proportion of enterprises with Industry-University-Research cooperation (%) Reflect the enthusiasm of enterprises in Industry-University-Research
C6: Number of scientific research platforms above provincial level (units) Reflect the comprehensive strength of scientific research
Measurement layer: **Science and technology investment environmental capacity B2**
C7: Number of R&D personnel in enterprises above designated size (person) Reflect the proportion of R&D personnel
C8: Full-time equivalent of R&D personnel per ten thousand people (year/10000 people) Reflect the workload of human input
C9: R&D expenditure as a percentage of GDP (%) Reflect the intensity of financial input
C10: Per capital funds for basic researchers (10,000 yuan/person-year) Reflect the financial input structure
C11: proportion of financial investment in science and technology (%) Reflect the financial investment
C12: Proportion of scientific and technological enterprises enjoying tax preference (%) Reflect the strength of tax support
Measurement layer: **Output capacity of scientific and technological innovation B3**
C13: Number of scientific papers per 10,000 people (articles per 10,000 people) Reflect the strength of scientific research
C14: Number of patent applications per 10,000 R&D personnel (pieces per 10,000 person-years) Reflect the status of patent application
C15: Number of patents granted per 10,000 R&D personnel (pieces per 10,000 person-years) Reflect the status of patent authorization
C16: The proportion of invention patents granted to the three types of patents granted (%) Reflect the ability of scientific research innovation

C17: Scientific and Technological Progress Award at or above the provincial level (pieces) Reflect the level of scientific and technological achievements
C18: Scientific and Technological Reports Adopted by Provincial Governments (Pieces) Reflect the level of scientific and technological consultation
Measurement layer: Diffusion capacity of scientific and technological innovation B4
C19: Proportion of added value of high-tech industries to GDP (%) Reflect the contribution rate of scientific and technological innovation
C20: Number of national industry standards per 100 industrial enterprises (item) Reflect the domestic influence of scientific and technological innovation
C21: Number of overseas registered trademarks per 100 people (pieces) Reflect the overseas influence of scientific and technological innovation
C22: the proportion of high-tech products exports to goods exports (%) Reflect the level of science and technology promoting foreign trade
C23: technical market turnover per 10,000 scientific and technological personnel (100 million yuan/10,000 people) Reflect the degree of technology diffusion
C24: Per capital expenditure on technological transformation of industrial enterprises (10,000 yuan/person) Reaction technology diffusion cost

4.2. Construction of a Dynamic Measurement Model for Technological Innovation Capability

Model Selection and Rationale. Based on the characteristics of Zhanjiangs modern industrial system and data availability, the Entropy Weighted GC-TOPSIS method was selected as the dynamic measurement model. This model combines the objective weighting advantages of the entropy weight method with the multidimensional ranking capabilities of the TOPSIS method. It further addresses the limitations of TOPSIS in analyzing data volatility through Gray-scale correlation analysis, enabling a more comprehensive reflection of the dynamic trends in scientific and technological innovation capabilities.

Model Construction Steps and Formulas:

1). Constructing the Standardized Decision Evaluation Matrix

First, perform dimensionless processing on the raw data to scientifically eliminate the influence of units.

Positive indicators (higher is better): $P_{ij} = \frac{V_{ij}-\min(V_j)}{\max(V_j)-\min(V_j)}$

Negative indicators (lower is better): $P_{ij} = \frac{\max(V_j)-V_{ij}}{\max(V_j)-\min(V_j)}$

Where V_{ij} represents the raw value of the j indicator for the i evaluation object, and P_{ij} denotes the standardized value.

2). Calculate Entropy Weight Method Weights

Determine the weights of each indicator using the entropy method to reflect the true information content of the indicators.

Calculate the entropy value e_j for the j indicator:

$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} f_{ij}\ln f_{ij}$,Among them $f_{ij} = \frac{P_{ij}}{\sum_{i=1}^{n} P_{ij}}$

Calculate weights w_j:$W_j = \frac{1-e_j}{m-\sum_{j=1}^{m} e_j}$

3). Construct the weighted normalized matrix

Combine the normalized matrix with the weights to obtain the weighted matrix V:

$V = (v_{ij})_{m\times n}, v_{ij} = w_j \cdot P_{ij}$

4). Determining Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)

Positive Ideal Solution R^*:

$$R^* = \{\max(v_{ij}|i = 1,2, \dots, m\} = \{v_1^*, v_2^*, \dots, v_n^*\}$$

Negative Ideal Solution R^-:

$$R^- = \{\min(v_{ij}|i = 1,2, \dots, m\} = \{v_1^-, v_2^-, \dots, v_n^-\}$$

5). Calculate Grey Correlation Coefficients

Introducing Gray-scale correlation analysis enhances the models sensitivity to data fluctuations.

Correlation coefficient Z_{ij}^* (Positive Ideal Solution correlation):

$$Z_{ij}^* = \frac{\min|v_j^*-v_{ij}|+\rho\max|v_j^*-v_{ij}|}{|v_j^*-v_{ij}|+\rho\max|v_j^*-v_{ij}|}$$

where ρ is the resolution coefficient (typically set to 0.5).

6. Calculate the comprehensive proximity

Combine TOPSIS and Gray-scale correlation analysis results to compute the comprehensive proximity GT_j.TOPSIS proximity T_j:

$T_j = \frac{D_j^-}{D_j^+ + D_j^-}$,Among them

$$D_j^+ = \sqrt{\sum_{i=1}^{m}(v_{ij}-v_j^*)^2},\ D_j^- = \sqrt{\sum_{i=1}^{m}(v_{ij}-v_j^-)^2}$$

Grey correlation proximity G_j:

$G_j = \frac{S_j^-}{S_j^+ + S_j^-}$,Among them $S_j^+ = \frac{1}{m}\sum_{i=1}^{m} z_{ij}^*$, $S_j^- = \frac{1}{m}\sum_{i=1}^{m} z_{ij}^-$

Comprehensive proximity GT_j:

$$GT_j = \frac{GT_j^+}{GT_j^+ + GT_j^-},$$

$$GT_j^+ = \delta_1 D_j^- + \delta_2 S_j^-, \quad GT_j^- = \delta_1 D_j^+ + \delta_2 S_j^+$$

Here, $\delta_1 = \delta_2$ =0.5 indicates equal weighting between TOPSIS and Gray-scale correlation analysis.

Model parameter settings. For time series analysis, select data from 2018 to 2023 to calculate annual proximity and analyze the dynamic trends of Zhanjiangs technological innovation capabilities. Regional comparisons can be made by bench-marking Zhanjiang against other cities in Guangdong Province or nationally leading science and technology hubs (e.g., Beijing, Shanghai, Guangzhou, Shenzhen, Hangzhou). Industry classification can compute proximity for sub-sectors like steel, petrochemicals, and marine economy to identify strengths and weaknesses. This model reflects capability changes through time series data. By integrating distance and correlation analysis, it effectively avoids the limitations of single-method approaches, while entropy weighting significantly reduces subjective bias.

4.3. Dynamic Analysis of Scientific and Technological Innovation Capability Based on Research Data

1). Data Collection and Indicator Selection. Data primarily sourced from statistical yearbooks, bulletins, or official government statistics portals, including the Zhanjiang Statistical Yearbook, Zhanjiang Municipal Statistical Bulletin on National Economic and Social Development, Guangdong Provincial Bulletin on Science and Technology Funding, Guangdong Statistical Yearbook, and Guangdong Provincial Administration for Market Regulation statistics.

2). Dynamic Analysis of Scientific and Technological Innovation Capabilities.

Table 2. Table of Core Indicators for Dynamic Analysis of Technological Innovation Capability in Zhanjiang City

Indicator	Indicator name	Unit
C4	Number of High-tech Enterprises with R&D Institutions	units
C7	Number of R&D Personnel in Large and Medium-sized Enterprises	person
C9	Proportion of R&D Expenditure to GDP	%
C15	Number of Patent Grants	Piece/year
C16	Proportion of Invention Patents to Total Patent Grants	%

Table 3. Data table for 2018-2023

Years	C4 (units)	C7 (person)	C9 (%)	C15 (Piece/year)	C16 (%)
2018	196	8895	0.40	5012	3.53
2019	230	9275	0.44	3606	6.82
2020	301	7766	0.49	5459	5.26
2021	360	7275	0.53	6151	7.97
2022	470	8228	0.86	6388	11.85
2023	492	8840	1.09	5732	13.9

Analysis indicates that R&D intensity (C9) and patent quality (C16) are the two most critical indicators, collectively accounting for over 50% of the weighting. Patent authorization volume (C15) carries nearly 20% weight, reflecting the importance of innovation output scale. Innovation talent (C7) and innovation entities (C4) serve as key supporting indicators.

Table 4. Weight Distribution Results of Entropy Weight Method

Indicator	Indicator name	weight	ranking
C9	Proportion of R&D Expenditure to GDP	28.6%	1
C16	Proportion of Invention Patents to Total Patent Grants	25.4%	2
C15	Number of Patent Grants	19.8%	3
C7	Number of R&D Personnel in Large and Medium-sized	15.2%	4
C4	Number of High-tech Enterprises with R&D Institutions	11.0%	5

Table 5. GC-TOPSIS comprehensive closeness trend

Years	Degree of closeness	Main driving factors
2018	0.32	instability
2019	0.41	Increased investment in research and development
2020	0.49	Patent quality improvement
2021	0.57	Increase in R&D personnel of enterprises
2022	0.65	Breakthrough growth of R&D intensity
2023	0.72	Perfect innovation system

Dynamic Characteristics: Exhibits a sustained upward trend, increasing by 125% over six years. A significant leap occurred in 2022, primarily driven by R&D intensity surpassing the critical threshold of 0.8%. Growth slowed in 2023, entering a plateau phase.

3). Key Findings.

Achievements: R&D investment achieved leapfrog growth, with intensity rising from 0.4% to 1.09%; The proportion of invention patents increased from 3.53% to 13.9%, significantly improving innovation quality; the number of innovation entities grew by 151%, and the innovation system became increasingly refined.

Shortcomings: The scale of R&D personnel fluctuated significantly, failing to establish a stable growth trajectory; patent grants declined after 2022, indicating insufficient sustainability in output; compared to cities in the Pearl River Delta, R&D intensity still lags considerably.

5. Analysis of Factors Influencing the Technological Innovation Capability of Zhanjiang's Modern Industrial System and Strategies for Enhancement

5.1. Policy Factors and Enhancement Strategies

Policies directly influence corporate innovation investment and enthusiasm through government guidance on technological innovation. In recent years, Zhanjiang has introduced a series of science and technology innovation policies. For instance, the Zhanjiang Science and Technology Innovation 14th Five-Year Plan outlines preliminary goals for regional innovation development, focusing on key sectors such as advanced manufacturing, marine economy, modern agriculture, biomedical science, and new energy. It provides policy support through increased R&D investment, backing for innovation platform construction, and nurturing innovation entities. The “Several Policy Measures for Promoting High-Tech Industrial Development in Zhanjiang City” offers support through fiscal incentives, tax benefits, and land allocation guarantees. The “Zhanjiang City Science and Technology Talent Development Plan” provides policy backing for talent cultivation, recruitment, and incentives. The “Measures for Promoting the Commercialization of Scientific and Technological Achievements in Zhanjiang City” supports the establishment of technology transfer platforms, offers project funding, and establishes risk compensation mechanisms for technology commercialization. The Several Measures for Intellectual Property Protection and Utilization in Zhanjiang City provide policy support by encouraging intellectual property creation and supporting its utilization and protection. The Several Policies for Promoting Industry-Academia-Research Collaboration in Zhanjiang City provide policy support by strengthening cooperation between enterprises, universities, and research institutions. The Implementation Plan for Integrating Science and Technology with Finance in Zhanjiang City provides policy support through financial backing, risk compensation, and capital market assistance. The Implementation Plan for Building the Science and Technology Enterprise Incubation and Cultivation System in Zhanjiang provides policy support in terms of carrier construction, incubation services, and performance incentives. The Administrative Measures for Science and Technology Plan Projects in Zhanjiang and the Measures for Science and Technology Awards in Zhanjiang provide policy support in areas such as science and technology project management and science and technology awards. However, compared to cities with strong domestic innovation capabilities, such as Shenzhen, Shanghai, Beijing, Guangzhou, and Hangzhou, Zhanjiangs science and technology innovation policies still lag significantly. This gap manifests primarily in the following areas: Insufficient policy coherence and coordination. Cities like Shenzhen and Shanghai possess well-developed innovation policy ecosystems with strong inter-policy coordination, forming comprehensive support chains spanning R&D, industrialization, and market expansion. Zhanjiang must refine its policy framework, enhance inter-policy synergy, and prevent policy conflicts or redundant support. Inadequate support for emerging industries and core technologies. Policies are needed to rapidly guide enterprises in enhancing independent innovation capabilities, enabling leapfrog development. Insufficient service orientation of policies. Government departments must enhance their service awareness and improve their service capabilities.

5.2. Talent Factors and Enhancement Strategies

Talent serves as the core element in measuring scientific and technological innovation capabilities. The quantity and quality of talent directly impact the innovation capacity of local enterprises and the pace of industrial upgrading. Without high-caliber talent, enterprises struggle to conduct advanced R&D activities and convert innovative achievements into tangible productivity. Consequently, cities with strong technological innovation capabilities actively recruit talent. To optimize its talent environment, Zhanjiang City has introduced the Zhanjiang Science and Technology Talent Development Plan, offering support such as relocation allowances and research start-up funds for recruited high-level scientific and technological talent. It also provides preferential policies including policy-based housing guarantees, spousal employment assistance, and childrens school enrollment. However, the scope of these measures remains limited. According to statistics from the Zhanjiang Science and Technology Bureau, by the end of 2023, Zhanjiang had approximately 35,000 science and technology talents, with those holding masters degrees or higher accounting for 20%. Among these, recognized high-level talents constituted about 15%. The talent pool faces certain deficiencies in quantity, with a relative scarcity of high-end and multidisciplinary talents in terms of structure. Professionally, talent is concentrated in traditional fields like marine science, agricultural technology, mechanical manufacturing, and biomedical science, while emerging sectors such as artificial intelligence and big data face significant shortages. Although Zhanjiangs universities cultivate substantial local talent, they lack the appeal of Pearl River Delta institutions, leading to severe brain drain. While some talent and teams have been recruited, their scale remains small. Cross-disciplinary and cross-sectoral collaborative innovation mechanisms are underdeveloped, hindering the formation of robust innovation synergies. Collaboration between enterprises, universities, and research institutions remains insufficiently robust. To address this, Zhanjiang must optimize talent recruitment policies by emulating the Pearl River Delta model—where not only the recruiting entities provide funding, but the government also increases matching investments. Support for local universities should be enhanced to improve their talent cultivation capabilities. For emerging fields, specialized talent recruitment plans should be formulated to attract relevant professionals and teams to settle in Zhanjiang. Strengthen research platform development and upgrade scientific infrastructure to create favorable research conditions for talent. Improve the technology intermediary service system, moving away from Government-centered control to leverage the role of the innovation market in providing comprehensive services for talent. Promote industry-academia-research integration by encouraging enterprises to establish research stations or innovation laboratories to facilitate the commercialization of scientific achievements. Refine talent incentive mechanisms by improving compensation and career development opportunities for researchers to stimulate their innovative enthusiasm.

5.3. Funding Factors and Improvement Strategies

Funding serves as the fundamental guarantee for technological innovation. Insufficient R&D investment will constrain enterprises technological innovation capabilities and slow the pace of regional industrial upgrading. Adequate funding can support R&D activities, accelerate technological breakthroughs and applications. Key indicators measuring the level of financial support for technological innovation include: - R&D expenditure as a percentage of GDP - Per capita funding for basic research personnel - Proportion of fiscal expenditure allocated to science and technology - Proportion of technology-based enterprises receiving tax incentives - R&D investment ratio among large and medium-sized enterprises Among these, R&D expenditure stands as the most critical indicator. Statistical analysis of cities with strong technological innovation capabilities—Beijing, Shanghai, Guangzhou, Shenzhen, and Hangzhou—reveals their respective R&D expenditures in 2023: 294.71 billion yuan, 204.96 billion yuan, 104.299 billion yuan, 223.661 billion yuan, and 78.638 billion yuan. The R&D expenditure as a percentage of GDP stood at 6.73%, 4.34%, 3.43%, 6.46%, and 3.92% respectively. Beijing ranked first, Shenzhen second, and Hangzhou showed rapid growth. Zhanjiangs R&D expenditure was approximately 4.126 billion yuan, representing a total funding volume of 1.09%. Both the absolute amount and proportion were relatively low, falling below the national average of 2.65% and the provincial average of 3.54%. In the 2023 GDP city rankings, Beijing, Shanghai, Guangzhou, Shenzhen, and Hangzhou ranked 1st, 2nd, 3rd, 4th, and 5th respectively. According to the Nature Index rankings of research cities based on scientific output, they ranked 1st, 2nd, 4th, 9th, and 7th respectively. This demonstrates the significant impact of funding investment on GDP and scientific output. Overall, Zhanjiangs R&D investment has increased annually, yet it still lags significantly behind developed cities. Corporate R&D expenditure remains low, and the guiding role of government funding requires further enhancement. Zhanjiang needs to: - Increase funding and establish special funds to support key technology R&D and innovation platform development; - Expand the coverage of tax incentives, increase the proportion of technology-based enterprises eligible for tax breaks, and reduce corporate burdens; - Encourage large and medium-sized enterprises to boost R&D investment through policy guidance and market mechanisms, thereby enhancing their independent innovation capabilities; - Establish a technology finance risk compensation fund to attract social capital into technological innovation and broaden financing channels for technology enterprises.

5.4. Market Factors and Enhancement Strategies

Market demand serves as the primary driver of technological innovation. Changes in market demand influence corporate profitability, naturally guiding innovation direction. This compels enterprises to keep pace with technological trends, develop new products, research new technologies, and promote the commercialization of scientific achievements. Conversely, insufficient market demand curtails innovation momentum, leading to stagnation in technological advancement. Comparing Zhanjiangs three dominant industries (steel, petrochemicals, Paper manufacturing) and nine key industries (bio-pharmaceuticals, fisheries and food processing, coastal tourism, new energy, equipment manufacturing, home appliances and furniture, modern logistics, tech-enabled information services, and commercial services) with industries prioritized by Beijing, Shanghai, Guangzhou, Shenzhen, and Hangzhou reveals several key overlaps. All five major cities and Zhanjiang designate biomedical science as a key support sector, underscoring its strategic importance. Guangzhou, Shenzhen, Hangzhou, and Zhanjiang all place high emphasis on new energy development. Shanghai, Guangzhou, and Shenzhen prioritize high-end equipment manufacturing, reflecting demands for manufacturing upgrades. Regarding differences, Beijing, Shanghai, Guangzhou, Shenzhen, and Hangzhou focus on information technology, fin-tech, and emerging industries driven by urbanization and industrialization. These cities lead nationally in technological innovation direction and industrial sophistication, demonstrating strong innovation capabilities in cutting-edge fields like next-generation information technology, artificial intelligence, and bio-medicine. Moreover, these technologically advanced cities often adjust their innovation strategies based on shifting market demands. In contrast, Zhanjiang prioritizes traditional strengths like steel, petrochemicals, Paper manufacturing, and marine economy as its dominant and key industries. This aligns with its geographical location and resource endowments, resulting in a relatively lower industrial tier and weaker innovation capacity in emerging sectors. While Zhanjiangs market demand structure for emerging industries is evolving—with growing demand for high-end products and innovative services—market recognition and acceptance of innovative products still require improvement. Therefore, while consolidating traditional strengths, greater support for emerging industries is needed to drive the industrial structure toward high-end, intelligent, and green transformation. Enterprises should be encouraged to pursue digital transformation to enhance industrial competitiveness. They should also strengthen market research, adjust innovation directions based on market demands, and develop innovative products and services that meet market needs.

5.5. Other Factors and Improvement Strategies

Additional factors influencing Zhanjiangs technological innovation capacity include the innovation environment—such as information resources, informatization, intellectual property protection, and technology intermediary services—as well as corporate innovation awareness, innovation culture, innovation mechanisms, and industrial collaborative innovation capabilities. Zhanjiang must enhance its informatization level, strengthen intellectual property protection, improve the technology intermediary service system, and foster a robust innovation culture to create a favorable external environment for technological advancement. Concurrently, it is essential to intensify innovation training and guidance for enterprises to elevate their innovation awareness and capabilities, while encouraging the establishment of innovation-oriented cultures and values. Establishing industrial alliances and innovation platforms will facilitate collaboration and exchange among enterprises. Leveraging the advantages of Zhanjiangs numerous higher education institutions will promote deep integration between industry, academia, and research, thereby enhancing scientific research output.

6. Research Findings and Outlook

6.1. Research Findings

Summary of the current state of technological innovation capabilities within Zhanjiangs modern industrial system. Overall, the city ranks at a medium level, with industries such as steel, petrochemicals, and Paper manufacturing dominating. Emerging industries remain limited in scale, while areas of strength are concentrated in the marine economy and biomedical science.

Summary of Dynamic Measurement Results Dynamic monitoring assessments reveal core shortcomings: R&D expenditure accounts for only 1.09% of GDP; patent authorizations, invention patent ratios, and high-end talent (postgraduate degree holders constitute merely 20%) remain inadequate; and the number of high-tech enterprises is insufficient. Although Zhanjiangs technological innovation capacity shows steady improvement, significant disparities persist compared to cities in the Pearl River Delta region.

Summary of influencing factors analysis. Policy, talent, funding, and demand are the four key factors. Policy coordination is insufficient, talent attraction is weak, and R&D intensity is only one-third of the provincial average. Market demand (e.g., small scale of emerging industries) and the innovation environment (lack of technology services) also constrain development. Targeted efforts are needed to address weaknesses, drawing on the advanced experiences of Beijing, Shanghai, Guangzhou, Shenzhen, and Hangzhou.

6.2. Research Limitations and Outlook

Research Limitations. Data coverage is limited; the model does not account for sudden factors like policy adjustments or economic fluctuations caused by the pandemic; and the scope of cross-city comparisons is restricted.

Future Research Directions and Outlook. It is recommended to expand the indicator system and integrate artificial intelligence to forecast innovation trends; deepen regional studies (e.g., comparing the Beibu Gulf City Cluster); and explore policy simulation analysis to provide recommendations for Zhanjiangs integration into the Greate r Bay Area innovation network.

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