A Study on the Measurement of Digital Economy Development from the Perspective of High-Quality Development-Taking Guangdong Province as an Example

Zihui Ling*

School of Business, Hunan University of Science and Technology, Xiangtan 411201, Hunan, China

*2579767677@qq.com

Abstract. As China's economic development enters a new stage, high-quality development has become a fundamental requirement for China's economic and social development, and the digital economy is an important engine for promoting high-quality economic development. Therefore, this study takes Guangdong Province as an example, using the entropy weight method and coupling coordination degree model to quantitatively evaluate the level and quality of its digital economy development from 2020 to 2024 based on the connotation of high-quality development. The study found that : 1) The level of high-quality development of Guangdong's digital economy has steadily improved, with a five-year growth rate of 163.5% in the comprehensive score; 2) The development of subsystems is uneven, with the economic dimension leading the way, the social dimension showing significant progress but large fluctuations, and the ecological dimension showing results but being unstable; 3) The synergy between systems has increased, with some subsystems achieving high coupling and low coordination, but the three major systems as a whole are still in a stage of barely coordinated development.

Keywords: Digital Economy, High-Quality Development, Entropy Weight Coupling, Guangdong Province

1 Introduction

The digital economy is a current hot topic in academic research and practical development. At the same time, the Party and the State have established high-quality economic development as the core theme of China's economic development in the new era. Against this backdrop, the digital economy has become a key lever for promoting high-quality economic development. New digital infrastructure, including big data, AI, IoT, blockchain, and cloud computing have spawned new business forms and models such as digital management, manufacturing, trade, and finance, pushing the economy toward deeper digitalization and intelligence. The 20th CPC National Congress Report called for accelerating the digital economy, while the Digital China

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Construction Overall Layout Plan (2023) proposed to accelerate the construction of Digital China, cultivate core digital industries to promote high-quality development. Therefore, analyzing the coupling and coordination mechanism between the digital economy and high-quality development can provide a path reference for enhancing economic efficiency and unleashing the full potential of digital growth.

Currently existing research on the digital economy is extensive. For research dimensions, studies have explored its empowering effects on green ecology [1-2], efficiency improvement and social equity [3-4], and its role in agricultural modernization and urban-rural coordination [5-6]. Methodologically, researchers have employed diverse approaches: the CGE model to simulate digital finance transmission channels [7], the ZINB model to examine platform economy effects on enterprise innovation [8], and the diamond model to analyze factors influencing digital trade competitiveness [9]. Regarding indicator system construction, existing studies exhibit multi-level characteristics. At the macro level, evaluation systems typically include digital infrastructure, industrialization, industrial digitalization, and environment [10], or dimensions such as infrastructure, industrial foundation, and support capacity [11]. At the meso level, studies focus on the integration of digital economy with manufacturing, covering informatization, digitalization, networking, intelligence, and virtualization [12] and with agriculture, selecting indicators such as digital facility planting, digital forestry, and automated breeding [13]. At the micro level, evaluation systems have been constructed around innovation resources and environment [14], green production, life, and ecology in rural contexts [15], affluence and commonality for common prosperity [16], and digital infrastructure, technology level, trade capability, and potential for digital trade [17-18].

In summary, current research largely focuses on measuring the scale of the digital economy or a single dimension. Although the indicator systems are becoming increasingly diverse, they generally fail to integrate the “five concepts” of high-quality development. Furthermore, research tends to focus on the national macro level, lacking in-depth analysis of specific provinces and rarely combining objective weighting with coupling coordination analysis. To address this gap, this study employs the entropy weight method and a coupling coordination degree model to construct a measurement system based on the five concepts of “innovation, coordination, green development, openness, and sharing.” Using data from Guangdong Province from 2020 to 2024, it conducts a systematic coupling diagnosis to reveal development quality, potential shortcomings, and interaction patterns, providing a decision-making reference for regional high-quality development of the digital economy.

2 Study Area, Methods, and Data Sources

2.1 Study Area

Located on the southern coast of mainland China, adjacent to Hong Kong and Macao, Guangdong Province is the core area of the Guangdong-Hong Kong-Macao Greater Bay Area and a forefront of reform and opening up. As the province with the largest economic output in China for 37 consecutive years, Guangdong leads the nation in both high-quality development and the digital economy. Its regional innovation capabilities have been among the best in the country for eight consecutive years, coordinated urban and rural development has progressed steadily, the “Green and Beautiful Guangdong” ecological construction has yielded remarkable results, its level of openness to the outside world is high, and its people’s livelihood has been continuously improved. Meanwhile, Guangdong’s digital economy has led the nation in scale for nine consecutive years, with complete digital infrastructure and deep integration of industrial digitalization and digital industrialization. Its diverse characteristics of economic, social, and ecological development serve as a model for measuring the high-quality development of the digital economy. Therefore, selecting Guangdong Province as the research object and analyzing its level of integration between the digital economy and high-quality development can effectively measure the development level of the digital economy in highly developed economic regions.

2.2 Research Methods

This study employs a combination of qualitative and quantitative analysis. First, it establishes the measurement dimensions and indicator system through literature review and policy analysis. Then, it uses the entropy weight method to determine objective indicator weights and calculate the overall development level of the system. Finally, a coupling coordination degree model is applied to analyze the relationship between the digital economy and the five concepts of high-quality development.

Entropy Method.

The entropy method is an objective weighting approach derived from information theory. Its principle is that greater data variation indicates more information, thus warranting a higher weight. This avoids subjective judgment bias, making weight allocation more objective and scientific. The application steps are as follows:

Data standardization: To eliminate dimensional differences and the influence of positive and negative attributes, the range method is applied. Positive indicators are normalized using formula (1), and negative indicators using formula (2), ensuring all values fall within [0, 1].

$$X_{ij}=\frac{x_{ij}-\min(x_j)}{\max(x_j)-\min(x_j)}+0.0001 \tag{1}$$

$$X_{ij}=\frac{\max(x_{ij})-x_{ij}}{\max(x_j)-\min(x_j)}+0.0001 \tag{2}$$

Where X_{ij} is the original value of the j-th indicator for the i-th sample, $\max(x_j)$ and $\min(x_j)$ are the maximum and minimum values of the j-th indicator, and 0.0001 is added to avoid zero values in subsequent calculations.

Entropy value calculation: The entropy value of the j-th indicator is:

$$e_j = -k\sum_{i=1}^{m} p_{ij}\ln(p_{ij}) \tag{3}$$

where $p_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}$ denotes as indicator weight, $k = \frac{1}{\ln m}$ denoted as the adjustment coefficient, and m as the sample size.

Calculate the difference coefficient and weights:

$$g_j = 1 - e_j \tag{4}$$

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \tag{5}$$

A smaller entropy value yields a larger difference coefficient, indicating greater variation and thus higher weight.

Overall evaluation value: Using weights, calculate the overall score of the i- th sample.

$$S_i = \sum_{j=1}^{n} w_j \times X_{ij} \tag{6}$$

Coupled Coordination Model. Coupling Coordination Model. This model quantifies the interdependence and benign coordination between systems. The application steps are as follows:

Calculation of C: For the three subsystems of economy, society, and ecology:

$$C = \left[\frac{U_A \times U_B \times U_C}{\left(\frac{U_A + U_B + U_C}{3}\right)^3}\right]^{\frac{1}{3}} \tag{7}$$

For any two subsystems (i≠j):

$$C = \left[\frac{U_i \times U_j}{\left(\frac{U_i + U_j}{2}\right)^2}\right]^{\frac{1}{2}} \tag{8}$$

Where UA, UB, and UC are the comprehensive development indices of the economic, social, and ecological subsystems, respectively, and i and j represent any two subsystems. The C value is in the interval [0, 1], reflecting interaction strength; larger values indicate stronger coupling.

Calculation of T and D: To avoid misinterpreting low-level mutual constraints as high coupling, the coordination degree D is introduced,

$$D = \sqrt{C \times T} \tag{9}$$

where T represents the overall development level of the three subsystems,

$$T = \alpha U A + \beta U B + \gamma U C \tag{10}$$

Given that the three subsystems are considered equally important, we take $\alpha = \beta = \gamma = 1/3$.

C and D levels: Referring to existing studies [19-20], C is classified into four levels and D into five levels to evaluate the synergy between the digital economy and high-quality development in Guangdong Province, as shown in Table 1:

Table 1. Levels and Classification Standards of Coupling and Coordination Degree in Digital Economy Measurement in Guangdong Province

C	Coupling	D	Coupling And Coordination Relationship	Grade
$0 < C \leq 0.4$	Barely Coupled	$0 < D \leq 0.2$	Incoordination	1
$0.4 < C \leq 0.6$	Low coupling	$0.2 < D \leq 0.4$	Barely coordinated	2
$0.6 < C \leq 0.8$	Moderate coupling	$0.4 < D \leq 0.6$	low degree of coordination	3
$0.8 < C \leq 1.0$	Highly coupled	$0.6 < D \leq 0.8$	Moderate coordination	4
-	-	$0.8 < D \leq 1.0$	Highly coordinated	5

2.3 Data Sources

To ensure the scientific reliability of this study, the core data were obtained from the 2020-2024 editions of the "Guangdong Statistical Yearbook", "China Statistical Yearbook" and the Guangdong Provincial Economic and Social Development Statistical Database. For a few missing data points, linear interpolation was used to estimate the data to ensure its completeness and continuity.

3 Research and Analysis

3.1 Construction of the Indicator System

To scientifically and systematically evaluate the development quality of Guangdong's digital economy, this study constructs an indicator system based on the following principles: (1) drawing on existing research to ensure alignment with the connotation of the digital economy; (2) structuring the system around economic, social, and ecological dimensions to reflect the core elements of high-quality development "innovation, coordination, green development, openness, and sharing"; (3) ensuring consistent statistical standards and data continuity; (4)reflecting the typical characteristics of Guangdong Province and highly targeted. The weights of each indicator are presented in Table 2.

Table 2. Guangdong Province Digital Economy Measurement and Evaluation System

Level 1	Level 2	Code	Level 3	Unit	Attribute	Weight
economy	Innovation	X1	Value added of digital and technology services industry / GDP	%	positive	7.02%
		X2	R&D expenditure / GDP	%	positive	6.03%
		X3	Number of invention patents granted per 10,000 people	Item	positive	6.14%
	open	X4	Digital technology product export value / total export value	%	positive	7.41%
		X5	Digital technology product import value / total import value	%	positive	6.49%
society	shared	Y1	Employment contribution rate of core industries in the	%	positive	6.21%

			digital economy			
	coordination	Y2	per capital express delivery volume	Item	positive	6.14%
		Y3	Mobile Internet penetration rate	%	positive	7.07%
		Y4	Ratio of per capital disposable income between urban and rural residents (rural / urban)	%	positive	6.44%
		Y5	Number of core digital economy enterprises / Total number of enterprises	%	positive	8.12%
Ecology	Resource utilization	Z1	Energy consumption reduction rate per unit of GDP	%	positive	6.61%
		Z2	Value added per unit of energy consumption in core industries of the digital economy	yuan / ton	positive	6.83%
	ecological environment	Z3	PM2.5 concentration	mg/m^3	negative	7.28%
		Z4	Proportion of excellent water bodies	%	positive	5.87%
		Z5	Forest coverage	%	positive	6.35%

3.2 Comprehensive Analysis

Based on the indicator system and entropy weight method, the data were substituted into formulas (1)-(6) to obtain the comprehensive score. The results show that from 2020 to 2024, the comprehensive score rose from 0.2534 to 0.6678, showing a saw tooth-shaped upward trend of “growth-decline-re-growth”.

In 2020-2021, the score improved significantly from 0.2534 to 0.4245, driven by the accelerated deployment of digital infrastructure under the "Digital Greater Bay Area" initiative. Simultaneously, the state explicitly proposed to cultivate and expand new business forms and models, elevating the online economy spurred by the pandemic to a national strategy. The score fell back to 0.3876 in 2021-2022. A related report from the Guangdong Provincial Development and Reform Commission pointed out that Guangdong Province was affected by global supply chain disruptions, contracting external demand, and downward pressure on the macroeconomy, resulting in a slowdown in import and export growth. From 2022 to 2024, the score rebounded steadily to exceed 0.66.With the implementation of the “Guangdong Province’s 14th Five-Year Plan for Digital Economy Development,” the province increased policy support for core digital, significantly enhancing the resilience and quality of digital economic development.

3.3 Subsystem Analysis

Substituting the standardized data into formulas (1)-(8), the scores of the three subsystems-economic, social, and ecological are shown in Fig 1. From 2020 to 2024, all three subsystems showed fluctuating upward trends, jointly driving the overall improvement and reflecting the positive momentum of Guangdong's digital economy in economic empowerment, social sharing and ecological green development. However, their evolutionary paths are different. The economic subsystem’s trend is highly consistent with the overall score, acting as the core driver of growth. This growth was primarily driven by innovation: X1, X2, and X3 increased steadily, supported by the 14th Five-Year Plan for Digital Economy Development. However, X4 and X5 declined in 2021－2022 due to global supply chain disruptions, exerting pressure on digital trade.

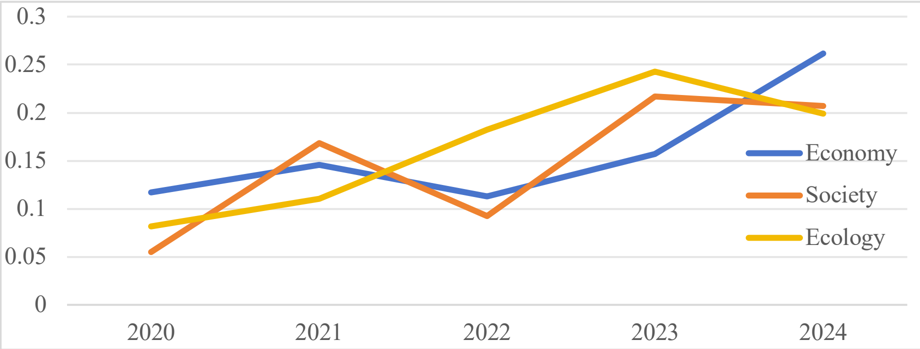

Fig. 1. Scores of various subsystems of Guangdong's digital economy (2020-2024)

The social subsystem score rose significantly from 0.05 to 0.21, reflecting the accelerated release of digital inclusivity. This increase was mainly driven by the rapid growth of Y2. Improvements in Y4 and Y5 benefited from sustained investment in digital infrastructure and the advancement of "digital government" and "smart city" initiatives. Meanwhile, periodic fluctuations in Y1 and Y3 negatively impacted the subsystem, indicating that there is still room for improvement in digital inclusiveness. The ecological subsystem followed an initial increase followed by a decline. Early growth stemmed from improvements in Z2, Z4, and a decrease in Z3. The 2024 decline was mainly due to a sharp drop in Z5,a pullback in Z1, and a rebound in Z3. Although the green efficiency indicators continued to improve, the negative fluctuations in the ecological environment quality indicators were more significant, reflecting the complexity and long-term nature of ecological governance, which is also a key factor restricting this subsystem.

3.4 Coupling Analysis

Substituting the indicator data into formulas (7)-(10) in sequence, we obtain the C, T, and D of each subsystem of the high-quality development of Guangdong's digital economy from 2020 to 2024. The results are shown in Fig 2. Overall, from 2020 to 2024, whether it is the three major systems as a whole or between any two systems, the coupling coordination relationship shows a trend of evolving from imbalance to initial coordination. This indicates that the internal structure of Guangdong's digital economy development is being optimized, and the balance of economy, society, and ecology is gradually being enhanced. However, there is still considerable room for improvement in the overall coordination level.

Economy-Society-Ecology Coupling and Coordination Relationship. The overall C value of the three systems remained below 0.4, indicating a "barely coupled" level, suggesting weak interaction among the three systems. The D value fluctuated from 0.1565 in 2020 to 0.2694 in 2024, experiencing a recurring cycle of "imbalance-barely coordinated-imbalance-barely coordinated," reflecting the complexity and difficulty of multi-objective coordinated development. Specifically, the D value in 2020 was 0.1565, indicating an uncoordinated state, hampered by the lagging development of the social and ecological subsystems, leading to system imbalance. In 2021, the D value entered a state of barely coordinated development for the first time, with synchronous growth in all three subsystems, and a significant increase in the social subsystem, narrowing the gap between the systems. In 2022, the D value returned to imbalance, primarily due to a sharp decline in the scores of the social subsystem and a simultaneous decrease in the economic subsystem. Although the score of the ecological subsystem increased, it could not offset the dramatic fluctuations of the former two, revealing the weakness of the overall coordination foundation of the three systems. The D value recovered and stabilized at a barely coordinated level in 2023-2024, which was due to the strong growth of the economic subsystem, which led to a significant enhancement of the overall coordination of the three systems. At the same time, with the recovery of the social and ecological subsystems, the three systems found a new balance point.

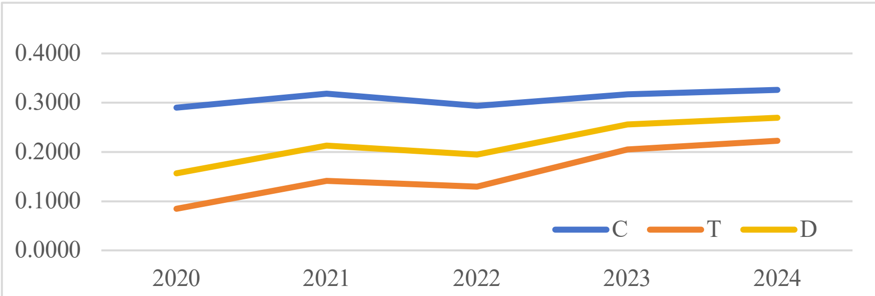

Fig. 2. Coupling Score Map of the Three Subsystems of Guangdong's Digital Economy

Coupling and coordination relationship between two systems.

The coupling degree between any two subsystems consistently exceeds 0.8, indicating strong interactions. The coupling coordination degrees of the economic-social, economic-ecological, and social-ecological systems exhibit highly similar trends: rising steadily from 2020 to 2022, before briefly dipping in 2023 and stabilizing in 2024. This suggests that a preliminary pattern of "synchronous resonance" has emerged among the economic, social, and ecological goals of Guangdong's digital economy. Economy-Society coordination rose from 0.2831 to 0.4825, the highest among the three groups, indicating smooth synergy between growth and social welfare. This is driven by digital industry expansion (X1, X3) creating jobs (Y1) and new business models, while digital infrastructure adoption (Y3) and e-commerce logistics growth (Y2) improved social efficiency, forming a virtuous cycle. Economy-Ecology coordination increased from 0.3125 to 0.4777, marking initial progress toward a "green economy." The key drivers are digital technology enabling energy-saving upgrades in traditional industries (Z1) and the low energy consumption of digital industries (Z2). However, lagging improvements in environmental quality indicators (Z3, Z5) suggest that current coordination focuses mainly on resource efficiency, while ecological quality gains remain limited. Society-Ecology coordination improved from 0.2589 to 0.4790 in 2023, before declining to 0.4506 in 2024. This improvement reflects synergies from digital public services and green lifestyles. However, the lowest coordination level among the three in 2024, and the only one to decline, reveals a complex trade-off between society and ecology, which constitutes a key weakness hindering overall synergistic improvement.

4 Conclusion and Discussion

This study evaluates the high-quality development level of Guangdong Province's digital economy from 2020 to 2024 using the entropy weight method and a coupling coordination degree model. The main findings are as follows: First, the overall score shows a steady saw tooth-like upward trend, increasing from 0.2534 in 2020 to 0.6678 in 2024, with an overall growth rate of 163.5%, indicating robust long-term momentum. Second, subsystem analysis reveals uneven development. The economic subsystem is the most advanced, providing core support for overall growth, followed closely by the social subsystem. In contrast, the ecological subsystem shows a trend of first increasing and then decreasing. Third, coupling analysis indicates that the coupling coordination relationship has evolved from a state of imbalance to preliminary coordination. Overall, the three subsystems remained at a barely coupled level throughout the study period, with coordination experiencing fluctuations. Meanwhile, the two pairs of subsystems maintained high coupling, with their D values changing synchronously from 2020 to 2024, suggesting that they have begun to achieve resonance.

Based on the above analysis, this study proposes that the following pathways for the future high-quality development of Guangdong's digital economy: First, deepen the integration of digital technologies such as AI, big data, and block chain with the real economy; Second, address the shortcomings of the ecosystem subsystem by building a collaborative system of "digital technology + ecological governance," Third, strengthen regional and urban-rural collaboration, promoting the interconnection of digital elements in Guangdong, Hong Kong, and Macao, improve rural digital infrastructure, and enhance the equalization of digital public services in counties; Fourth, accelerate the improvement of the digital economy governance system and the digital security guarantee mechanism to build a solid institutional guarantee for the healthy and orderly development of the digital economy.

While these findings offer valuable insights, this study has limitations. Due to scope and time constraints, it focused primarily on quantitative measurement and did not explore practical implementation pathways. Future research should strengthen empirical analysis and compare international development models to provide more robust pathways for Guangdong's digital economy.

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