Measurement of the Integrated Development Level of Industrial Chain and Innovation Chain in Guangxi under the Background of High-Quality Development

Yongyi Shen[1], Xin Su[1,*], Yue Zhao[1], Zhuo Wang[2]
[1]*School of Business, Guilin University of Electronic Technology, Guilin, Guangxi, China*
[2]*Huaibei Mining Co., Ltd, Huaibei, Anhui, China*
**Corresponding Author.*

Abstract: The synergistic advancement of industrial and innovation ecosystems plays a crucial role in bolstering regional economic competitiveness and fostering sustainable growth, which contributes to achieving superior development outcomes. This research examines Guangxi's development trajectory during the 2013-2022 period by establishing a comprehensive assessment framework for chain integration. The methodology incorporates three principal analytical tools: the entropy weighting approach for objective measurement, coupled system modeling for interaction evaluation, and coordination degree assessment for developmental alignment. Furthermore, constraint factor analysis identifies key impediments to integration. Empirical findings demonstrate that while Guangxi's dual-chain convergence exhibits progressive improvement, the current integration maturity remains at an initial stage. Diagnostic results highlight several primary constraining elements, including regional technology diffusion capacity, innovation output commercialization efficiency, spatial concentration of manufacturing enterprises, industry-academia-research partnership intensity, and cluster-based economic productivity. These evidence-based insights offer valuable theoretical foundations and practical guidance for optimizing chain integration strategies in regional development contexts.

Keywords: Integrated Development of "Dual Chains"; Entropy Weight Method; Coupling Coordination Degree; Obstacle Degree

1. Introduction

Industrial development constitutes a fundamental pillar for achieving high-quality economic growth, with technological innovation serving as the principal catalyst for such progress. A strategic approach involves coordinating innovation chains based on industrial needs while simultaneously aligning industrial development with technological advancements, thereby accelerating the transition toward an innovation-driven economy. Recent studies have demonstrated that the synergistic development between industrial and innovation systems has emerged as a critical factor in stimulating regional economic expansion.

Statistical data reveals that Guangxi's GDP growth rates during 2016-2021 fluctuated between 3.7% and 7.5%, consistently trailing neighboring provinces in Southwest China including Sichuan and Guizhou [1]. This relative underperformance stems largely from structural weaknesses in Guangxi's industrial composition, which remains predominantly dependent on conventional sectors. With China's economic transformation entering a new phase, the declining growth trajectory of Guangxi's industrial value-added output suggests that traditional industries have reached developmental constraints.

The convergence of industrial and innovation chains represents both an inevitable evolutionary phase and a strategic pathway for industrial modernization. This integrated model promotes the commercialization of research outputs [2], ensures technological solutions address actual production challenges, and enables the modernization of established industries while strengthening competitive sectors. Such coordinated development carries profound implications for unlocking regional economic potential, improving industrial competitiveness, and ultimately realizing sustainable economic advancement.

2. Literature Review

The initial proposal that the industrial chain consists of interconnected industries through input-output relationships was made by foreign scholars [3]. In contrast, the innovation chain is characterized as an organizational framework that encompasses diverse stages of innovation activities [4]. Blackman characterized the merging of industrial and innovation chains as indicative of advancements in technological services and the evolution of industrial structures, whereas other researchers have identified it as innovations arising at well-defined industry boundary intersections [5]. In recent years, numerous domestic scholars have diligently investigated the integration of industrial and innovation chains. For instance, Li Xuesong and colleagues highlighted that these chains can produce both horizontal and vertical synergies, thereby enhancing overall factor productivity mainly through technological progress. Han Jiangbo and his team contended that the notion of industrial and innovation chains emerges from technology push and market pull dynamics, achieving synergies via feedback loops. Furthermore, industrial and innovation chains demonstrate complementary and mutually enhancing effects, with their integration representing a long-term, systematic strategy [6]. In terms of assessing the integration of industrial and innovation chains, researchers frequently construct evaluation index frameworks for these chains. Zhang Qizi and associates evaluated the trade competitiveness index and the dynamic trends across various industries in China. Their analysis of China's role in the global value chain led them to conclude that the dual-spiral advancement of the innovation and industrial chains is pivotal for China's shift from an investment-driven model to one focused on innovation, ultimately fostering high-quality development.

At present, there is no standardized evaluation framework for assessing synergized development of industrial and innovation chains, and the scholarly community frequently undertakes quantitative evaluations regarding their integration status. Regarding research methodologies, scholars mainly utilize principal component analysis, composite system synergy models, coupling coordination degree models, and grey relational analysis models, depending on variations in the measurement targets and the selection of indicators. In terms of research topics, various scholars have engaged in thorough discussions from diverse regional and perspective-based viewpoints. For instance, Wang Xueyuan and Li Jiaxian, adopting a multi-agent collaboration approach, assessed the degree of "inter-chain integration" between industrial and innovation chains and observed higher levels of integration in regions such as Guangdong, Beijing, and Shanghai. Similarly, Zhang Gui and Zhao Yifan noted that the integration of high-tech industrial and innovation chains within the Beijing-Tianjin-Hebei area exhibits a positive trend, albeit with notable differences across various stages. Additionally, Gong Zhongjie and Ma Li, utilizing patent application and company data from the Pearl River Delta city cluster, identified that the electronic computer sector in this area has developed an effective division of labor for both production and innovation, reflecting a substantial level of integration between the industrial and innovation chains.

Drawing from the literature reviewed earlier, it is clear that there has been considerable advancement within the academic realm regarding the understanding of how industrial and innovation chains integrate and the pathways involved. Nonetheless, there are several limitations in current research that warrant attention: Firstly, many studies concentrate on theoretical dimensions, employing qualitative approaches to investigate the integration of industrial and innovation chains, or they focus on summarizing practical experiences, with few addressing the structural mechanisms underlying "dual-chain" integration. Secondly, scholars seldom broaden the investigative lens on "dual-chain" integration to encompass less developed regions in China, like Guangxi, leaving a noticeable gap in the research landscape. In response to these challenges, this paper seeks to introduce innovative approaches as follows: Firstly, it builds on earlier findings to formulate a novel evaluation index system for "dual-chain" integration and applies a coupling coordination degree model to quantitatively measure the synchronized development levels of industrial and innovation chains in Guangxi. Secondly, it examines how various factors influence the integration of "dual chains" in Guangxi, investigates the disparities and underlying reasons when compared to other regions, and offers suggestions tailored to Guangxi's specific features to foster high-quality economic growth in the area.

3. Research Methods

This investigation adopts a structured analytical framework to assess the synergistic relationship between industrial and innovation chains through quantitative measurement techniques. The entropy weighting approach is introduced as the primary methodology for determining indicator importance, which enhances the objectivity and credibility of the evaluation outcomes by reducing human interference and capitalizing on data variability.

3.1 Entropy Weight Method

Indicator weighting approaches typically fall into two categories: subjective assessment techniques and data-driven methods. While subjective approaches depend substantially on expert opinion, potentially introducing evaluation bias, this research employs the entropy method to maintain scientific objectivity. This technique demonstrates clear theoretical foundations, broad applicability, and the capacity to determine weights according to indicator variability. Its effectiveness in addressing inter-indicator relationships makes it particularly suitable for analyzing chain integration.

Originating from thermodynamic principles, entropy quantifies system disorder and has been extensively applied across engineering and socioeconomic domains. Information theory posits that information measures system order, while entropy quantifies disorder - these measures share equal magnitude but opposite polarity. For a system capable of existing in m distinct states, where each state occurs with probability P_i, (where i ranges from 1 to m), the system's entropy can be mathematically expressed as:

$$E = -\sum_{i=1}^{m} P_i \ln P_i \quad (1)$$

Clearly, when $P_i = 1/m (i = 1,2,\cdots,m)$,meaning the probability of each state occurring is equal, the entropy reaches its maximum value:

$$E_{max} = \ln m \quad (2)$$

Now, suppose there are m units to be evaluated and n evaluation indicators, forming the original indicator data matrix $R = (r_{ij})_{m\times n}$ .For a given indicator r_j ,the information entropy is:

$$E_j = -\sum_{i=1}^{m} P_{ij} \ln P_{ij} \quad (3)$$

$$P_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad (4)$$

The principle underlying entropy weighting can be summarized as follows: indicators exhibiting lower information entropy values demonstrate greater variability in their data distribution, thereby containing more substantial informational content and exerting stronger influence in composite assessments. Consequently, such indicators warrant higher weighting coefficients in the evaluation system. On the contrary, indicators characterized by higher entropy values display reduced data variability, contribute less informational value, and consequently merit diminished weighting significance. This fundamental relationship enables the derivation of objective indicator weights through entropy-based calculations that quantify the relative dispersion of each variable's values. By applying these mathematically determined weights to the corresponding indicators, researchers can generate composite evaluation outcomes with enhanced objectivity and reduced subjective bias.

3.2 Construction of the Coupling Degree Model

This paper adopts the concept of coupling in physics to analyze the positive correlation degree between the industrial chain and the innovation chain, quantitatively evaluating the relationship between the "dual chains" to determine their coupling degree.

Let μ be the order parameter of the innovation chain, where μ_{ij} represents the contribution value of each evaluation indicator of the innovation chain, i.e., the j-th variable parameter of the i-th indicator, with i=1,2,…,n; j=1,2…,m. Let ω be the order parameter of the industrial chain, where ω_{ij} represents the contribution value of each evaluation indicator of the industrial chain, i.e., the j-th variable parameter of the i-th indicator, with I = 1, 2, …, n'; j=1,2…, m'. The upper limits α_{ij}, η_{ij} and lower limits β_{ij}, ζ_{ij} of the order parameters for the" dual chains "are determined based on historical data comparisons.

Let x_{ij} and y_{ij} represent the parameters of the j-th variable of the i-th indicator in the order parameters of the "dual chains" subsystems. The evaluation model for the subsystems of the "dual chains" is obtained as follows:

First, the contribution value of each evaluation indicator of the innovation chain is:

$$\mu_{ij} = \frac{x_{ij}-\beta_{ij}}{\alpha_i-\beta_{ij}}(i = 1,2,\cdots,n; j = 1,2\cdots,m) \quad (5)$$

The contribution value of each evaluation indicator of the industrial chain is:

$$\omega_{ij} = \frac{y_{ji}-\zeta_{ij}}{\alpha_j-\eta_{ij}}(i = 1,2,\cdots,n'; j = 1,2\cdots,m') \quad (6)$$

In Equations (5) and (6), the values of μ_{ij} and ω_{ij} range from 0 to 1.A value closer to 1 indicates that x_{ij} and y_{ji} contribute more to their respective subsystems.

Second, the order parameters of the two systems are integrated using the linear weighting method to obtain the contribution models of the evaluation indicators for the innovation chain and industrial chain subsystems:

$$\mu_i = \sum\lambda_{ij} \times \mu_{ij}(i = 1,2,\cdots,n) \quad (7)$$

$$\omega_i = \sum\delta_{ij} \times \omega_{ij}(i = 1,2,\cdots,n') \quad (8)$$

In Equations (7) and (8), $\sum\lambda_{ij} = 1, \sum\delta_{ij} = 1$.

Finally, the coupling correlation function is used to measure the coupling correlation degree between the industrial chain and the innovation chain. The variable C represents the degree of coupling coordination between the innovation and industrial chains. When only two systems interact, the coupling correlation degree is expressed as:

$$C = \sqrt{\frac{\mu\times\omega}{(\mu+\omega)^2}} \quad (9)$$

In Equation (9), the value of C ranges from [0,1]. A higher C indicates a closer degree of integration between the industrial chain and the innovation chain.

3.3 Construction of the Coupling Coordination Degree Model

While the coupling degree measures the correlation level of the "dual chains" it does not reflect their development levels. It is possible for the coupling degree to appear high even when both chains are at a low development level. To further determine the development levels of the innovation chain and industrial chain, a coupling coordination degree model is established for deeper analysis [7].

The coupling coordination degree model is as follows:

$$D = \sqrt{C \times T} \quad (10)$$

$$T = a \times \mu + b \times \omega \quad (11)$$

In the equations, a and b represent the contribution coefficients of the innovation chain and industrial chain, respectively, with a+b = 1. Considering the equal importance of the industrial chain and innovation chain, a=b=0.5. The closer the value of D is to 1, the higher the integrated development level of the "dual chains"[8].

The classification of coupling coordination levels between Guangxi's manufacturing and R&D value chains is determined according to the measured values of their interaction intensity, with detailed categorization presented in Table 1.

Table 1. Hierarchy of Coupling Coordination Degree

Coupling Coordination Degree Interval	Coordination Level	Coupling Coordination Type
0~0.1	1	Extreme Discoordination
0.1~0.2	2	Severe Discoordination
0.2~0.3	3	Moderate Discoordination
0.3~0.4	4	Mild Discoordination
0.4~0.5	5	Near Discoordination
0.5~0.6	6	Barely Coordinated
0.6~0.7	7	Primary Coordination
0.7~0.8	8	Intermediate Coordination
0.8~0.9	9	Good Coordination
0.9~1.0	10	High-Quality Coordination

3.4 Obstacle Degree Model

The obstacle degree model is used to diagnose the obstacle factors that affect the development of a system. It is calculated based on the factor contribution degree F_j and the indicator deviation degree I_{ij}. To directly reveal the main internal factors affecting coupling coordination, this paper adopts this model to analyze the factors that hinder the coupling process. This analysis is beneficial for taking corresponding measures to promote coupling coordination. The calculation formulas are as follows:

$$I_{ij} = 1 - Y_j \quad (12)$$

$$O_j = \frac{F_j I_{ij}}{\sum_{i=1}^{n} F_j I_{ij}} \quad (13)$$

$$Q_j = \sum O_j \quad (14)$$

In the equations, I_{ij} represents the indicator deviation degree; Y_j represents the standardized value of the indicator; F_j represents the factor contribution degree, which can be expressed by the weight of a single indicator; O_j represents the obstacle degree of the subsystem; Q_j represents the obstacle degree of the system [9].

4. Empirical Research

This section systematically examines the synergistic development between industrial and innovation chains in Guangxi through quantitative assessment. Utilizing authoritative datasets and establishing a multidimensional evaluation framework, the research measures the coordinated development level of these dual systems. The subsequent subsections elaborate on data collection procedures, indicator selection criteria, and analytical methodologies for weight determination and integration assessment.

4.1 Data Sources

The investigation utilizes provincial economic statistics spanning 2013-2022, primarily sourced from national statistical compilations including the China City Statistical Yearbook, China Industrial Statistical Yearbook, and China Statistical Yearbook on Science and Technology. Gaps in the dataset were addressed through established imputation techniques to ensure data continuity.

4.2 Construction of the Indicator System

Drawing on existing research literature and the evaluation indicator systems for integration degree, this paper references the research methods of, Wang Yudong et al. [10] and Liu Jiashu et al. [11]. Based on empirical data from innovation activities of industrial enterprises above a designated size, the study constructs an evaluation indicator system for the integration of industrial and innovation chains from the perspectives of these two subsystems. The system adheres to the principles of scientific rigor, objectivity, and authenticity. The indicator attribute "+" indicates a positive correlation between the indicator and the development level of the subsystem. The specific indicators include the following 12 items, which as shown in Table 2.

4.2.1 Industrial chain system

1) Degree of Technology Sharing: Calculation formula: Regional technology market transaction contract amount/National technology market transaction amount. This indicator directly reflects the activity level of the regional technology market and the mobility of technological achievements, indicating the degree of technological integration and collaborative innovation within the industrial chain.

2) Depth of Industry-University-Research Collaboration: Calculation formula: R&D expenditure of industrial enterprises above a designated size to universities/External R&D expenditure of industrial enterprises above a designated size. This indicator is selected based on the core role of industry-university-research collaboration in technological innovation and industrial upgrading, measuring the cooperation level between industrial enterprises and academic institutions.

3) Enterprise Density: The spatial concentration of qualifying industrial enterprises is determined by dividing their total count by the geographic area in square kilometers. This metric serves as a quantitative representation of industrial agglomeration patterns, providing crucial insights into the spatial organization and clustering intensity of manufacturing activities.

4) Agglomeration Benefit Density: The metric is computed by dividing the yearly production value generated per square kilometer by the aggregate profits of qualifying industrial enterprises. This ratio serves as an effective measure of land-use productivity, quantifying the economic returns derived from each unit of industrial land area.

5) Degree of Recycling Utilization: Measured by the comprehensive utilization rate of

industrial solid waste. This indicator reflects the efficiency of resource recycling and environmental protection within the industrial chain.

6) Degree of Ecological Governance: Calculation formula: Completed investment in industrial pollution control projects/GDP. This indicator measures the relationship between regional investment in ecological governance and its total economic output, reflecting the environmental responsibility of the industrial chain.

Table 2. Evaluation Indicator System for Coupling Coordination Degree of Industrial Chain and Innovation Chain

Subsystem	First-Level Indicator	Second-Level Indicator	Specific Indicator	Attribute	Order Parameter
Industrial Chain System	Integration Level	Degree of Technology Sharing	Regional technology market transaction contract amount/National technology market transaction amount	+	ω_{11}
		Depth of Industry-University-Research Collaboration	R&D expenditure of industrial enterprises above a designated size to universities/External R&D expenditure of industrial enterprises above a designated size	+	ω_{12}
	Clustering Level	Enterprise Density	Number of industrial enterprises above a designated size/Per square kilometer	+	ω_{21}
		Agglomeration Benefit Density	Annual output value per square kilometer/Total profit of industrial enterprises above a designated size	+	ω_{22}
	Ecological Level	Degree of Recycling Utilization	Comprehensive utilization rate of industrial solid waste	+	ω_{31}
		Degree of Ecological Governance	Completed investment in industrial pollution control projects/GDP	+	ω_{32}
Innovation Chain System	R&D Capability	Personnel Investment	Full-time equivalent of R&D personnel in industrial enterprises above a designated size	+	μ_{11}
		Basic Research Investment	R&D basic research expenditure/Internal R&D expenditure ratio	+	μ_{12}
		Number of Patents Granted	Number of valid invention patents of industrial enterprises above a designated size	+	μ_{13}
	Achievement Transformation Capability	Technology Market Transaction Volume	Transaction volume of the technology market	+	μ_{21}
		Sales Revenue of New Products	Sales revenue of new products	+	μ_{22}
		Proportion of New Product Exports	Export value of new products/Total export value of goods	+	μ_{23}

4.2.2 Innovation chain system

1) Personnel Investment: This metric quantifies R&D workforce engagement using full-time equivalent measurements within qualifying industrial enterprises, serving as a proxy for human capital allocation toward innovation initiatives.

2) Basic Research Investment: Calculation formula: R&D basic research expenditure/Internal R&D expenditure ratio. This indicator measures the proportion of investment in basic research, reflecting the enterprise's emphasis on long-term innovation capabilities.

3) Number of Patents Granted: Measured by the number of valid invention patents of industrial enterprises above a designated size. This indicator reflects the technological innovation achievements and level of enterprises.

4) Technology Market Transaction Volume: Measured by the transaction volume of the technology market. This indicator reflects the commercialization level of technological achievements and the activity of technology transfer.

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achievements and the activity of technology transfer.

6) Sales Revenue of New Products: Measured by the sales revenue of new products. This indicator reflects the market acceptance of innovation achievements.

7) Proportion of New Product Exports: Calculation formula: Export value of new products/Total export value of goods. This indicator measures the competitiveness of new products in the international market and their contribution to exports.

4.3 Determining Indicator Weights Using the Entropy Weight Method

Step 1: Standardize the raw data using the range method to eliminate the influence of different units.

$$x'_{ij} = \begin{cases} \frac{x_{ij}\text{-}\min(x_{ij})}{\max(x_{ij})\text{-}\min(x_{ij})} \bullet \rho + (1-\rho) \\ \frac{\max(x_{ij})-x_{ij}}{\max(x_{ij})\text{-}\min(x_{ij})} \bullet \rho + (1-\rho) \end{cases} \quad (15)$$

Here, x_{ij} represents the j-th measurement indicator in the i-th year, starting from the first year. $x'ij$ is the standardized measurement indicator. $\max(x_{ij})$ and $\min(x_{ij})$ represent the maximum and minimum values of the indicatorx_{ij},used for dimensionless processing. A value$0 < \rho < 1$ is set, withρ=0.995 to avoid potential issues in calculating natural logarithms.

Table 3. Calculation Results of Indicator Weights

Second-Level Indicator	Entropy Value	Difference Coefficient	Weight	Rank
Degree of Technology Sharing	0.6596	0.3404	0.1594	2
Depth of Industry-University-Research Collaboration	0.8167	0.1833	0.0859	5
Enterprise Density	0.7620	0.2380	0.1115	3
Agglomeration Benefit Density	0.7939	0.2061	0.0965	4
Degree of Recycling Utilization	0.9308	0.0692	0.0324	11
Degree of Ecological Governance	0.9558	0.0442	0.0207	12
Personnel Investment	0.8840	0.1160	0.0543	9
Basic Research Investment	0.8573	0.1427	0.0668	6
Number of Patents Granted	0.8671	0.1329	0.0622	7
Technology Market Transaction Volume	0.5496	0.4504	0.2109	1
Sales Revenue of New Products	0.8784	0.1216	0.0570	8
Proportion of New Product Exports	0.9095	0.0905	0.0424	10

Step 2: Calculate the entropy value$E_j$for each indicator.

$$E_j = -\frac{1}{\ln n}\sum_{i=1}^{n}\left[\left(\frac{x'_{ij}}{\sum_{i=1}^{n} x'_{ij}}\right)\ln\left(\frac{x'_{ij}}{\sum_{i=1}^{n} x'_{ij}}\right)\right] \quad (16)$$

Step 3: Calculate the difference coefficient$G_j$for each indicator.

$$G_j = 1 - E_j\left(0 < E_j < 1\right) \quad (17)$$

Step 4: Calculate the weight ϕ_j for each indicator.

$$\phi_j = \frac{G_j}{\sum_{j=1}^{m} G_j}\left(\sum_{j=1}^{m} G_j = 1\right) \quad (18)$$

The results are shown in Table 3.

4.4 Measurement of Integration Level

Step 1: The integrated assessment values for both industrial and innovation chain subsystems are computed by implementing the mathematical formulations specified in Equations (5)-(8).

Step 2: Calculate the coupling degree of Guangxi's "dual chains" based on Equation (9).

Step 3: Calculate the comprehensive coordination index and coupling coordination degree of Guangxi's "dual chains" based on Equations (10) and (11).

The results are shown in Table 4:

Table 4. Integration Development Level of Guangxi's Dual Chains

Year	Industrial Chain Comprehensive Development Evaluation Index	Innovation Chain Comprehensive Development Evaluation Index	Comprehensive Coordination Index	Coupling Degree	Coupling Coordination Degree
2013	0.1811	0.0758	0.1284	0.4561	0.2420
2014	0.0890	0.0730	0.0810	0.4976	0.2007
2015	0.0866	0.0818	0.0842	0.4998	0.2052
2016	0.0899	0.1400	0.1149	0.4880	0.2368

2017	0.0582	0.1275	0.0928	0.4639	0.2075
2018	0.1016	0.1661	0.1338	0.4853	0.2549
2019	0.1197	0.1704	0.1451	0.4923	0.2672
2020	0.1534	0.1463	0.1499	0.4999	0.2737
2021	0.3301	0.4242	0.3771	0.4961	0.4325
2022	0.2498	0.2351	0.2425	0.4998	0.3481

From the data in Table 4, it can be observed that during the period 2013–2022, the comprehensive development levels of Guangxi's industrial chain and innovation chain generally showed a fluctuating upward trend. Specifically, from 2013 to 2015, as well as in 2020 and 2022, the comprehensive development level of the industrial chain was higher than that of the innovation chain, indicating a stronger driving effect of the industrial chain on economic development. From 2016 to 2019 and in 2021, the comprehensive development level of the innovation chain was higher, surpassing that of the industrial chain, indicating a stronger driving effect of the innovation chain on economic development. The analysis reveals that Guangxi's industrial-innovation chain integration exhibited moderate incoordination during 2013-2020, approaching balanced status in 2021, and showed slight imbalance in 2022. This progression demonstrates that the region's dual-chain convergence continues to operate at a preliminary stage of development.

4.5 Obstacle Degree Analysis

The analysis of constraint factors in Guangxi's dual-chain integration system during 2013-2019 is visually presented in Figures 1 and 2. These graphical representations reveal that among industrial chain components, technology diffusion capacity emerges as the most significant limiting factor, whereas for innovation chain elements, technology commercialization volume constitutes the primary constraint.

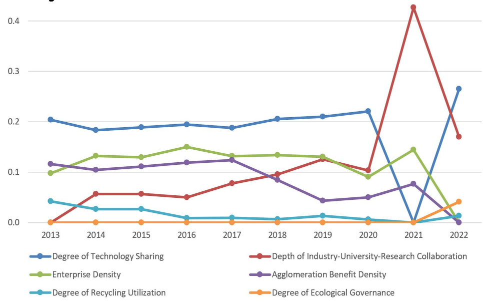

Figure 1. Obstacle Degrees of Indicators in the Industrial Chain Subsystem

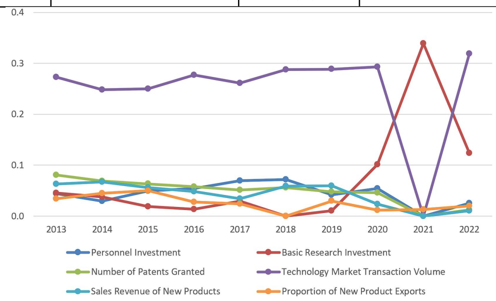

Figure 2. Obstacle Degrees of Indicators in the Innovation Chain Subsystem

Using Equations (15), (16), and (17), the obstacle factors for the integration of Guangxi's "dual chains" from 2013 to 2019 were calculated, and the top five obstacle factors for each year are listed. As shown in Table 5,the most frequently occurring obstacle factors are: Technology Market Transaction Volume(X_{10}),appearing 9 times; Degree of Technology Sharing(X_1),appearing 9 times;Enterprise Density(X_3),appearing 9 times;Depth of Industry-University-Research Collaboration(X_2),appearing 6 times;and Agglomeration Benefit Density(X_4),appearing 6 times.

Table 5. Top Five Obstacle Factors for the Integration of Guangxi's "Dual Chains"

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
X_{10}	X_{10}	X_{10}	X_{10}	X_{10}	X_{10}	X_{10}	X_{10}	X_2	X_{10}
X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_8	X_1
X_4	X_3	X_3	X_3	X_3	X_3	X_3	X_2	X_3	X_2
X_3	X_4	X_4	X_4	X_4	X_2	X_2	X_8	X_4	X_8
X_9	X_9	X_9	X_9	X_2	X_7	X_{11}	X_3	X_{12}	X_6

5. Conclusions and Recommendations

This section summarizes the key findings from the empirical analysis and provides actionable recommendations to enhance the integration of Guangxi's industrial and innovation chains. The study reveals the current state of "dual chain" integration, identifies major obstacles, and proposes strategies to promote high-quality development. The following subsections detail the conclusions drawn from the research and offer specific policy and practical recommendations to address the identified challenges.

5.1 Conclusions

5.1.1 The longitudinal analysis spanning 2013-2022 demonstrates that Guangxi's industrial and innovation chains exhibited a progressive yet unstable developmental trajectory. Specifically, the coupling coordination analysis reveals three distinct phases: a prolonged period of moderate incoordination (2013-2020), transitional near-coordination status in 2021, and subsequent advancement to mild incoordination by 2022. These empirical results collectively suggest that the synergistic development between these two economic systems remains at a preliminary stage with considerable potential for enhancement.

5.1.2 Findings on obstacle degree analysis

Through systematic examination of subsystem indicators and computation of constraint indices for the 2013-2019 period, five primary limiting factors were identified within the industrial chain dimension. The obstacle degree analysis highlights the following key constraints in descending order of significance: technology diffusion capacity (quantified by regional technology market share), commercialization efficiency of technological outputs, spatial concentration of industrial enterprises, collaborative intensity between industry and academia, and land productivity in industrial clusters. These constraining elements collectively contribute to the observed developmental challenges in the region's industrial-innovation integration process.

The research outcomes indicate that while Guangxi has achieved measurable progress in coordinating its industrial and innovation systems, the integration process continues to face multiple structural barriers. The evolutionary pattern from moderate to mild incoordination suggests gradual improvement, yet the persistent constraints in technology transfer and industrial organization underscore the necessity for targeted policy interventions. These findings provide valuable empirical evidence for understanding the complex dynamics of regional industrial-innovation integration in developing regional economies.

5.2 Recommendations

5.2.1 Fostering the development of "specialized, refined, unique, and innovative" SMEs to boost agglomeration benefits

To begin with, the current criteria for certifying "Little Giant" enterprises need suitable modifications, particularly by incorporating favorable policies concerning output value recognition in western regions. This approach aims to inspire higher engagement from enterprises in these areas. This is crucial for start-ups and transitional firms that frequently encounter funding challenges. Thus, it is essential to enhance financial assistance for these businesses, which may include establishing more direct financing avenues and offering a wider range of funding options. Secondly, raising the efficiency of tax and fee support can be achieved through the development of favorable tax regulations for specialized, refined, unique, and innovative SMEs, aimed at lowering their tax liabilities and boosting their profitability and capacity for reinvestment. Concurrently, improving government services by streamlining administrative approval procedures and enhancing the efficiency and convenience of policy execution is necessary. Lastly, accelerating enterprises' digital transformation is vital, which can be facilitated by promoting the use of cutting-edge technologies like cloud computing, big data, and artificial intelligence to improve their management capabilities and foster technological innovation. Furthermore, it is important to nurture a cohort of professional digital transformation service providers to deliver specialized assistance to SMEs and to create dedicated funds to support projects related to enterprise digital transformation.

5.2.2 Strengthening the internal motivation of the innovation chain and encouraging the deep integration of industry, academia, and research

Guangxi should increase financial support for basic research, particularly in cutting-edge fields such as materials science and information science, to ensure a continuous source of scientific and technological innovation. In addition, establish a cooperation development special fund for promoting the applied researches and technical innovation of industry-academia-research connection; intensify cultivating and attracting scarce talents; and cooperate with Chinese domestic or foreign universities or scientific institutes to build a pool talent training base and R&D center. Introduce preferential policy to attract outstanding talents to come to work in our region, thereby giving full play to supporting personnel force under conditions of enterprise developing demands. Based on this solid ground, establish an effective association joint R&D project including consolidation resources & sharing information--developing technology & transforming achievements etc., among industry-academia-research key technology deep collaboration.

5.2.3 Promoting the synchronized development of the industrial chain and innovation chain

Firstly, support enterprises at all levels of the industrial chain to cooperate in technology innovation. Build an industrial technology innovation alliance and promote the development of technology and industry together, enhance the stickiness of the industrial chain and the execution degree of the innovation chain. Secondly, reconstruct the innovation chain, first ensure that leading scientific research institutions and enterprise groups are supported, so that scientific and technological achievements can quickly be converted into output results of the industrial chain. Thirdly, implement the industrial chain expansion plan, guide enterprises to enter downstream profitable links as much as possible, and actively cultivate new industrial chains to make more realizable innovative chains.

5.2.4 Improving the ecosystem for dual-chain integration and promoting open and efficient resource utilization

Firstly, perfect the policy system, and introduce a series of policy support policies for dual-chain connection in aspects such as tax reduction, finance, and talent introduction; Secondly, build a resource sharing mechanism, encourage and promote the open sharing of scientific research experimental equipment, talents, information, and other innovation resources, and pay attention to the utilization efficiency of innovation resources; Thirdly, create a market environment, use market demand to promote technology development and innovation, and make the results of the innovation chain the competitiveness of the industrial chain.

5.2.5 Integrating into the open development framework and promoting leapfrog development

Firstly, we need to make a plan for opening strategy in order to deepen the close relationship of economic cooperation with countries and regions along the "Belt and Road", drive the international market of domestic products and services of Guangxi, and create a better business environment to attract foreign companies to introduce advanced technologies. Secondly, in order to promote closer cooperation between Guanxi and the Greater Bay Area, an industrial undertaking platform should be built on the basis of forming corresponding cooperative matching relationships between Nanning city and Liuzhou city and other cities in the Greater Bay Area through building cross-city industry chains, using the scientific and technological innovation resources in the Greater Bay Area to introduce or nurture high-end manufacturing industries; enclave parks can also be built and used in the Greater Bay Area cities to support the circulation and development of innovative elements such as technology, talents, and capital. Learn from it to improve the enterprise operation environmental system by simplifying government affairs, reducing levies and charges, improving administrative management service level, improving customs clearance facilitation level, etc.; cooperate more actively in new science and education collaboration construction between universities/institutions and enterprises in this area.

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References

[1] Jiang Hongqun. The Impact and Countermeasures of Guangxi's Economic Slowdown under the New Normal. Guangxi Social Sciences, 2018(3): 36-40.

[2] Hong Yinxing, Li Wenhui. The Dilemma and Solutions for the Modernization of Less-Developed Regions in the Construction of a Unified National Market.

Contemporary Economic Research, 2025(1): 5-12.
[3] Hirschman A O. The Strategy of Economic Development. New Haven: Yale University Press, 1958: 62-75.
[4] Visvanathan S. From Laboratory to Industry: A Case Study of the Transfer of Technology. Contributions to Indian Sociology, 1977, 11(1): 117-136.
[5] Blackman C R. Convergence between Telecommunications and Other Media: How Should Regulation Adapt. Telecommunications Policy, 1998, 22(3): 163-170.
[6] Han Jiangbo. Research on the Integration of Innovation Chains and Industrial Chains: Based on Theoretical Logic and Mechanism Design. Journal of Technology Economics and Management Research, 2017(12).
[7] Qiao Pengliang. Research on the Coupling Development of Strategic Emerging Industries and Traditional Industries in Guangxi. Guangxi Social Sciences, 2014(3): 24-27.
[8] Wang Lu, Fang Xingming. Spatiotemporal Evolution and Driving Factors of the Coupling Coordination between Social Welfare Levels and Resource Consumption. Ecological Economy, 2025, 41(1): 185-194.
[9] Yang Xiumin, Geng Jing, Xu You, et al. Spatiotemporal Changes and Obstacle Diagnosis of Land Comprehensive Carrying Capacity in Hainan Island Based on the TOPSIS Model. Acta Ecologica Sinica, 2022, 42(22): 9324-9334.
[10] Wang Yudong, Zhang Bo, Wu Chuan, Xu Yulian. Research on the Synergy Measurement of Innovation Chains and Capital Chains in High-Tech Industries: Based on a Composite System Synergy Model. Science and Technology Progress and Policy, 2019, 36(23): 63-68.
[11] Liu Jiashu, Shi Hongbo, Zhou Mengqi. Research on the Effect of Innovation Chain and Capital Chain Integration on High-Quality Economic Development. Review of Economy and Management, 2022(1): 103-115.