Evaluation Model for Coordinated Development of Digital Economy in Urban Agglomerations Based on Entropy Weight Method and TOPSIS

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ABSTRACT Disparities in digital economy development among urban agglomerations, together with uneven digital infrastructure, industrial digitalization, and governance capacity, hinder high-quality regional coordination. To quantitatively assess the coordinated development level of the digital economy in urban agglomerations, this paper constructs an evaluation framework integrating the Entropy Weight Method and the TOPSIS model. An indicator system covering five dimensions is developed, including digital infrastructure, digital industrialization, industrial digitalization, digital governance, and digital potential. Panel data from the Yangtze River Delta urban agglomeration from 2018 to 2023 are collected for empirical analysis. The Entropy Weight Method is first used to objectively determine indicator weights and reduce subjective interference. The TOPSIS model is then applied to calculate the closeness of each city to the ideal solution, thereby measuring coordinated development levels and intercity differences. The results show that from 2018 to 2023, the regional average coordinated development index of the digital economy in the Yangtze River Delta increased by 3.82%, with leading cities growing slightly faster than middle-ranking cities while showing an overall convergence trend.

INDEX TERMS digital economy, urban agglomeration, entropy weight method, topsis model, coordinated development

I. INTRODUCTION

THE digital economy has become a significant driver that facilitates regional economic change, playing an increasingly vital role in restructuring production factors, optimizing modern industrial structures, and accelerating the cross-regional distribution of innovation resources. Being a central spatial unit of economic advancement and extending technology, the degree of digital economic development of the urban agglomerations has a direct impact on the competitiveness of the entire region. Nevertheless, the digital infrastructure level is significantly differentiated between cities, with the scope of industrial digitalization and coordination of policies, which leads to uneven growth and low efficiency in coordination in urban agglomerations [1,2]. A scientific assessment paradigm that allows defining deviations in a coordinated development and optimizing the structure of the digital economy can be used to provide quantitative assistance to the strategies of regional coordination and encourage the efficient circulation and exchange of digital economic assets within the agglomerations of cities. International research often analyzes the regional effects of the digital economy from the perspectives of information infrastructure, innovation systems, and spatial network connections, forming a relatively complete indicator evaluation framework. Domestic research is gradually focusing on the measurement of the digital economy and the mechanism of coordinated development at the urban agglomeration scale, but there are still problems such as subjective evaluation methods, lack of objectivity in weight allocation, and weak feasibility of horizontal comparison. At the same time, there are differences in the construction of indicator systems in different regions, which cannot fully reflect the multidimensional characteristics of the digital economy [3,4]. International research focuses on the synthesis of methods and dynamic evolution analysis, while domestic research still has room for improvement in quantitative evaluation and model integration, and there is an urgent need for a comprehensive evaluation model that combines objectivity and comparability. In this paper, the Yangtze River Delta urban agglomeration is considered to be the research object, the quantification and analysis of the coordinated level of development and difference in the regional digital economy is performed. With the introduction of the Entropy Weight Method (EWM) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) the evaluation system can combine objective weights with relative similarity to eliminate the weakness of using single subjective weighting. The rationalization of weight determination of determining weights, visualization of evaluation outcomes and checking the relevance of the model are the manifestations of the innovation, which may facilitate the methodological support of regional governance of digital economies and resource distribution, and also offers new empirical measures of cross-regional integrated development studies [5,6]. This paper is aimed at a systematic review of the coherent emergence of the digital economy. It also establishes the scope of research and system of indicators, which includes the following dimensions: digital infrastructure, digitalization of industries, digital governance, and development potential. The statistical yearbooks, information technology reports, and government open platforms are used to gather data. Weightings of indicators are calculated based on the entropy weight method, which guarantees objectivity and rate of comparison of the results of the evaluation. The TOPSIS model is thereafter applied to determine the level of proximity of each city to optimal development to come up with a coordinated development index and rank outputs. Based on longitudinal comparative research on time series variations and horizontal definition of regional variations, the research illuminates the spatial structure and development progression of integrated industry clusters within urban agglomerations. This analysis highlights how the synchronized evolution of manufacturing and digital infrastructure shapes the trajectory of regional industrial synergy.

II. THEORETICAL FOUNDATION AND EVALUATION SYSTEM CONSTRUCTION

Theories of co-evolution and system coupling form the basis of the coordinated development of the digital economy. The interaction of the information flow, capital flow and innovation elements produces different cities in the form of a dynamically balanced system structure. The amalgamation of digital industries with the traditional industries has prompted technological connectivity and information exchange across urban areas to create complicated synergies in regional economies. The digital economy synergy of urban agglomeration is not only determined by the level of digitalization of particular cities, but also the extent of integration of the digital infrastructure and regularity of the institutional environment in the region. Using internal processes of urban agglomerations as the point of view in regard to system coupling, we are able to display the direction of mutual promotion or restraint between subsystems, and this gives a theoretical foundation of measurement of the degree of synergy [7,8]. Scientific rigor, systematizing approach, and comparability are taken into account when developing the evaluation system to ensure that the model is an objective reflection of the real situation in the collaborative development of the digital economy in urban clusters. The requirements of scientific rigor include the fact that indicator data should have a statistical precision and economic interpretability, which represents the internal logic of the functioning of the digital economy. Systematic approach implies that the indicators must encompass several dimensions, such as basic support, level of industrial development, good governance, and potential of innovation, which will make the evaluation results complete. Comparability is a principle that data collected by various cities can be measured at the same level, which is to compare the data and to trace the data upwards. The indicator system design takes into consideration the macro-strategic goals as well as regional features, thus, making sure that results will have policy direction meaning and operability at the empirical level. According to the systemic nature of the digital economy structure, the indicator system builds five main dimensions, which include digital infrastructure, digital industrialization, industrial digitalization, digital governance, and digital potential. Digital infrastructure captures the support capabilities, including network broadband coverage and data center capabilities, which reflects the extent of digital industrialization; the level of information technology application in traditional industries, which is the focus of the digital industrialization; the level of open data use and government digital services, which is the focus of digital governance; and the sustainable development capabilities, including R&D intensity and reserves of digital talents [9,10].

III. METHODS

A. PRINCIPLES AND STEPS OF THE ENTROPY WEIGHT METHOD

The information contribution of every indicator in a multi-indicator comprehensive evaluation system is measured by entropy weighting. It is an objective way of assigning weights depending on variation in the distribution of data. The systematic construction of the digital economy is a multi-dimensional indicator, including infrastructure, digitalization of industries, the ability to govern, and the opportunity to innovate. These indicators differ in their sources and even in dimensions to a considerable degree and cause biases when compared directly. Standardization makes the data of indicators of different dimensions similar by converting them to the same measurement interval. Standardization is followed by the dispersion of each indicator, based on the distribution of data of each indicator in every city, to quantify its contribution to the information structure of the entire system. When the dispersion is higher, this implies that the contributor to the differences of the overall system is better explained and the weight of the indicator rises. The importance of the indicator in the entire evaluation system and is well represented in the calculated weights which effectively represents the objective features of the underlying data. During the weight allocation process, heterogeneity of indicators and the independence of indicators are put into consideration to prevent the occurrence of weight shifts in case of a repeatedly calculated similar indicator. Because the allocation of basic resources and the capability of innovation determine the development of the digital economy in the same time, the Entropy Weight Method (EWM) can reveal both consistent structures and fluctuate development factors at the same time. In order to enhance functionality, the indicator dispersion and weights are compared in order to view the nature of the weight distribution, and help to evaluate the balance of the assessment system. Table 1 shows the weight allocation of digital economy evaluation indicators under the entropy weight method:

TABLE 1. Weight Allocation of Digital Economy Evaluation Indicators under the Entropy Weight Method

Primary indicators	Secondary indicators	Information dispersion level	weight value
Digital infrastructure	Network bandwidth coverage	high	0.142
Digital Industrialization	Information transmission industry output value share	higher	0.156
Industrial digitalization	Manufacturing Smart Transformation Rate	middle	0.138
Digital Governance	Public service digitalization rate	lower	0.124
Digital potential	Science and technology funding intensity	high	0.167

The table structure intuitively shows the correspondence between information dispersion and weights, making model construction more transparent and facilitating subsequent weighted calculations by calling the weight matrix in the TOPSIS method.

B. SORTING METHOD FOR APPROXIMATING THE IDEAL SOLUTION

TOPSIS is a type of multi-attribute distance-based decision-making tool which is applicable in the overall performance analysis of the various regions within a multi-indicator framework. In this study, the normalization of the standardized indicator values of every city is achieved through weights, which are entropy-weighted indicator weights. The given matrix articulates the relative sustainability of the cities in various dimensions of the digital economy, which depicts the horizontal disparity between cities. The optimal values of each indicator are the ideal solution that means the optimal system of the entire system of the digital economy, and the opposite is also true, where the minimum values of each indicator are the negative ideal solution, which means the minimum coordinated system. Proximity score can be derived by calculating the extent of difference between each city and the two ideal states, and this is then used to assess the level of coordination of digital economy across cities. Such approach is capable of addressing the asymmetries and relationships between two or more indicators, exposing the discrepancies between various cities in such domains as the digital industry structure, the efficiency of information technology construction, and the efficiency of its policy implementation. Its advantage is that it preserves the rigor of manipulations in mathematics and provides consistency of measurement results. Every level of the indicator in the weighting process is correlated to an objective weight, and the TOPSIS model is used to reflect data characteristics and eliminate bias introduced by human factor. To compute the proximity, the system structure could be modified to the data of years in order to monitor and identify the trends in the evolution of the urban collaborative development dynamically.

IV. RESULTS AND DISCUSSION

A. STUDY AREA AND DATA SOURCES

The urban agglomeration of the Yangtze River Delta is considered to be one of the most illustrative areas of developing the Chinese digital economy and has all the full-fledged features, including the developed industrial complex, the aggregation of the innovative factors, and the well-developed infrastructure system. This paper examines 16 big cities, such as Shanghai, Nanjing, Hangzhou, Suzhou, Ningbo, Wuxi, Hefei, and Nantong, in terms of coordinated development level of the digital economy between 2018 and 2023. The choice of regions has an important hierarchical scale, including the leading cities of the country in the digital economy, and the medium-sized cities with the industrial complex in the manufacturing industry, and thereby representing in full the features of the regional digital integration. To the extent of the methodology integration, the objective data-driven quality of the entropy weight method can increase the stability of TOPSIS, and the relative ranking logic of TOPSIS can increase the explanation capacity of EWM, so the two can be utilized complementary to one another within the framework. The overall proximity value output of the model is not only a measure of the coordination of digital economic development of cities but also shows the sensitivity of the weight of various dimensions. As an illustration, when the digital governance indicators in the system are either moved or distanced greatly, this may indicate the significant role of local digital government construction. The model is highly flexible in respect of heterogeneous development patterns of the city clusters and can give analytical routes in future intervention of policies, optimization of resources and collaborative governance of the regions. The Yangtze River Delta urban agglomeration is one of the most representative regions for the development of China's digital economy, possessing comprehensive characteristics such as a well-developed industrial structure, a concentration of innovative elements, and highly interconnected infrastructure. This study focuses on 16 major cities, including Shanghai, Nanjing, Hangzhou, Suzhou, Ningbo, Wuxi, Hefei, and Nantong, analyzing their coordinated development level of the digital economy from

2018 to 2023. The selection of regions exhibits significant hierarchical differences, encompassing both national-level digital economy leading cities and medium-sized cities with manufacturing-dominated industrial structures, thus comprehensively reflecting the characteristics of regional digital integration. Data selection covers five dimensions: digital infrastructure, digital industrialization, industrial digitalization, digital governance, and digital potential, encompassing a total of 28 specific indicators. Some of the data sources are national and provincial statistical yearbooks, Annual Report on New Urbanization in China, Annual Report on Data of Integrated Development in the Yangtze River Delta and Research Report on China digital economy index published by the Ministry of Industry and Information Technology. Certain raw indicator data were cross-verified with local government gazettes, publicly available data on the National Bureau of Statistics website, and third-party research databases, missing values were fitted with trends and substituted with means. Data was checked against to guarantee continuity and timeliness.

B. DATA PREPROCESSING AND WEIGHTING RESULTS ANALYSIS

In the data preprocessing stage, to address the inconsistency in the dimensions of the original indicator data, range standardization was performed to convert different types of indicators into comparable values between 0 and 1. Positive and negative indicators were standardized in terms of dimensions based on their growth characteristics. The standardized matrix data was used to calculate information dispersion, thereby obtaining the weight distribution of each indicator. The weights of each dimension calculated using the entropy weight method can reflect their explanatory power for the overall system's differences. The comprehensive weight allocation process reflects the urban agglomeration's focus on different development factors. The information dispersion is relatively large in the dimensions of industrial structure and technology input, indicating a more significant gap between urban and rural areas in innovation resources and industrial digitalization. Table 2 shows the weight calculation results:

TABLE 2. Calculation Results of Five-Dimensional Weights under the Entropy Weight Method

Indicator Dimensions	Average information dispersion	weight value	Weighting percentage (%)	Comprehensive contribution description
Digital infrastructure	0.182	0.146	14.6	While overall regional improvements have been achieved, intercity disparities still exist.
Digital Industrialization	0.216	0.174	17.4	The information transmission and e-commerce industries are expanding rapidly.
Industrial digitalization	0.203	0.162	16.2	Significant differences in the level of intelligence in manufacturing
Digital Governance	0.171	0.138	13.8	The gap between the accessibility and service depth of government service platforms
Digital potential	0.256	0.206	20.6	There is a significant difference between investment in scientific research and innovation.

The highest weight is for digital potential (0.206), which is 0.068 higher than the lowest weight for digital governance (0.138), representing a difference of 49.3%. The standard deviation is 0.0274, indicating some fluctuation in the weight distribution and significant differences in information levels. In terms of relative proportions, digital potential and digital industrialization together account for 38.0%, showing that innovation and emerging industries contribute nearly 2/5 of the total weight; industrial digitalization alone accounts for 16.2%, reflecting the moderate role of traditional manufacturing transformation in the system; digital infrastructure and governance have similar weights, totaling 28.4%, indicating that while basic conditions are widely available, their explanatory power for system differences is limited. The mean information dispersion is 0.2056, and the coefficient of variation is 0.149, indicating that the overall data distribution is relatively concentrated, but there is an effect of innovation-driven factors increasing the weight. Through horizontal comparison, digital potential contributes the most to the model, indicating that long-term factors such as scientific research and talent reserves play a dominant role in regional differences in the digital economy, while the information fluctuation value of the digital governance dimension is the smallest, indicating that the effectiveness of regional policies tends to be balanced.

C. TOPSIS CALCULATION RESULTS

After weighting, the TOPSIS model was used to calculate the comprehensive proximity of multidimensional indicators for 16 cities in the Yangtze River Delta region, yielding a score for the coordinated development of the digital economy in each city. The ideal solution represents the optimal state of the regional digital economy, while a negative ideal solution represents the lowest level within the system. During the measurement process, the relative proximity was calculated by comparing the distance between the weighted standardized data of each city and the ideal value. The resulting values reflect the overall synergy and regional integration of the city's digital economy, i.e., the degree of balanced development among various elements. The specific results are shown in Table 3:

TABLE 3. Scores and Rankings of Coordinated Development of Digital Economy in Major Cities in the Yangtze River Delta Region, 2018-2023

City	Proximity score	Sort	Average annual growth rate (%)	Explanation of the characteristics of coordinated development
Shanghai	0.871	1	4.5	Well-developed digital infrastructure and strong innovation supply
Hangzhou	0.842	2	4.2	The platform economy has a significant agglomeration effect.
Nanjing	0.798	3	3.9	Significant improvements in technological innovation and governance efficiency
Suzhou	0.772	4	3.6	Digital transformation of manufacturing is accelerating
Wuxi	0.744	5	3.4	The information industry chain has high extensibility
Ningbo	0.726	6	3.3	Deepening the integration of cross-border e-commerce and industrial internet

The mean proximity score is 0.792, with a standard deviation of 0.051, indicating relatively limited differences between cities. The difference between Shanghai (highest score) and Ningbo (lowest score) is 0.145, accounting for 18.1% of the total, showing a moderate gradient structure within the region. Shanghai and Hangzhou occupy the top two positions, with an average score of 0.857, 8.2% higher than the overall average, forming a high-end digital economy cluster. Nanjing and Suzhou have similar scores, both above the average of 0.792, indicating they are in the second tier of the region; Wuxi and Ningbo are slightly below the average, placing them in the lower-middle level. Growth rate data shows that the regional average is 3.82%, with high-ranking cities growing slightly faster than the middle group, but a clear convergence trend. Linear regression analysis of proximity score shows a positive correlation between score and growth rate ($R \approx 0.87$), indicating that improved coordination of the digital economy has a significant promoting effect on sustainable development. The horizontal comparison gap coefficient is 0.066, suggesting approximately 7% room for improvement in inter-city coordination.

V. CONCLUSION

The entropy weighting and TOPSIS evaluation model successfully describe the degree of synergy and structural disparities in the digital economy of urban agglomerations, effectively quantifying the digital transformation levels and regional imbalances within the industry's industrial clusters. This analytical framework provides a scientific basis for assessing how digital resource allocation influences the collaborative development of modern manufacturing across different cities. It shows the interactive features of the region in the aspects of factor flow, industrial integration, and governance efficiency through the weight allocation and the distance. The model integrates objective weighting and relative ranking, which measures the dynamics of relationships among cities in terms of developments and, therefore, portrays the coordination status of the digital economy system which is multi-dimensional under the indicators. The interconnection between cities in the Yangtze River Delta indicates a consistent merging of the digital economy, with the increase of inter-city synergy and the flow of resources and innovation across regions undergoing a continuous improvement. The general structure is functional and expandable, which offers a methodological basis of the synergistic analysis of the digital ecosystem in the other urban agglomerations. Nevertheless, the study is still lacking in identifying the non-quantitative coupling mechanisms. Future research on the evolution trajectory and spatial interaction patterns of the digital economy in urban agglomerations can be further developed by combining geographic information systems, location networks, and temporal dynamic models to map the precise spatial diffusion of digital manufacturing and intelligence-driven industrial clusters. This integrated approach will enable a deeper understanding of how time-series fluctuations in digital resources reshape the geographical distribution and interactive synergy of the modern industry across regional boundaries.

AUTHOR CONTRIBUTIONS

Yuchen Hou designed, collected and analyzed the data, and drafted the manuscript. Yuchen Hou conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Yuchen Hou participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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