Statistical Measurement of Zhuhai's Digital Economy Development Level Based on Entropy Method

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Abstract: Against the backdrop of the increasing popularity of mobile internet and the expanding commercialization of fifth-generation mobile communications (5G), the digital economy is booming with continuous innovations and integrations of internet technologies such as artificial intelligence, blockchain, cloud computing, and big data. As one of the special economic zones, Zhuhai has emphasized in its work report the need to "vigorously develop the digital economy." Based on panel data from Zhuhai and its surrounding cities from 2018 to 2022, this paper empirically measures the level of digital economic development in Zhuhai and conducts a deep analysis of its development from the perspective of temporal characteristics. The research results indicate that: (1) Among various evaluation indicators of the digital economy, the output value of the communication and other electronic equipment manufacturing industries (in tens of thousands of yuan) has the greatest impact on the development of the digital economy, followed by the total volume of telecommunications business (in tens of thousands of yuan). The number of internet broadband users (in tens of thousands of households) and FTTH/O fiber-optic access users (in tens of thousands of households) have relatively smaller impacts. (2) In terms of temporal characteristics, the annual growth rate of Zhuhai's digital economy exhibits a steady decline, which differs from that of surrounding cities. (3) Regarding spatial characteristics, the development of the digital economy is highly unbalanced among different cities in Guangdong, and there is still a significant gap between Zhuhai and its surrounding cities. Based on the measurement results, countermeasures and suggestions are proposed to enhance the digital economic development in Zhuhai.

Keywords: Digital Economy; Entropy Method; Zhuhai; Statistical Research

1. Introduction

Since the financial crisis of 2008, trade protectionism and anti-globalization trends have gradually emerged, posing significant obstacles to the development of the globalized economy. In 2020, the outbreak of the novel coronavirus pandemic swept across more than 200 countries and regions worldwide, profoundly affecting the global governance landscape while simultaneously exposing China's economic development to dual pressures of uncertainty and instability. Against this backdrop, accelerating the development of the digital economy, promoting its deep integration with the real economy, and building internationally competitive digital industrial clusters are particularly crucial. The digital economy is conducive to alleviating domestic circulation issues and providing robust support for China's new economic development paradigm. The "Overall Layout Plan for the Construction of Digital China" released on February 27, 2023, points out that building a digital China is an important engine for advancing Chinese-style modernization in the digital era and a powerful support for constructing new competitive advantages for the country. Accelerating the construction of digital China holds significant meaning and far-reaching impact on comprehensively building a socialist modern country and comprehensively advancing the great rejuvenation of the Chinese nation. In 2023, China's technological innovation capabilities in cloud computing, big data, and other fields rank among the world's first tier, with over 4,000 artificial intelligence enterprises. 5G

applications have been integrated into 71 of the 97 major categories of the national economy, directly driving an economic output of 1.86 trillion yuan in 2023, an increase of 29% compared to 2022 [1]. According to the "Forecast and Development Trend Prospect Report on China's Digital Economy Market Demand from 2022 to 2027" released by the China Commerce Industry Research Institute, the scale of China's digital economy market reached 50.2 trillion yuan in 2022, ranking second in the world and accounting for 41.5% of GDP. With the accelerated release of the development momentum of the digital economy, it is expected that the scale of China's digital economy market will grow to 56.7 trillion yuan in 2023 and further increase to 63.8 trillion yuan in 2024.

2. Current Status of Digital Economy Development in Major Cities of Guangdong Province

Guangdong Province is the best province in China in terms of digital economy development. In 2022, Guangdong's digital economy grew by 6.4 trillion yuan, accounting for 12.8% of the national digital economy added value, and ranking first in the country for six consecutive years. The gross domestic product (GDP) of Guangdong's digital economy accounts for 49.7% of the country's total GDP, making it a core engine driving the high-quality development of Guangdong's economy [2].

Based on 2021 data, the ratio of digital industrialization to industrial digitization in Guangdong's digital economy is approximately 1:2. On the one hand, the emerging information technology industry has driven continuous breakthroughs in digital industrialization areas such as artificial intelligence, industrial internet, and cloud computing. On the other hand, the transformation and upgrading of the large-scale traditional manufacturing industry in the Pearl River Delta region has released tremendous demand potential, providing a vast market space for industrial digitization [3].

As of October 2023, based on the data released by various cities in Guangdong Province, Shenzhen's digital economy has reached nearly one trillion yuan, and Guangzhou's exceeds 300 billion yuan. The number of invention patents related to digital technology innovation in Guangzhou and Shenzhen exceeds 10,000, with digital new infrastructure investments amounting to several hundred billion yuan. With a basically complete digital industrial chain, they have developed into the core cities of digital economy with the highest degree of digitization in China. Dongguan and Foshan's digital economy scales have exceeded one hundred billion yuan, and the number of invention patents related to digital technology innovation ranks second only to Guangzhou and Shenzhen. Their digital economy industries are developing rapidly, and they are classified as secondary core cities. Zhuhai and Huizhou rank slightly lower in comprehensive digital economy levels, and there is still room for improvement. Zhongshan, Jiangmen, and Zhaoqing are promoting the digital transformation of their manufacturing industries, and their future momentum remains to be observed. The key industries of Guangdong's digital economy include: new-generation electronic information, software and information technology services, intelligent connected vehicles, and intelligent robots. [4]. According to national patent publication data, the new-generation electronic information industry has a prominent leading advantage with 62,013 valid invention authorizations. Software and information technology services, ultra-high-definition video display, and smart home appliances follow closely behind, with valid invention authorization numbers exceeding 18,000 each. New industries such as intelligent robots and intelligent connected vehicles rank third, with valid invention authorization numbers exceeding 9,000 each. [5]. Based on indicators such as corporate patents, industrial scale, and technological innovation, the research team selected 58,000 high-quality enterprises in the digital economy sector among Guangdong-registered companies. In terms of city and industry distribution, Shenzhen has the largest number of high-quality digital economy enterprises, totaling 27,000, accounting for 46.5% of the total number of high-quality enterprises in Guangdong Province, leading the way in digital economy development. Guangzhou has 15,060 high-quality digital economy enterprises, ranking second. In Guangdong

Province, the number of high-quality enterprises in the intelligent connected vehicles and digital creativity sectors is the highest, with software and information technology services, blockchain, and quantum information industries trailing behind Shenzhen. Dongguan has 5,220 high-quality digital economy enterprises, performing prominently in areas such as ultra-high-definition video, new-generation electronic information, and intelligent robots, ranking third. Foshan ranks fourth, with a relatively high proportion of high-quality enterprises in smart home appliances. Additionally, Zhongshan has 2,125 high-quality enterprises, Zhuhai has 1,700, and Huizhou has 1,380, ranking fifth, sixth, and seventh respectively. Compared to Guangzhou and Shenzhen, the number of high-quality digital economy enterprises in these cities is significantly lower [6].

3. Current Status of Digital Economy Development in Zhuhai

As a special economic zone, Zhuhai's government work report proposes to "vigorously develop the digital economy", strengthen the linkage of departmental, industrial, and regional digital development, and strive to create a new trend of digital integration development in the city.

Zhuhai is rich in data resources and has accumulated massive and diverse data in areas such as trade, ports, shipping, logistics, customs, commodity inspection, healthcare, and communications. It also has relatively complete infrastructure as a strong support for the digital economy. In 2020, Zhuhai had 2.7676 million 4G users, 1.02 million internet broadband access users, and over 6,000 5G base stations, basically achieving continuous coverage of the 5G network in the city. In the same year, Zhuhai's software business revenue reached 46.36 billion yuan, with the operating income of above-scale information service industry reaching 26.839 billion yuan and the total telecommunications business reaching 36.108 billion yuan. [7] Meanwhile, Zhuhai has given birth to locally grown innovative enterprises such as Gree Electric Appliances and Yuanguang Software, which are among the top 100 Chinese digital economy innovators in 2020. To keep up with the trend of digital economy, Zhuhai has launched the construction of the Y-Lin Digital Economy Industrial Park, attracting a number of high-quality projects in the digital economy industry (such as Chaofan Vision, Fuhong Technology, Antai Innovation, etc.) to accelerate the clustering. The Hengqin Advanced Intelligent Computing Platform, as the first advanced intelligent computing platform in the Greater Bay Area, has settled in Zhuhai. A number of excellent digital economy industrial projects such as Tencent (Zhuhai) Smart Industry Headquarters and Huawei (Zhuhai) Artificial Intelligence Innovation Center have been launched one after another. In 2019, the Hengqin International Internet Data Dedicated Channel was opened, and in 2020, the first phase of the Hengqin Artificial Intelligence Supercomputing Center was completed. In terms of digital industrialization, Zhuhai takes the Feiqi Interconnected Enterprise Operation and Management Platform as the starting point, utilizes blockchain technology to improve enterprise collaboration efficiency, vigorously develops the software and information technology service industry, and builds a high-tech industrial base with the High-tech Zone as the platform. In terms of industrial digitization, Zhuhai is fully promoting the development of new integrated industries, new models, and new formats of the real economy, intelligent manufacturing, and platform economy in Zhuhai through methods such as "digital + service", "digital + finance", and "digital + manufacturing" [8].

However, constrained by the size of the economy and industrial characteristics, Zhuhai faces the following prominent challenges in promoting the development of the digital economy: 1. The digital economy lacks advantages in scale and catching-up potential. According to the "2022 Digital Transformation Index Annual Report" released by the Tencent Research Institute, Shenzhen and Guangzhou are the two leaders in the development of the Pearl River Delta region, with their combined index accounting for 70%. The development levels of Dongguan and Foshan are also leading nationwide (ranked 15th and 16th in the country's digital economy in 2022, and 3rd and 4th within Guangdong Province). Zhuhai ranks 8th in the development of the digital economy in Guangdong Province and 9th in

terms of year-on-year growth. The scale of the digital economy in Zhuhai lags far behind Shenzhen and Guangzhou, and its development speed is also slower than that of Huizhou, Zhaoqing, Zhongshan, and Jiangmen, which have caught up rapidly. 2. Lack of large-scale platform enterprises and unicorn companies. Most of the digital economy enterprises in Zhuhai are scattered and lack the quantity and quality compared to the "dual cores" of Guangzhou and Shenzhen. There are no good platform enterprises or unicorn companies to promote an innovative and entrepreneurial atmosphere based on the digital economy, and there is still a gap in creating a new ecosystem for the development of the digital economy [9]. 3. The industrial ecosystem for the digital economy is not yet complete. As a newly established park, Zhuhai Y-Link Digital Economy Industrial Park still lacks strength, and there are no other professional parks to support it, let alone benchmark digital economy industrial parks. 4. Financing for digital economy enterprises is difficult. The digital economy is a sunrise industry, dominated by small and medium-sized enterprises in their early stages of development. These enterprises face tight financial constraints and have huge financing needs. Zhuhai's financial environment has long been criticized, and financial support and coverage need to be strengthened. 5. There is a significant talent gap in the digital economy. Zhuhai has a small population, a relatively low concentration of information technology talents, a lack of skilled talents, and a scarcity of high-end talents in artificial intelligence. The digital economy requires compound talents who are proficient in information technology and manufacturing. Zhuhai still has room for improvement in attracting talents in terms of its entrepreneurial environment, policy support, and living amenities [10]. According to research and investigations, both Shenzhen and Guangzhou belong to the balanced type of digital economy, with both digital industrialization and industrial digitization levels exceeding the national average. Foshan belongs to the upgrading type of digital economy, with a relatively fast process of digital transformation in traditional industries. On the other hand, Dongguan falls into the leading type of digital economy, exhibiting significant advantages in digital industrialization [11]. In contrast, Zhuhai lacks a distinct strength in the process of "dual transformation" and does not have a clear digital industrial advantage compared to cities like Huizhou, Zhongshan, and Jiangmen. Therefore, it is difficult for Zhuhai to find a strong "booster" for the rapid growth of its digital economy in the short term.

4. Construction of Evaluation Index System and Data Sources

According to the definition of digital economy in this paper, it refers to a new economic form that takes data as the main factor of production, information communication as the main transmission channel, information technology as the main support, and integrates the real economy and information economy. Based on the theory of technological-economic paradigm, this paper constructs an index system for the level of digital economy development from three aspects: digital technology infrastructure system, core industry system of digital economy, and social application system of digital economy [12].

4.1 Constructing an Evaluation Index System

4.1.1 Construction theories and principles

The digital economy is a new economic form that takes data as the main production factor, information communication as the main transmission channel, and information technology as the main support, integrating the real economy and the information economy. Based on the theory of technological-economic paradigm, this article constructs an indicator system for measuring the development level of the digital economy from the three systems of digital technology infrastructure, the core industrial system of the digital economy, and the social application system of the digital economy. The selection of indicators for the digital economy should be as comprehensive and objective as possible, reflecting the current status of China's digital economy development from multiple levels and perspectives [13].

(1) Principle of combining scientificity with systematicness. When constructing the evaluation indicator system for the development level of the digital economy, it must be based on corresponding theories,

starting from the definition of the connotation of the digital economy, and constructing the indicator system according to the characteristics and contents of digital economy development. It should not only have relevant theories as support but also reflect the actual situation. To scientifically and accurately measure the level of digital economy development, the design of the indicator system must proceed from the overall perspective, comprehensively considering various influencing factors in the process of digital economy development in different regions, making it systematic [14].

(2) Principle of combining generality with representativeness. Due to the wide coverage of digital economy development, selecting indicators with generality and representativeness is a crucial step in constructing a complete indicator system. It should be noted that the selection of indicators is not the more, the better. Sometimes, it may have the opposite effect, causing problems such as information redundancy, increased calculation errors, and enhanced collinearity. Therefore, when selecting indicators, comprehensive consideration should be given to their generality and representativeness for digital economy development.

(3) Principle of combining relevance with scalability. When constructing the indicator system, it is necessary to consider the relationship between the research object and the indicators. Under the premise of data availability and calculability, indicators with high relevance to the research object should be selected as much as possible. When constructing the indicator system for measuring the development level of the digital economy, it is necessary to comprehensively consider the correlation between the indicators and the digital economy. At the same time, indicators with high inclusiveness and scalability in statistical caliber should be selected to provide references for future related research [15].

4.1.2 Indicator design and establishment of evaluation model

To scientifically and comprehensively measure the level of digital economy development in Zhuhai and its neighboring cities of Guangzhou, Shenzhen, Dongguan, and Foshan, this paper constructs an indicator system based on the principles of index system development and previous research outcomes. This system encompasses three primary indicators: digital economy infrastructure, core digital economy industries, and digital economy social applications. These primary indicators are further divided into 13 secondary indicators, as detailed in Table 1.

(1) Selection of Indicators for Digital Economy Infrastructure. As the fundamental condition for digital economy development, digital economy infrastructure has been described in various studies using a comprehensive indicator approach. Domestic scholars such as Kuang Jinsong and Shi Xiaofei have measured China's digital economy by including indicators like internet broadband access, internet users, and mobile phone users. Cheng Guangbin and Li Ying also considered mobile phone users, internet broadband access, computers per hundred people, and website counts as reflections of digital economy infrastructure. Generally, digital economy infrastructure can be categorized into terminal facilities and mobile devices. Terminal facilities often involve indicators like internet broadband access, internet users, and fiber-optic access users, while mobile devices encompass metrics such as mobile phone users and mobile phone users per hundred people. [16]. Drawing from previous research, this paper selects specific indicators for digital economy infrastructure, including mobile phone users (in tens of thousands), internet broadband users (in tens of thousands), and FTTH/O fiber-optic access users (in tens of thousands).

(2) Selection of Indicators for Core Digital Economy Industries. Core digital economy industries are the driving force of digital economy growth. With the rapid development of technologies like big data, artificial intelligence, and blockchain, the digital economy is gaining momentum. However, due to the difficulty in collecting certain statistical data, this paper references the "Classification of the Digital Economy and Its Core Industries (2023)" published by the National Bureau of Statistics to select indicators from three perspectives: industrial scale, industrial performance, and industrial research and development. The industrial scale considers metrics like enterprise informatization and e-commerce activities, the

proportion of enterprises engaged in e-commerce transactions, and the proportion of personnel in computer services and software. Industrial performance encompasses software business income, information technology service income, and e-commerce sales. Industrial research and development takes into account expenditures on R&D in high-tech industries, the number of R&D personnel in high-tech industries, and the number of patent grants in high-tech industries. Based on previous research, this paper selects specific indicators for core digital economy industries, including the proportion of personnel in computer services and software, full-time equivalent of R&D personnel (person-years), and the number of patent grants [17].

(3) Selection of Indicators for Digital Economy Social Applications. The social applications of the digital economy reflect the deep integration of digital technologies with traditional industries, contributing to the development of digital industries and the digital transformation and upgrading of traditional industries. Therefore, when selecting indicators for digital economy social applications, it is essential to reflect the penetration and integration of digital technologies into traditional industries while considering data availability. Drawing from previous research, this paper selects specific indicators for digital economy social applications, including internet users per hundred people, total telecommunications business per capita, mobile phone users per hundred people, total telecommunications business (in tens of thousands), the output value of the computer, communication, and other electronic equipment manufacturing industries (in tens of thousands), the proportion of the output value of these industries in GDP, and the digital inclusive finance index.

Table 1 Evaluation Index System of Digital Economy

Primary Indicator	Secondary Indicator	Data Source
Indicators of Digital Economy Infrastructure	The number of mobile phone users (in tens of thousands)	Guangdong Provincial Communications Administration
	The number of internet broadband subscribers (in tens of thousands)	Guangdong Provincial Communications Administration
	The number of FTTH/O fiber-optic access users (in tens of thousands)	Guangdong Provincial Communications Administration
Key Indicators of Core Industries in the Digital Economy	Proportion of personnel engaged in computer services and software	Statistical Yearbooks of Various Cities
	Full-time equivalent of research and development personnel (person-years)	Statistical Yearbooks of Various Cities
	Number of patent grants (units)	Statistical Yearbooks of Various Cities
Indicators Related to the Application of Digital Economy in Society	Number of internet users per 100 people	Statistical Yearbooks of Various Cities
	Total telecommunication services per capita	Statistical Yearbooks of Various Cities
	Number of mobile phone users per 100 people	Statistical Yearbooks of Various Cities
	Total telecommunication services (in ten thousand yuan)	Statistical Yearbooks of Various Cities
	Output value of computer, communications, and other electronic equipment manufacturing (in ten thousand yuan)	Statistical Yearbooks of Various Cities
	Proportion of output value of computer, communications, and other electronic equipment manufacturing in GDP	Statistical Yearbooks of Various Cities
	Digital inclusive finance index	Statistical Yearbooks of Various Cities

4.2 Data Sources

This article selects Zhuhai and its surrounding cities, including Guangzhou, Shenzhen, Dongguan, and Foshan, as the research objects. The indicator data are derived from the "Statistical Yearbook", "Guangdong Provincial Communications Administration", "China Science and Technology Statistics Yearbook", "China High-Tech Industry

Statistics Yearbook", and EPS database of each city from 2018 to 2022.

5 Model Construction

This article focuses on the development level of digital economy in Zhuhai. During the process of data collection, there were some missing data. To ensure the accuracy and reliability of the measurement results, various methods for handling missing values were comprehensively analyzed. Considering the actual situation, the final decision was made as follows: if a certain indicator for a certain location is missing for one year, time series linear interpolation will be used to replace the missing value; if a certain indicator for a certain location is missing for two consecutive years or more, the mean value of the corresponding year's data from neighboring provinces and cities will be used to replace the missing value [18].

5.1 Introduction to Entropy Method

The entropy method is an objective weighting approach. The construction of the indicator system for measuring the level of digital economy development determines the weight of each indicator based on the information provided by the observed values of the indicator data. The greater the uncertainty of an indicator, the greater the amount of information it contains, and thus the larger the corresponding weight it receives [19]. This article adopts the entropy method to measure the level of digital economy development in Zhuhai and its surrounding cities from 2018 to 2022. This method is highly objective, and since the indicators selected in this article are all objective statistical data, it is suitable to adopt this method.

5.2 Calculation Process of Entropy Method

The calculation process of using the entropy method to evaluate the comprehensive development level of China's digital economy is as follows:

(1) Standardization of Data

Due to differences in the magnitude and dimension of various indicator data, as well as differences in positive and negative indicators, they are not comparable. Therefore, it is necessary to standardize the indicator data before performing calculations. At the same time, to avoid the impact of zero values on subsequent calculations, 0.01 is added to all data. The processing formula is as follows [20].

Positive indicators:

$$Y_{\omega ij} = \frac{X_{\omega ij} - \min(X_{\omega ij})}{\max(X_{\omega ij}) - \min(X_{\omega ij})} + 0.01 \quad (1)$$

negative indicators:

$$Y_{\omega ij} = \frac{\max(X_{\omega ij}) - X_{\omega ij}}{\max(X_{\omega ij}) - \min(X_{\omega ij})} + 0.01 \quad (2)$$

Among them, “ω ” represents the year, "i” represents the city, "j”represents the indicator, “$X_{\omega ij}$” represents the original indicator data of the "j” indicator in the "i" city in the “ω" year, "min($X_{\omega ij}$)" represents the minimum value of the indicator data, "max($X_{\omega ij}$)" represents the maximum value of the indicator data, and “$Y_{\omega ij}$ " represents the data obtained after standardizing the original indicator data.

(2) Calculate the proportion of indicators:

Determine the proportion of each indicator for each city in eachyear:

$$P_{\omega ij} = \frac{Y_{\omega ij}}{\sum_{\omega}\sum_{i} Y_{\omega ij}} \quad (3)$$

" $P_{\omega ij}$ " represents the proportion of the "i" scheme under the "j" indicator in year “ω” for that particular indicator.

(3) Calculate the information entropy of indicator.

Calculate the information entropy of each indicator:

$$E_j = -\frac{1}{\ln(\omega i)} \sum_{j=1}^{n} P_{\omega ij} \ln P_{\omega ij} \quad (4)$$

(4) calculate the weight of indicators:

Calculate the weights of each indicator.

$$W_j = \frac{1 - E_j}{\sum_{j=1}^{n} (1 - E_j)} \quad (5)$$

(5) Calculate the comprehensive score for each year.

$$S_i = \sum_{j=1}^{n} W_j Y_{wij} \quad (6)$$

In the formula: "S_i" represents the comprehensive evaluation score,and "W_j" represents the final weight of the indicator.

5.3 Determination of Indicator Weights by Entropy Method

Based on the entropy method, the data from 2018 to 2022 were calculated to obtain the weights of various indicators for digital economy development, as shown in Table 2.

Table 2 Weights of Various Indicators for Measuring the Development Level of Digital Economy

Primary Indicator	Secondary Indicator	Information Entropy Value e	Information Utility Value d	Secondary Index Weight (%)	Primary Index Weight(%)
Indicators of Digital Economy Infrastructure	The number of mobile phone users (in tens of thousands)	0.906	0.094	5.358	15.296
	The number of internet broadband subscribers (in tens of thousands)	0.911	0.089	5.025	
	The number of FTTH/O fiber-optic access users (in tens of thousands)	0.913	0.087	4.913	
Key Indicators of Core Industries in the Digital Economy	Proportion of personnel engaged in computer services and software	0.856	0.144	8.147	21.893
	Full-time equivalent of research and development personnel (person-years)	0.868	0.132	7.468	
	Number of patent grants (units)	0.889	0.111	6.278	
Indicators Related to the Application of Digital Economy in Society	Number of internet users per 100 people	0.875	0.125	7.106	55.705
	Total telecommunication services per capita	0.9	0.1	5.646	
	Number of mobile phone users per 100 people	0.892	0.108	6.131	
	Total telecommunication services (in ten thousand yuan)	0.797	0.203	11.532	
	Output value of computer, communications, and other electronic equipment manufacturing (in ten thousand yuan)	0.662	0.338	19.181	
	Proportion of output value of computer, communications, and other electronic equipment manufacturing in GDP	0.878	0.122	6.91	
	Digital inclusive finance index	0.878	0.122	6.91	

6. Empirical Research

6.1 Analysis of Indicator Weights

Based on the complete dataset of this survey, the weights of the primary indicators of digital economy infrastructure, core industries related to the digital economy, and social applications related to the digital economy accounted for 15.296%, 21.893%, and 55.705% respectively. In the current evaluation system, as China's 5G infrastructure construction has entered the mid to late stage, and the focus is now on the application of the digital economy, the indicators related to digital economy social applications serve as the primary evaluation metrics for the overall level of digital economy development [21]. Among the secondary indicators, the output value of computer, communications, and other electronic equipment manufacturing industries (in ten thousand yuan) accounted for the largest weight, at 19.181%. In contrast, the weights of mobile phone subscribers (in ten thousand households), internet broadband subscribers (in ten thousand households), and FTTH/O fiber optic access subscribers (in ten thousand households), which belong to the digital economy infrastructure, were the lowest, at 5.358%, 5.025%, and 4.913% respectively. This indicates that the current digital economy infrastructure in Guangdong Province can basically support the application of the digital economy. However, it is necessary to strengthen support for cooperation between telecommunications, broadcasting, television, satellite transmission service enterprises, and 5G technology enterprises to develop new services and application scenarios, create new growth points, and add new momentum to the information service industry and economic development. Therefore, it is imperative to accelerate the improvement of new infrastructure that is suitable for the development of the digital economy industry.

6.2 Comprehensive Evaluation Analysis of Digital Economy Development Level

Using the entropy method and combining the weights, a comprehensive evaluation score for each indicator of digital economy development was calculated based on time series data from 2018 to 2022 (see table 3 below). According to table 3, Zhuhai's overall score showed a fluctuating downward trend over the past five years, with the highest score in 2018 and the lowest in 2022. Among the comparison cities, Shenzhen has consistently ranked first in the past five years. Zhuhai, except for being slightly higher than Foshan in 2018, ranked last from 2019 to 2022 (see table 4 below). This is because although Zhuhai's digital economy data has been increasing steadily each year, the magnitude of its growth compared to surrounding regions has not been well reflected in all aspects of digital economy development, leading to a decreasing numerical value in Zhuhai's overall digital economy development level evaluation score.

Table 3. The Comprehensive Score of Digital Economy Development in Zhuhai and its Surrounding Cities

Region	2018	2019	2020	2021	2022
The average value	0.3992	0.4	0.3862	0.39	0.3978
Zhuhai	0.105	0.064	0.055	0.064	0.041
Guangzhou	0.649	0.673	0.717	0.666	0.626
Shenzhen	0.979	0.956	0.885	0.958	0.976
Dongguan	0.168	0.161	0.200	0.169	0.206
Foshan	0.095	0.146	0.074	0.093	0.140

Table 4. Comprehensive Scoring and Historical Rankings of Digital Economy Development in Zhuhai and Its Neighboring Cities

Region	2018	2019	2020	2021	2022	Overall ranking
Zhuhai	4	5	5	5	5	5
Guangzhou	2	2	2	2	2	2
Shenzhen	1	1	1	1	1	1
Dongguan	3	3	3	3	3	3
Foshan	5	4	4	4	4	4

According to Table 5 (see the figure below), in terms of growth rate, Zhuhai City has the lowest annual growth rate compared with surrounding cities at -12.19%, indicating a relatively slow development speed of digital economy in Zhuhai. There is a significant gap compared with the large growth rates of surrounding cities. The reasons are as follows: first, Zhuhai's new digital infrastructure construction is still in its infancy and cannot provide strong support for the development of digital economy; second, Zhuhai is currently in a crucial period of digital transformation, and the digital economy cannot bring significant economic benefits to Zhuhai's economic development; third, due to the huge differences in regional development levels in Guangdong, Shenzhen and Guangzhou have unique advantages in digital economy development, while Zhuhai has a deep "digital divide" with other cities, which has lowered the overall level of digital economy development in Zhuhai.

Table 5. Annual Growth Rate of Digital Economy Development in Zhuhai and its Neighboring Cities

Region	The average value	Zhuhai	Guangzhou	Shenzhen	Dongguan	Foshan
Growth rate	-0.07%	-12.19%	-0.71%	-0.06%	4.52%	9.47%

7 Conclusion and Suggestions

7.1 Conclusion

The article empirically measures the development level of the digital economy in Zhuhai based on panel data from 2018 to 2022, comparing it with neighboring cities. It further delves into the development of the digital economy in Zhuhai from the perspective of temporal characteristics. The

research findings are as follows:

(1) Regarding the impact of various evaluation indicators of the digital economy on its development, the output value of the communications and other electronic equipment manufacturing industry (in ten thousand yuan) has the greatest influence, followed by the total volume of telecommunications services (in ten thousand yuan). The number of internet broadband users (in ten thousand households), FTTH/O fiber access users (in ten thousand households), and other indicators have a relatively smaller impact on the development of the digital economy.

(2) In terms of temporal characteristics, the level of Zhuhai's digital economy has shown a fluctuating downward trend, which differs from neighboring cities.

(3) From a spatial perspective, the development of the digital economy is highly unbalanced among different cities in Guangdong province, and Zhuhai's digital economy development needs to be further enhanced.

7.2 Suggestions

Based on the above conclusions, the following suggestions are made:

(1) Advance the construction of new infrastructure and implement a sustainable development strategy for inclusive digital finance.

To accelerate the development of digital industrialization, it is first necessary to strengthen the construction of new infrastructure such as the Internet of Things, industrial internet, and satellite internet. The application of 5G technology combined with telecommunications, broadcasting, television, and satellite transmission services can drive a new round of rapid industry development. By building a high-speed, intelligent, and secure information and communication network, powerful technical support can be provided for inclusive digital finance. At the same time, investment in areas such as new energy, smart grids, and the internet of vehicles should be increased to promote the optimization of the energy structure and provide stable energy support for inclusive digital finance [22]. The key to implementing a sustainable development strategy for inclusive digital finance lies in strengthening financial service innovation and enhancing the inclusiveness of financial services. We should make full use of digital technology to expand the coverage of financial services, allowing more people to enjoy convenient and efficient financial services. At the same time, financial supervision should be strengthened to prevent financial risks and ensure the healthy and stable development of inclusive digital finance. In addition, attention should be paid to the sustainability of financial services, promoting the integration of financial institutions with sustainable development goals to achieve a win-win situation for both economic and social benefits [23].

(2) Improve the development mechanism of the digital economy and enhance its development environment.

The sustained and healthy development of the digital economy greatly depends on its development environment. To enhance the overall development level of the digital economy, it is necessary to start from the development mechanism of the digital economy and dismantle the "digital barriers" to its development [24]. On the one hand, policies should clearly outline the sovereignty system, transaction system, mobility system, and sharing system of digital technology to avoid multiple "digital obstacles" set by different institutional entities. On the other hand, Zhuhai should further standardize the development mechanism of the digital economy to enhance its overall development level. It should learn from the successful paths of excellent digital economy cities such as Shenzhen, Guangzhou, Dongguan, and Foshan to find a unique development path suitable for itself. Efforts should be made to optimize the entrepreneurial market environment, cultivate "unicorn" enterprises in key and core technological fields, and build a hierarchical, tiered, and targeted financial support system for "unicorn" enterprises. Financial support and tax relief policies should be strengthened for key enterprises and industries in the digital economy, selecting key industry enterprises for support and providing investment and policy support to enterprises with relatively backward digital economy development [25]. This mainly manifests in direct investment in digital economy construction and more preferential fiscal and tax policies. Enhancing the quality

and scale of the supply of digital economy factors for these enterprises, attracting the aggregation of digital economy industries, and driving the overall development of the digital economy. Actively use and innovate digital technology to present a new situation of diverse development in Zhuhai's digital economy.

(3) Strengthen the transformation of digital scientific and technological achievements and increase the cultivation and attraction of high-end digital talents.

We should also focus on strengthening the construction of public pilot centers and achievement transformation centers. These centers can help connect various links in production, learning, and research to form seamless integration, significantly promoting the efficient integration of technological innovation and achievement transformation. By pooling various innovative resources, these centers will serve as bridges connecting research institutions and the industrial sector, facilitating the transition of technological achievements from the laboratory to the market, providing strong technical support and innovative momentum for Zhuhai's industrial development. The development of the digital economy requires talent accumulation, and digital talents are a significant driving force for the progress of the digital economy. Without appropriate talent support, the digital economy cannot achieve true reform and progress. Therefore, in talent cultivation, it is necessary to prioritize the quality of talent cultivation and increase efforts to cultivate digital technology talents. Zhuhai, affiliated with the Greater Bay Area, should leverage the policy advantages of the region and strengthen the introduction and connection with overseas outstanding personnel. The government should establish incentive mechanisms to attract more talents to participate in digital technology construction projects. Additionally, universities should collaborate with government and enterprises, encouraging outstanding students to participate in digital economy construction projects. This not only maximizes the utility of talent resources but also enhances the professional skills training of talent within the university. Through cooperation with enterprises in practical projects, skill competitions, and the establishment of training bases, the practical ability and professional literacy of digital skills talents can be improved, providing high-quality talent resources and technical support for the development of the digital industry [26].

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