Original Research Article

Statistical measurement of digital finance development and regional architectural disparities

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Abstract: To identify the impact of digital finance development on regional development disparities while incorporating the construction sector dimension, this study constructs a "Regional Development Gap Index (UUDI)" based on panel data from 21 prefecture-level cities in Guangdong Province from 2013 to 2023. The TOPSIS-entropy weighting method is employed for multi-indicator comprehensive measurement, with principal component analysis (PCA) conducted for robustness testing. The indicator system incorporates construction-related metrics across economic, social, and environmental dimensions (e.g., construction value-added share, prefabricated building proportion, green building floor area ratio, energy consumption and carbon emission intensity per unit floor area), reflecting the sector's role in regional development quality, green transition, and public service accessibility. The study's primary contributions are: providing a regional disparity measurement framework that combines methodological transparency and reproducibility; systematically embedding green and digital transformation elements of the construction industry into traditional comprehensive evaluations; and establishing a unified measurement and data foundation for subsequent quantitative identification of digital finance's impact on the coupled development of "construction-city" systems. The methodology and data sources are detailed in the 'Methodology' and "Data" sections of this paper.

Keywords: digital finance; regional development disparities; TOPSIS-entropy weight method; PCA robustness; green and digital transformation in construction

1. Introduction

In recent years, digital finance has enhanced capital allocation efficiency and financial accessibility through mobile payments, supply chain finance, and data empowerment, emerging as a vital force driving high-quality regional economic development. Concurrently, as a core sector for fixed-asset formation and urban functional provision, the construction industry's green and digital transformation—Including prefabricated construction, BIM/digital construction, and green building assessment—Is profoundly influencing urban factor aggregation, public service delivery, and ecological governance. However, existing research on regional development disparities primarily focuses on macroeconomics and public services, often neglecting the construction industry's bridging role among "development quality, ecological constraints, and public services." Furthermore, the definition of indicators and weighting settings frequently lack objectivity and comparability.

To address these shortcomings, this paper introduces the TOPSIS-entropy weighting method within a multidimensional indicator system. On one hand, entropy weights reflect the information contribution of each indicator, mitigating subjective weighting biases. On the other hand, the comprehensive distance to the ideal solution characterizes each city's relative performance, forming a highly discriminative and traceable "Regional

Development Gap Index (UUDI)." Methodologically, this study standardizes positive/negative indicators for trend consistency, calculates information entropy and objective weights, constructs a weighted standardized matrix, and extracts Euclidean distances between optimal/suboptimal solutions to derive the UUDI. Additionally, PCA is applied for dimensionality reduction testing, generating UUDI_PCA to assess robustness. Regarding data, this study utilizes panel data from 21 cities in Guangdong Province spanning 2013–2023, compiled from the China Urban Statistical Yearbook, ensuring consistent measurement criteria and temporal continuity. Building upon three core dimensions—Economic, social, and environmental—It systematically incorporates construction-related indicators to reflect the sector's pivotal role in advancing green and low-carbon development, public services, and livability enhancement.

2. Introduction to the TOPSIS entropy weight method

The TOPSIS Entropy Weight Method is a comprehensive evaluation technique that combines the advantages of the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method and the entropy weight method, finding extensive application in multi-criteria decision analysis.

The TOPSIS method operates by normalizing the raw data matrix to identify the optimal and suboptimal solutions among a finite set of alternatives. It then calculates the distance between each evaluation object and both the optimal and suboptimal solutions. By comparing these distances, it establishes a ranking of the evaluation objects. Its core principle is that an evaluation object is superior if it is closer to the optimal solution and farther from the suboptimal solution.

The Entropy Weighting Method is an objective weighting approach that determines indicator weights based on their variability. In information theory, entropy measures uncertainty. An indicator with lower information entropy indicates greater variability, providing more information and thus playing a larger role in comprehensive evaluations, resulting in a higher weight. Conversely, an indicator with higher information entropy receives a lower weight[1].

3. Data sources and processing

The data for this study is derived from panel data on 21 prefecture-level cities in Guangdong Province, sourced from the China Urban Statistical Yearbook covering the years 2013 to 2023. The China Urban Statistical Yearbook is a comprehensive annual reference publication that reflects the socioeconomic development of Chinese cities. Its data is authoritative, systematic, and continuous, providing rich and reliable information for researching the impact of digital finance on regional development disparities in Guangdong.

Following the collection of raw data, the data preparation phase commenced. The initial data cleaning task involved removing duplicate entries. Due to the complexity of data sources, some records may have been entered multiple times. These duplicates could interfere with subsequent analysis results and thus needed to be identified and eliminated. By writing a data cleaning program, each record in the dataset was compared to locate duplicates, retaining only one instance to ensure data uniqueness.

Missing value handling was another critical step in data preparation. In real-world datasets, missing values may occur for various reasons. Different methods were applied based on the characteristics of each indicator. For critical indicators with few missing values, mean imputation was used: calculating the average value of that indicator across other years or cities and using this average to fill in the gaps. For indicators with numerous missing values that had minimal impact on overall analysis, direct deletion was considered[2].

Furthermore, to better align the data with analytical requirements, certain datasets underwent standardization. Significant variations in the units and magnitudes of different indicators could skew subsequent analysis outcomes, necessitating normalization to eliminate such scale effects. Common standardization methods include linear transformation and range transformation. This study selected appropriate standardization techniques based on the specific characteristics of the data.

Following data cleaning, missing value handling, and standardization, the final dataset for subsequent analysis was obtained. This dataset not only ensures data quality and accuracy but also lays a solid foundation for subsequent applications: measuring digital financial development levels and regional development gaps in Guangdong using the TOPSIS entropy weight method, and establishing regression models for empirical analysis.

4. Development of the indicator system

4.1. Regional development disparity indicator system

To accurately measure the impact of digital finance on regional development disparities in Guangdong, it is necessary to establish a scientifically sound indicator system that separately assesses the level of digital finance development and regional development gaps in Guangdong. The following regional development gap indicator system is constructed across three domains: Economic, social, and environmental.

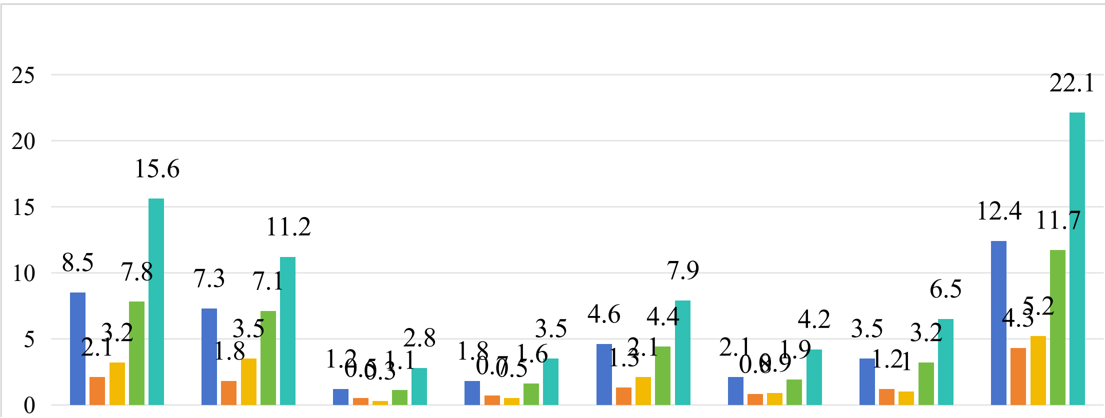

Figure 1. All data.

Table 1. Statistical measures of economic dimension indicators.

Name	Mean	Standard Deviation	Minimum value	Median	Maximum value
Per Capita Regional Gross Domestic Product (ten thousand yuan/person)	8.5	2.1	3.2	7.8	15.6
Regional Gross Domestic Product Growth Rate (%)	7.3	1.8	3.5	7.1	11.2
Per Capita Local Fiscal Revenue (ten thousand yuan/person)	1.2	0.5	0.3	1.1	2.8
Per Capita Local Fiscal Expenditure (ten thousand yuan/person)	1.8	0.7	0.5	1.6	3.5
Per Capita Disposable Income of Urban Residents (ten thousand yuan/person)	4.6	1.3	2.1	4.4	7.9
Per Capita Net Income of Rural Residents (ten thousand yuan/person)	2.1	0.8	0.9	1.9	4.2
Per Capita Fixed Asset Investment (ten thousand yuan/person)	3.5	1.2	1	3.2	6.5
Foreign Capital Dependence Ratio (%)	12.4	4.3	5.2	11.7	22.1

Table 2. Statistical measures for social dimension indicators.

Name	Mean	Standard Deviation	Minimum value	Median	Maximum value
Population density (people/square kilometer)	850	320	150	780	2200
Number of hospitals and health centers per capita (per 10,000 people)	0.8	0.3	0.2	0.7	1.5
Number of medical institution beds per capita (per 10,000 people)	45	12	20	43	80
Proportion of education expenditure in fiscal expenditure (%)	15.2	3.5	8.7	15	22.4
Pension insurance coverage rate (%)	85.3	12.4	62.1	88.5	98.7
Health insurance coverage rate (%)	92.1	8.7	70.5	93.2	99.5
Per capita residential land area (square meters/person)	30	10	15	28	55
Per capita number of buses (buses/10,000 people)	12	4	5	11	25
Per capita number of taxis (taxis/10,000 people)	8	3	2	7	15

Table 3. Statistics for environmental dimension indicators.

Name	Mean	Standard Deviation	Minimum value	Median	Maximum value
Green Coverage Rate (%)	42.3	9.2	25.6	43.1	60.5
Per Capita Green Space Area (square meters/person)	12.5	3.8	5.2	11.7	20.3
Rate of Harmless Treatment of Domestic Waste (%)	92.7	8.2	70.5	95.3	99
Rate of Centralized Treatment of Sewage (%)	88.4	7.5	65.1	89.2	98.6
Per Capita Industrial Wastewater Discharge (tons/person)*	5.2	2.1	1.5	4.8	10.3
Per Capita Sulfur Dioxide Emission (kilograms/person)*	3.8	1.5	0.9	3.5	7.2

4.2. Methods for measuring regional development disparities

At the methodological level, existing literature measures regional development disparities using conventional approaches. This study innovatively employs the TOPSIS Entropy Weighting Method to quantify regional development gaps. Known as the "Technique for Order Preference by Similarity to Ideal Solution," this technique excels at handling multi-indicator, multi-sample comparative evaluations. By calculating the relative proximity of each year's optimal city region to other regions, it not only quantifies development gaps between regions but also enables dynamic observation of development level rankings. Specifically, the Regional Development Gap Index (UUDI) ranges from[1]. Values closer to 0 indicate higher development equilibrium, while values closer to 1 reveal significantly widening development disparities. The specific calculation process is as follows:

Based on the data in **Tables 1-3**, both positive and negative indicators are trend-standardized and subsequently normalized. This yields the following equation[3]:

$$X_{ij} = \left[x_{ij} - \min\left(x_{ij}\right)\right] / \left[\max\left(x_{ij}\right) - \min\left(x_{ij}\right)\right] \quad \text{Formula (1)}$$

$$X_{ij} = \left[\max\left(x_{ij}\right) - x_{ij}\right] / \left[\max\left(x_{ij}\right) - \min\left(x_{ij}\right)\right] \quad \text{Formula (2)}$$

In the formula, Equation (1) represents forward indicators, Equation (2) represents backward indicators, X_{ij} false denotes the standardized matrix, i represents urban areas, and j denotes indicators.

By constructing the above indicator system, we can comprehensively and objectively measure the level of digital finance development and regional disparities within Guangdong, providing robust data support for subsequent empirical analysis. Subsequently, weights are determined using the entropy weighting method. By calculating the jth indicator and information entropy, we obtain:

$$E_j = -\frac{1}{\ln n}\sum_{i=1}^{n}\left[\left(x_{ij} / \sum_{i=1}^{n} x_{ij}\right)\ln\left(\left[x_{ij} / \sum_{i=1}^{n} x_{ij}\right)\right]\right. \quad \text{Formula (3)}$$

$$W_j = \left(1 - E_j\right) / \sum_{j=1}^{m}\left(1 - E_j\right) \quad \text{Formula (4)}$$

In the above equation, E_j denotes information entropy, and W_j denotes its corresponding weight; subsequently, after weighting, the weighted standard matrix is obtained:

$$c_j^{+} = \left(\max c_{i1}, \max c_{i2}, \ldots, \max c_{im}\right) \quad \text{Formula (5)}$$

$$c_j^{-} = \left(\min c_{i1}, \min c_{i2}, \ldots, \min c_{im}\right) \quad \text{Formula (6)}$$

In the formula, c_j^{+} denotes the optimal value of the jth indicator in the matrix, while c_j^{-} represents the worst value of the jth indicator. Based on the Euclidean distance $s_i^{+} = \sqrt{\sum_{i=1}^{m}\left(c_j^{+} - c_{ij}\right)^2}$ to the optimal value and the Euclidean distance β_1 to the worst value of the comprehensive indicator, the diluted variable β_2 can then be calculated.

By repeating the above steps annually, the regional development gaps at the city level in Guangdong Province from 2013 to 2023 can be calculated. For robustness testing, principal component analysis (PCA) was also employed for dimensionality reduction. The development gap index (UUDI_PCA) was computed using the TOPSIS entropy weight method. This approach is also recognized as a method for measuring development levels[4].

5. Future work and outlook

For subsequent research and application, this paper proposes the following directions to further refine the identification and policy translation of the "digital finance-construction industry-regional coordinated development" framework:

Deepening Construction Industry Metrics and Standardizing Definitions: Beyond existing economic/social/environmental dimensions, further refine green and digital indicators for the construction sector. Examples include: - Prefabricated construction share of new floor area - Green building area/star-rated proportion - Energy consumption and carbon intensity per unit output during construction - Construction waste reduction rate - BIM/digital construction adoption rate - Engineering quality and safety incident intensity Conduct cross-city calibration to ensure metric consistency. Spatial Correlation and Network Spillover Identification: Incorporate spatial weight matrices (geographic adjacency, economic distance, or transportation accessibility) into the UUDI framework to examine cross-regional spillover and transmission pathways between digital finance and construction factors. Identify convergence/divergence mechanisms within the "core-periphery (Pearl River Delta-non-Pearl River Delta)" structure. Robust Effect Identification: Combining instrumental variables (e.g., basic telecommunications infrastructure deployment, historical financial outlet density shocks), breakpoint/event studies, or difference-in-differences designs to discern the causal impact of digital finance on regional disparities and construction sector greening, while controlling for common trends and policy resonance.

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