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Grey Relational Analysis of Industrial Structure and Economic Growth in Guangdong Province from an Incremental Perspective

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Abstract: The optimization and upgrading of the industrial structure are key drivers of high-quality economic development. As the largest provincial economy in China, Guangdong's industrial evolution serves as a bellwether for the nation. Based on an incremental perspective, this paper measures the correlation between industrial fluctuations and GDP in Guangdong Province from 2014 to 2023.The research results indicate that the Tertiary Industry shows the highest degree of correlation, with other service industries and Transportation, Storage & Postal services performing particularly prominently; In the Secondary Industry, the synchronization of the Construction Industry is significantly higher than that of the industrial sector, indicating that the investment side within the secondary industry is more sensitive to incremental fluctuations. The Primary Industry has the lowest synchronization, which is consistent with the characteristics of Guangdong's agricultural structure. Based on these findings, this paper proposes policy recommendations to provide references for the sustained and healthy development of Guangdong Province's economy.

Keywords: Guangdong Province; Industrial structure; Economic growth; Grey relational analysis

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1. Introduction

Economic growth and industrial structure evolution are interdependent and mutually reinforcing, where the industrial structure is both the result of past economic growth and the foundation for future high-quality development. The Third Plenary Session of the 20th Central Committee proposed "accelerating the formation of institutions and mechanisms better adapted to new quality productive forces," charting the course for the high-end, intelligent, and green upgrading of the industrial structure during the "15th Five-Year Plan" period. As the province with the largest economic output and the highest level of openness in China, Guangdong has ranked first in GDP for 35 consecutive years. The evolution of its industrial structure not only determines the level of high-quality development within the province but also has a demonstrative effect nationwide.

Currently, Guangdong is in a critical period of transforming its development model and shifting its growth drivers. Addressing traditional factor constraints and cultivating new quality productive forces have become core tasks. This paper adopts the grey relational analysis method to systematically evaluate the correlation intensity between the three industries and their subdivided sectors of Guangdong Province and the regional GDP over the period 2014–2023. This provides a basis for local industrial policy formulation and the implementation of the "15th Five-Year Plan," while also offering references for national industrial optimization.

2. Literature review

Over the past decades, Grey Relational Analysis has been widely adopted as the core tool to uncover the non-linear nexus between industrial structure and economic growth. Qian *et al.* found, using Henan panel data, that the secondary industry still exhibits the strongest linkage with GDP, yet the gap with the tertiary sector is narrowing, signalling that central provinces are approaching the late-industrialisation turning point [1]. Ji coupled grey relational analysis with GM(1,1) and showed that while Guangdong's tertiary sector leads overall, only real estate stands out internally, with advanced manufacturing remaining the main engine of industrial growth [2]. Mo confirmed the robust "secondary-primary-tertiary" ranking at the prefecture level and found even smaller linkage gaps at the county level, providing a basis for region-specific policies [3]. Tang *et al.* proposed a cyclic-residual-corrected GM(1,1) framework that markedly reduces forecasting errors in small, high-volatility samples, offering a reliable tool for county-level industrial planning [4]. Tao *et al.* employed a PVAR model to verify that long-run equilibrium and short-run dynamic feedback exist between economic growth and industrial upgrading, setting policy boundaries for grey relational results [5].

Bai & Chen confirmed, using Chinese provincial panels, that industrial structure upgrading exerts a significant positive effect on growth quality, with stronger impacts in high-income regions [6]. McArthur & McCord found an inverted-U relationship between manufacturing share and GDP growth in sub-Saharan Africa, furnishing new cross-country evidence of premature de-industrialisation [7]. Rodrik argued, via sectoral decomposition, that producer services yield a markedly higher marginal contribution to total factor productivity than consumer services, though the sample is OECD-heavy and extrapolation to transition economies requires caution [8]. Li & Qin first combined grey relational analysis with a spatial Durbin model and showed that raising sectoral linkage coefficients significantly enhances TFP spillovers to neighbouring regions, endowing grey relational findings with spatial policy relevance [9].

These studies indicate that grey relational analysis has covered provincial-city-county layers in China and gained forecasting power through residual correction, while overseas research has coupled it with spatial econometrics to verify sectoral spillovers on productivity. However, existing research predominantly focuses on the level of three broad industrial sectors, leaving a relative gap in fine-grained measurement of long-term grey correlations between "industry categories" and GDP following the 2019 industrial classification revision. Additionally, integrated studies combining correlation diagnosis and trend prediction remain insufficient.

Therefore, based on GDP data of Guangdong Province from 2014 to 2023, this study employs Grey Correlation Analysis to systematically measure the correlation strength between the three major industries (along with their subsectors) and GDP, identifying core driving sectors such as finance, information software, and advanced manufacturing. This provides a scientific basis and decision-making reference for cultivating new quality productive forces and achieving high-quality development in Guangdong during the "15th Five-Year Plan" period.

3. Indicator construction and data sources

3.1. Indicator selection

To comprehensively evaluate the economic development level and industrial structure characteristics of Guangdong Province, this paper, based on the National Bureau of Statistics' "Industrial Classification for National Economic Activities" (GB/T 4754-2017) and the 2019 revision, selects 13 representative indicators for Guangdong Province from 2014 to 2023. The specific classifications are as follows:

(1) Reference Sequence: Gross Regional Product (GDP, X_0);

(2) Primary Industry: Primary Industry Output Value (X_1), Agriculture, Forestry, Animal Husbandry & Fishery Output Value (X_4);

(3) Secondary Industry: Secondary Industry Output Value (X_2), Industrial Output Value (X_5, including Mining, Manufacturing, Production and Supply of Electricity, Heat, Gas & Water), Construction Output Value (X_6);

(4) Tertiary Industry: Tertiary Industry Output Value (X_3), Wholesale & Retail Trade Output Value (X_7), Transportation, Storage & Postal Services Output Value (X_8), Accommodation & Catering Output Value (X_9), Financial Industry Output Value (X_{10}), Real Estate Output Value (X_{11}), Other Services Output Value (X_{12}, including Information Transmission, Software & IT Services, Leasing & Business Services, Scientific Research & Technical Services, etc.)

3.2. Data sources and processing

Data are sourced from the National Bureau of Statistics website and are current price data (price fluctuations have been eliminated to ensure time series comparability). To eliminate dimensional differences, the original data were standardized using the "Mean Value Method," with Equation (1):

$$\bar{x}_j(k) = \frac{x_j(k)}{\bar{x}_j} \quad (1)$$

$$(j=0,1,\ldots,m;\ k=1,2,\ldots,n)$$

Where $\bar{x}_j=\frac{1}{n}\sum_{k=1}^{n} x_j(k)$ represents the average value of the j-the indicator from 2014 to 2023.

Considering that absolute scale can easily mask the true pulling effect of industrial growth rate fluctuations on economic growth, this paper uses the annual increment of each indicator as the research sequence to calculate its grey relational degree with the GDP increment . Some incremental data show negative values (For example, the value added increment of the secondary industry in 2023 is $\triangle X_2'=-0.065$), mainly due to short-term capacity adjustments in traditional industries (such as textiles, chemicals) within the industrial sector. This has been supplemented with explanations based on annual industry reports.

3.3. Data presentation

The core data for GDP and various industries in Guangdong Province from 2014 to 2023 (Unit: 100 million Chinese Yuan) are shown in **Table 1**.

Table 1. GDP and data of various industries in Guangdong Province (2014–2023)

Industry	2014	2015	2016	2017	2018
X_0	69,593.40	75,820.80	83,493.40	93,004.80	101,875.90
X_1	3,038.70	3,189.80	3,500.50	3,611.40	3,836.40
X_2	31,930.40	33,913.80	35,499.20	38,536.60	41,398.50
X_3	34,624.30	38,717.30	44,493.70	50,856.70	56,641.10
X_4	3,118.40	3,275.10	3,593.60	3,712.70	3,948.90
X_5	29,497.80	31,315.50	32,677.90	35,344.00	37,651.10
X_6	2,496.20	2,684.40	2,909.50	3,289.30	3,849.80
X_7	7,946.30	8,030.90	8,924.70	9,642.10	10,476.00
X_8	2,507.80	2,680.50	2,896.10	3,187.70	3,386.30
X_9	1,333.40	1,452.80	1,575.90	1,654.30	1,749.40
X_{10}	4,872.80	6,119.70	6,570.00	7,311.20	7,962.30
X_{11}	5,486.00	6,149.70	6,615.70	7,688.90	8,533.70
X_{12}	12,334.80	14,112.30	16,656.80	19,620.50	22,744.80
Industry	**2019**	**2020**	**2021**	**2022**	**2023**
X_0	110,468.10	113,708.90	127,577.40	132,547.10	137,905.40
X_1	4,350.60	4,732.70	4,984.70	5,340.40	5,555.20
X_2	43,528.60	43,756.40	50,555.80	52,843.50	52,679.50
X_3	62,588.80	65,219.70	69,179.00	70,934.70	79,670.70
X_4	4,478.30	4,880.80	5,153.70	5,541.70	5,769.20
X_5	39,222.00	39,004.80	44,513.30	45,547.50	46,177.60
X_6	4,415.00	4,864.10	5,602.20	5,956.40	6,675.60
X_7	11,005.30	10,728.90	12,151.00	12,571.50	13,328.20
X_8	3,614.20	3,361.40	4,079.00	4,410.50	4,904.20
X_9	1,930.50	1,609.60	1,979.80	1,958.60	2,292.60
X_{10}	8,751.20	10,122.80	11,115.60	11,685.70	12,018.70
X_{11}	9,543.20	10,377.00	11,042.80	10,450.60	11,151.10
X_{12}	25,598.00	26,943.30	30,355.60	32,768.30	35,588.40

Data Source: National Bureau of Statistics

4. Empirical analysis

4.1. Grey relational analysis method

Grey relational analysis determines the degree of influence of various variables on the reference variable by calculating the grey relational degree between the reference sequence and each comparison sequence. The specific steps are as follows:

Sequence determination: Denote the reference sequence as $X_0=\{x_0(1), x_0(2), ..., x_0(n)\}$, and the comparison sequences as $\{x_j(1), x_j(2), ..., x_j(n)\}$, j=1, 2, ..., m.

Data standardization: Standardize the original data by mean value, specifically using Equation (2).

$$\bar{x}_j(k) = \frac{x_j(k)}{\bar{x}_j} \tag{2}$$

Calculate the relational coefficient using Equation (3).

$$\mu_{0j}(k) = \frac{\min \Delta_{0j} + \rho \max \Delta_{0j}}{\Delta_{0j}(k) + \rho \max \Delta_{0j}} \tag{3}$$

Where $\Delta_{0j}(k)=|x_0(k)-x_j(k)|$ (the absolute difference between the reference sequence and the comparison sequence), and the resolution coefficient (ρ = 0.5). (Based on the data characteristics of this paper, verification through sensitivity analysis indicates that when ρis in the range of 0.1 to 0.9, there is no significant change in the ranking of correlation degrees; thus, the commonly used value of 0.5 is selected).

Calculate the relational degree, referring to Equation (4).

$$\xi_j = \frac{1}{n} \sum_{k=1}^{n} \mu_{0j}(k) \ (j=0, 1, \cdots, m; k=1, 2, \cdots, n) \tag{4}$$

4.2. Calculation process

The incremental sequence for the years 2014–2023 was calculated, and normalized to obtain the absolute differences Δ_{0j} for each year. The minimum difference $\min\Delta_{0j}$=0.023 and the maximum difference $\max\Delta_{0j}$=2.704 was determined. The correlation coefficient was calculated using the formula above (Ta**ble 2**).

Table 2: Correlation Coefficients between Each Industry and GDP for the Years 2014–2023

Year	γX_1	γX_2	γX_3	γX_4	γX_5	γX_6
2014	0.91	0.87	0.921	0.875	0.799	0.875
2015	0.865	0.966	1	0.842	0.999	0.792
2016	0.904	0.795	0.895	0.96	0.793	0.751
2017	0.649	0.95	0.963	0.644	0.961	0.789
2018	0.835	0.961	0.98	0.807	0.918	0.958
2019	0.652	0.839	0.943	0.701	0.781	0.933
2020	0.601	0.823	0.931	0.622	0.746	0.733
2021	0.639	0.658	0.98	0.631	0.708	0.669
2022	0.689	0.871	0.841	0.841	0.701	0.89
2023	0.934	0.671	0.931	0.96	0.784	0.897
Year	γX_7	γX_8	γX_9	γX_{10}	γX_{11}	γX_{12}
2014	0.658	0.838	0.852	0.968	0.936	0.995
2015	0.703	0.918	0.903	0.646	0.955	0.938
2016	0.765	0.906	1	0.791	0.801	0.991
2017	0.961	0.935	0.716	0.854	0.89	0.965
2018	0.877	0.8	0.799	0.837	0.984	0.942
2019	0.859	0.869	0.815	0.951	0.873	0.987
2020	0.636	0.52	0.334	0.524	0.689	0.931
2021	0.862	0.987	0.867	0.754	0.625	0.775
2022	0.929	0.706	0.651	0.938	0.518	0.828
2023	0.738	0.857	0.43	0.857	0.867	0.783

4.3. Relational degree results and analysis

The average relational degrees between each industry and GDP from 2014 to 2023 were calculated. The relational degrees of each industry with GDP are, in order: 0.7678, 0.8404, 0.9385, 0.7883, 0.819, 0.8287, 0.7988, 0.8336, 0.7367, 0.812, 0.8138, 0.9135. The results are shown in **Table 3**.

Table 3. Relational degree and ranking of various industries with GDP

Industry	Relevance	Rank
X_1	0.7678	11
X_2	0.8404	3
X_3	0.9385	1
X_4	0.7883	10
X_5	0.819	6
X_6	0.8287	5
X_7	0.7988	9
X_8	0.8336	4
X_9	0.7367	12
X_{10}	0.812	8
X_{11}	0.8138	7
X_{12}	0.9135	2

4.3.1. The three major industries

The tertiary sector has the highest correlation coefficient, indicating that its incremental changes are highly synchronized with GDP growth, signalling that Guangdong has entered a "service-led" stage. The tertiary sector accounted for more than half of GDP in 2023, with other services contributing significantly due to the rapid growth of new business forms such as the digital economy and technology services. The secondary sector still has a strong supporting role, with the construction industry having a higher correlation coefficient than industry, reflecting the investment-driven economic pull of urban renewal and new infrastructure in Guangdong. The primary sector has the lowest correlation coefficient, consistent with Guangdong's "small agriculture" characteristics, and its incremental fluctuations are less synchronized with GDP due to natural conditions and planting cycles.

4.3.2. Subsectors

High-synchronization industries, like other services (X_{12}), transportation, storage, and postal services (X_8), and construction (X_6) are the core driving forces. The high correlation of X_{12} is mainly due to the fact that the growth rate of new business forms, such as information transmission and technology services is significantly higher than that of GDP, making it an important engine within the service industry. X_8 benefits from the construction of logistics hubs and cross-border channels in the Greater Bay Area, with freight volume continuing to expand and highly synchronized with the regional economic rhythm. X_6 relies on urban renewal, urban village renovation, and new infrastructure, with strong investment demand and close linkage with economic increments. Low-synchronization industries, including accommodation and catering (X_9) has the lowest correlation. During the repeated outbreaks of the epidemic, its revenue declined significantly, and its recovery pace lagged behind the overall economy, resulting in weak synchronization. The financial industry (X_{10}) has a medium correlation due to adjustments in monetary policy and real estate regulation, the pace of credit allocation deviates from GDP fluctuations to a certain extent, suppressing synchronization.

5 . Conclusions and recommendations

5.1. Research conclusions

The industrial pattern of the three major industries in Guangdong Province presents a "tertiary, secondary, primary" situation, which is highly consistent with the "Petty-Clark" law. Other services, transportation, storage, and postal services, and construction are the core driving forces for incremental growth. The accommodation and catering industry and the primary industry have weaker synchronization, while the financial industry deviates from GDP due to policy regulation. This structure provides a clear basis for monitoring short-term fluctuations and formulating classified policies.

5.2. Policy recommendations

5.2.1. Strengthen high-synchronization sectors to reinforce core pulling force

Targeting other service industries (X12), transportation, storage, and postal services (X8), and construction (X6), differential measures will be formulated in light of empirical results and policy orientations. For other service industries, relying on policies such as the "Guangdong Province Development Plan for the Software and Information Service Strategic Pillar Industry Cluster (2023–2025)", digital service agglomeration zones will be laid out in the Guangdong-Hong Kong-Macao Greater Bay Area, with a focus on nurturing new business forms such as industrial internet and technology consulting. In the transportation, storage, and postal services sector, taking national logistics hubs like Guangzhou and Shenzhen as carriers, the construction of cold chain logistics infrastructure will be expanded, cross-border logistics routes between the Greater Bay Area and ASEAN will be launched, and logistics service efficiency will be optimized to reduce logistics costs. Regarding the construction industry, efforts will be concentrated on non-real estate areas such as urban renewal and affordable housing, in connection with the "Guangdong Province Green Building Development Regulations" and the "Guangdong Province Carbon Peak Implementation Plan in the Urban and Rural Construction Field", to steadily increase the proportion of prefabricated buildings in new constructions and to advance the renovation of urban villages, avoiding reliance on commercial housing development.

5.2.2. Support low-synchronization sectors to enhance adaptability

For Accommodation & Catering (X_9), Agriculture, Forestry, Animal Husbandry & Fishery (X_4), and Wholesale & Retail Trade (X_7), leverage existing policy systems for targeted efforts. In terms of the accommodation and catering industry, in combination with the "High-Quality Development Project of Hundreds of Counties, Thousands of Towns and Tens of Thousands of Villages", the "Guangdong Flavored Culture and Tourism Joint Ticket" will be launched. Consumption coupons will be issued through linked platforms to boost the increase of tourist sources. In terms of agriculture, forestry, animal husbandry and fishery, 103 modern agricultural cross-county clusters will be embedded. The provincial agricultural credit guarantee fund will be utilized to enhance the loan coverage rate of characteristic agricultural products. In terms of the wholesale and retail industry, relying on the "Implementation Details of Guangdong Province's County Commercial Construction Action", the "Guangdong Trade Nationwide" exhibition group will be organized to promote the increase of agricultural product sales outside the province.

5.2.3. Strengthening the industrial base and enhancing the resilience of industrial chains

In response to the situation where the correlation degree of industry (X_5) is in the middle, we focus on digitalization, greening, and industrial chain security. In terms of digitalization, in accordance with the "Implementation Plan for the Digital Transformation of Manufacturing in Guangdong Province", we will achieve a device networking rate of more than 80% for large-scale industrial enterprises and provide subsidies for enterprises that have completed the transformation. In terms of greening, relying on the "Implementation Plan for Carbon Peak in the Industrial Field of Guangdong Province", we will provide free energy-saving diagnosis for enterprises, increase the quota of "carbon efficiency loans", and support energy-saving projects. In terms of industrial chain security, we will deepen the "chain leader + chain master" mechanism, focus on ensuring the industrial chains of electronic information, new energy vehicles, etc., establish a "white list" of supporting enterprises, and provide joint supply guarantee services.

5.2.4. Optimizing financial services to promote synchronization of industry chains

In response to the relatively low correlation degree of the financial industry (X_{10}), we will strengthen cross-border and inclusive financial instruments. In terms of cross-border finance, in accordance with the "Opinions on Financial Support for the Construction of the Guangdong-Hong Kong-Macao Greater Bay Area," we will expand the participation quota of the "Cross-Border Wealth Management Connect" and promote the scale of cross-border transfer of supply chain accounts receivable. In terms of inclusive finance, we will promote "Guangdong Trade Loan" and "Science and Technology Loan" to increase the loan coverage rate of manufacturing and science and technology innovation enterprises. Relying on the Guangzhou Futures Exchange, we will guide new energy enterprises to use industrial silicon and lithium futures for hedging to reduce the impact of price fluctuations.

5.3. Research limitations and prospects

Although this paper supplements the long time-series data for 2014–2023, it does not incorporate emerging indicators such as R&D input and the digital economy, which could be added in future studies. Additionally, grey relational analysis focuses on static correlation; in follow-up research, a VAR model can be introduced to examine the dynamic causal relationship between industries and GDP, providing more comprehensive support for policy formulation.

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