frontiers | Frontiers in Environmental Economics

TYPE Original Research
PUBLISHED 19 July 2024
DOI 10.3389/frevc.2024.1396615

OPEN ACCESS

EDITED BY
Jin Hooi Chan,
University of Greenwich, United Kingdom

REVIEWED BY
Hui Nee Au Yong,
Tunku Abdul Rahman University, Malaysia
Haining Wang,
University of Greenwich, United Kingdom

*CORRESPONDENCE
Wentao Wang
enterpriser@qq.com

RECEIVED 06 March 2024
ACCEPTED 02 July 2024
PUBLISHED 19 July 2024

CITATION
Wang W (2024) Regional measurement and dynamic evolution of the development level of China's digital economy.
Front. Environ. Econ. 3:1396615.
doi: 10.3389/frevc.2024.1396615

Regional measurement and dynamic evolution of the development level of China's digital economy

Wentao Wang*

School of Economics and Management, China University of Mining and Technology, Xuzhou, China

In the wave of digital transformation, digital economy, as one of the core growth poles of the national economy, which is becoming a new driving force to promote economic development. In view of the problem of the unbalanced development of China's digital economy, and to construct an indicator system for the level of digital economic development. The study is based on the panel data of 30 provinces (Tibet is not included in the study due to missing data) from 2013 to 2021, and comprehensively utilizes the entropy method, the Tyrell index and the Moran index method, the regional level of China's digital economic development is measured. And based on this, it further reveals the regional differences in China's digital economic development and the dynamic evolution characteristics of source and distribution. The purpose of this study is to provide practical experience and effective measures for promoting the coordinated development of digital economy in various regions and narrowing the regional digital divide. The study shows that the level of China's digital economy development has been increasing, and the digital economy has become the main engine of national economic development. The development of China's digital economy shows significant positive spatial dependence, spatial agglomeration and regional imbalance, and the development of the digital economy faces the problem of digital divide. The regional differences in the level of China's digital economy development are mainly due to inter-regional differences, and there is a trend of gradual reduction. There is also a certain degree of ups and downs in the process of regional digital economy development, and its spatial heterogeneity and convergence characteristics need to be further studied.

KEYWORDS

digital economy, regional differences, entropy value method, Theil index, Moran's index

1 Introduction

1.1 Research background

In recent years, along with the rapid development of emerging information technologies such as big data mining, blockchain, new artificial intelligence, cloud computing, 5G, mobile Internet and the Internet of Things, China is undergoing a comprehensive digital transformation. The digital economy is driving China's economy from a phase of rapid growth to a phase of digital transformation, and has become a core driver of China's economic development. At the 2016 G20 Hangzhou Summit, the G20 Initiative on Digital Economy Development and Cooperation, signed by leaders from multiple countries, explicitly defined the digital economy as an economic

activity dominated by digitized knowledge and information, supported by modern information networks, and improving efficiency and optimizing the economic structure through the effective application of information and communication technologies, a definition that has been widely recognized (Liu and Lu, 2023). The White Paper on the Development of China's Digital Economy released by the China Academy of Information and Communications Technology shows that the scale of China's digital economy will reach 50.2 trillion yuan in 2022, with a year-on-year growth of 10.3%, which has been significantly higher than the growth rate of GDP in the same period for 11 consecutive years, and has accounted for a proportion of GDP of 41.5%, and the integration of the digital economy with the real economy has become increasingly close .

The digital economy has become one of the core growth poles of the national economy. Due to the large differences in resource endowment, location advantages and industrial structure of various regions in China, the development of domestic digital economy is characterized by a gradient from east to west. The imbalance in regional digital economy development may lead to developed regions gaining greater development advantages, thus increasing the economic development gap between regions and bringing about a serious digital divide.

The innovation of this study is to construct a comprehensive index evaluation system for innovative digital economy. The unique feature of this index is that it adheres to the combination of comprehensiveness and focus, foresight and operability, systematicity and orientation, closely combines with the requirements of the "14th Five-Year Plan" for the development of digital economy, and takes into account the accessibility of the index data. It closely combines the requirements of the "14th Five-Year Plan" for the development of digital economy, takes into account the accessibility of the indicator data, and focuses on selecting indicators with strong representativeness to scientifically reflect the development of the national digital economy, guide localities to establish a scientific outlook on development, and accelerate the improvement of the level of digital economy development.

Unbalanced regional economic development is a major problem facing China in the process of development. Although the State has paid more attention to the coordinated development of regions in the last decade, the regions that got rich first and got richer faster still dominate the process of economic and social development in China. Narrowing the development gap between regions is the core problem that must be emphasized and solved in the next development process of China. Therefore, the main issue of this paper is to explore the current situation of regional differences in China's digital economy development and the factors affecting it.

1.2 Literature review

The world-famous American economist and business strategy master Don Tapscott, Digital Economy first proposed the concept of the digital economy in his book Digital Economy in 1996. He explains in detail in his book that the digital economy, also known as the network economy, the smart economy, or the Internet economy, has focused on depicting how the Internet has changed the paradigm and the impact of our daily lives. Human resources are an important factor in maintaining core competencies and are a model of performance excellence for businesses, efficiency, and the economy. Critical to the development of the digital economy is the need for a cadre of digital talent to deploy, organize, and operate it (Nguyen, 2023). The development of information and communication technologies (ICT) and the widespread use of the Internet and mobile communications have brought the process of globalization to a new stage. This new process represents a change in the nature of the globalization process and has been referred to as the "digital economy" (Ozgun, 2023).

The number of digital innovations in today's world economic environment is growing, but the development of the innovation process is not efficient enough, which significantly slows down the process of digital modernization of the world economy (Shevchenko et al., 2023). The E-Commerce Directive, enacted on June 8, 2000, laid the foundation for the EU's legal framework for digital services. However, at this stage, the digital economy underwent profound changes and developed into a platform economy. The rules on which the Directive is based are effectively adapted to the primary stage of development of the platform economy (Rodríguez, 2021). The spread and improvement of digital technologies affect industrial relations, economic structures, and education development and determine new requirements for communications, computing power, information systems, and services (Belozyorov et al., 2020). In traditional industries, economic value is created within the organization, whereas in the digital economy, value is created outside the organization as partners, suppliers and customers interact with each other (Salykov et al., 2024). COVID-19 In the wake of the pandemic, the adoption of digital technologies continues to surge, with businesses and consumers increasingly relying on digital platforms. According to the International Data Corporation (IDC), global spending on digital transformation is expected to reach nearly $3.9 trillion by 2027 (IDC Media Centre, 2023; Jallouli et al., 2024).

The digital economy is a new way to fully utilize information technology in business, changing the way people produce, manage, and live through online services and other programs. With the rapid development of Internet technology and the gradual formation of the habit of using mobile devices, new forms of communication technology have triggered changes in the global business sector. This is mainly due to the unique advantages of the digital economy, such as increased labor productivity and access to emerging markets. Russian President Vladimir Putin has made digital maturity a key indicator for assessing the effectiveness of the governors' work, such as the digital maturity (i.e., the ability to use domestic IT solutions) of the organs of state power, local government bodies, and organizations of the constituent entities of the Russian Federation. The Republic of Dagestan is a region in Russia with a low level of digital maturity. The realization of the digital transformation of the region's economy requires increasing the digital maturity index to the values of the developed regions of the country, such as the capital, Moscow, and the second-largest city, St. Petersburg, among other regions. In general, the digital economy is a new form of economic relationship characterized by the extensive use of information technology

and the Internet in all areas of social reproduction to ensure accelerated economic development by reducing social transaction costs, increasing economic efficiency, and dramatically changing the way in which enterprises, individuals, and the state interact.

Since 2008, scholars in China have studied the intrinsic meanings and characteristics of the digital economy. They proposed that the digital economy is a new, higher-order, and all-powerful economic model based on information technology and the Internet, which explicitly refers to all economic behaviors that consider digital information and knowledge as key factors of production, rely on networked organizational structures, and use information technology and the Internet as the main pillars. China's digital economy has boomed in the post-pandemic era. In particular, the digital economy has been transformed into a power source and major support for high-quality economic development in a new development model based primarily on the domestic cycle complemented by a dual cycle at home and abroad (Wang and Chen, 2023). The rapid development of the global digital economy has had a significant impact on fiscal revenues and expenditures, which is reflected by the fact that the digital economy can significantly increase the level of urban scale and has a significant nonlinear impact on economies of scale (Zhang et al., 2023).

Scholars have used an extended gravity model to conduct empirical analysis using cross-country panel data for 55 countries and territories from 2013 to 2021. The results show that the digital economy can promote the growth of exports of clean and polluting products. However, the promotion effect is stronger for clean product exports than for polluting products exports. An extended gravity model was used to conduct an empirical analysis using cross-country panel data for 55 countries and regions from 2013 to 2021. The results showed that the digital economy can promote the growth of exports of both clean and polluting products; however, the promotion effect is stronger for exports of clean products than for exports of polluting products (Xu et al., 2023).

Digital economy is an important engine of innovation-driven development strategy and plays an important role in promoting the high-quality development of regional economy. Based on the panel data of 286 cities in mainland China, this study examines the impact of digital economy on the innovation level of cities using a multi-temporal double-difference (DID) method. The findings show that digital economy can significantly improve the level of urban innovation. Digital economy enhances the innovation level through industrial structure upgrading. In addition, this study found that the digital economy has a stronger effect on the improvement of innovation quality. Meanwhile, compared with the western region, the innovation output in the central and eastern regions is more significantly affected by the "Digital China" strategy. Therefore, the implementation of local digital economy development strategies should be accelerated to realize the high-quality development of regional economy (Zhang and Liu, 2024). The relationship between the digital economy and the green innovation efficiency of enterprises has an inverted U-shape. The digital economy improves enterprises' green innovation efficiency by promoting the optimization and upgrading of industrial structures (Zheng et al., 2023).

The digital economy regulates resource dependence and air pollution. The digital economy provides a new path for air pollution management, as reflected in three main aspects. First, the application of digital technology promotes real-time transmission of information resources and deepens public participation in environmental protection, which has become an important method for managing air pollution. Second, the digital economy has the unique advantage that it is not limited by space or time. It can optimize resources by reducing the cost of information searches and promoting the effective use of production and data resources (Wang and Chen, 2022). The development of the digital economy is conducive to reducing carbon emission intensity, and there is strong heterogeneity in the impact of carbon emission intensity across different regions and types of cities. The digital economy can contribute to macroeconomic growth, green innovation and low-carbon economic development (Wang and Zhong, 2023).

Over the past decade, the digital economy based on the Internet, Internet of Things, cloud computing, blockchain, big data, and artificial intelligence has shown explosive growth in China. With its ability to optimize resource allocation and reduce energy consumption, the digital economy has become an important guarantee for sustainable development (Xin et al., 2023). In the new industrialization era, the digital economy has become an important driver of productivity growth and economic development in the new industrialization era. The widespread application of digital technology has fundamentally reshaped people's way of life, production, and management. We are keen to promote the close integration of digital technologies, such as the Internet, big data, artificial intelligence, cloud computing, and other digitalized technologies with the real economy to facilitate the prosperous development of our digital economy (Yang et al., 2023). Digital transformation has a significant positive impact on business performance. Specifically, deepening a company's digital transformation increases its operational efficiency and international market share, which in turn enhances its international competitiveness (Chen C. et al., 2023).

Scholars have studied the impact of the digital economy on the level of inclusive green growth at the city level in China using the Durbin model to analyze the existence of spillover effects between regions, and the main conclusions are as follows. First, the digital economy has become an important force for supporting inclusive green growth and is also an important guarantee for promoting regional economic development, reducing ecological and environmental risks, and enhancing population wellbeing. Second, green growth is significantly affected not only by the level of the local digital economy but also by the digital economy of neighboring regions (Xie et al., 2023). A green economy is an important element of economic transformation and development, while digital economy is the core driving force to realize rapid economic development. Governments should focus on regional green development, actively guide the digital economy to promote green development, accelerate the development of the digital economy, and realize healthy economic development (Chen S. et al., 2023). The digital economy promotes green innovation, and there are significant differences in the impact of different types of financing on green innovation, with the impact on

state-owned enterprises being more pronounced (Li and Wang, 2023).

Promoting all-around reform of the digital economy and establishing a digital industry cluster with global competitive strength has become a leading force for high-level economic development in China. The development of the digital economy is conducive to increasing enterprises' international reach and improving their international position in supply chain networks (Jing et al., 2023). Scholars have explored the relationship between the digital economy and urban green development efficiency (GDE) in China's Yangtze River Delta region using panel data from 41 cities from 2011 to 2020 and measured the digital economy index (DEI) and urban green development efficiency (GDE) using entropy and econometric models based on superefficiency relaxation, respectively. In conclusion, the Digital Economy Index (DEI) has a positive impact on Green Development Effectiveness (GDE). Information and communication technology (ICT) is a key factor that enhances the impact of the digital economy on GDE. The impact of the digital economy on GDE exhibits a gradient pattern. The digital divide plays a more important role (Luo et al., 2023).

The scholars selected four key factors, namely, digital infrastructure, innovation capacity, industry scale, and digital technology application, as evaluation indices of China's digital economy development and measured the regional differences and dynamic evolution of China's digital economy development by utilizing the Gini coefficient, kernel density estimation method, and Markov chain method. China's digital economy has a low level of development and large regional differences, a phenomenon of uncoordinated development, a high distribution pattern in the east and a low distribution pattern in the central and western parts of the country (Tang et al., 2023). Digitalization of the economy is critical for MSMEs as it reduces operational costs and enables MSMEs to access a wider range of potential customers. MSMEs must be technologically literate in digital technologies in order to grow their business and survive in response to market demand. Digital technology can bring many benefits to MSMEs, including the promotion of their personalized products to a larger market share (Komala and Firdaus, 2023). The digital economy is a key force driving the recovery of the green economy. The study based on data from 276 cities in China from 2012 to 2018 used Tobit regression modeling and quantile regression modeling to investigate the growth of the digital economy, modernization of the economic framework, and the correlation between green total factors and green total factor productivity (GTFP). The study found that China's GDP may grow significantly as a result of the digital economy, although there are significant regional differences (Xu, 2024).

Through the specific analysis of the above literature, synthesizing the definition of the meaning of digital economy by scholars at home and abroad, and combining the current development characteristics and future development trend of digital economy, this study summarizes the connotation of digital economy as follows: digital economy refers to the digitalized knowledge and information as the key factors of production, digital technological innovation as the core driving force, and modern information network as the important carrier, through the deep fusion of digital technology and real economy, and continuously improving the level of digitalization and intellectualization of traditional industries, accelerating the reconstruction of economic development and governmental governance mode. Through the deep integration of digital technology and the real economy, it continuously improves the digitalization and intelligence of traditional industries and accelerates the reconstruction of economic development and governmental governance model of a new type of economic form. It can be said that digital economy represents the sum of a series of economic activities of production, circulation and consumption around the key production factor of data.

The development of digital economy, accelerate the promotion of digital industrialization, relying on information technology innovation drive, and constantly give birth to new industries, new business forms and new modes, with new kinetic energy to promote new development. To promote industrial digitization, use the Internet new technology and new applications to carry out an all-round, all-angle, all-chain transformation of traditional industries, improve total factor productivity, and unleash the amplification, superposition, and multiplication of digital on economic development. It is necessary to promote the deep integration of the Internet, big data, artificial intelligence and the real economy, and accelerate the digitization, networking and intellectualization of manufacturing, agriculture and service industries.

The digital economy includes four parts: digital industrialization, industrial digitization, digital governance, and data valorization. Among them, digital industrialization refers to the products and services brought by digital technology, which at this stage includes the electronic information manufacturing industry, the information and communication industry, the software service industry, and the Internet industry. Digital industrialization is the basic part of the digital economy, but also the core driver of the digital economy. Industrial digitization refers to the application of digital technology in traditional industries to increase production and improve efficiency. Industrial digitization is the integration part of the digital economy and an extension of the digital economy. Digital governance refers to the combination of digital technology and social management to promote the development of the governance system to a higher level and accelerate the modernization of the national governance system and governance capacity. Data valorization refers to the fact that data, as a key production factor of the digital economy, runs through all the processes of digital economic development, constantly combines and repeats with other production factors, accelerates cross-fertilization, and gives rise to a multidisciplinary, multidimensional, systematic, and revolutionary breakthrough in production factors.

2 Comparative analysis of digital economy development in China and the United States

At present, the digital economy has become the core force that reshapes the global economic structure and changes the pattern of global competition, and it is an important engine that

drives economic growth for the current and future periods. China and the United States are in the "first echelon" of global digital economy development, with their own development advantages and characteristics. A comparative study of the digital economy in China and the United States is of great significance in finding countermeasures to solve the dilemmas of China's digital economy development.

China's digital economy is developing at a faster pace, while the United States has a larger digital economy. Overall, the scale of China's digital economy is still a certain gap compared with the United States, and the scale of China's digital economy in 2021 is equivalent to 46% of the United States. The scale of China's digital economy in 2021 amounted to 7.06 trillion U.S. dollars, second only to the United States (1,531 billion U.S. dollars,) the total amount of the world ranked second. From the perspective of penetration, the U.S. digital economy accounted for 65% of GDP, industrial industry digitization accounted for 36%, tertiary industry digitization accounted for 61%; China's digital economy accounted for 41.5% of GDP, industrial industry digitization accounted for less than the global average, the tertiary industry digitization accounted for 40%, and the penetration rate of digital economy of various industries is less than that of the United States.

China's Internet enterprises are not sufficiently innovative, while the United States' Internet enterprises are highly innovative. In recent years, some excellent Internet enterprises have emerged in China and the United States, becoming the front-runners in the development of the digital economy. For example, the representative enterprises of the United States are Apple, Google, Microsoft, Amazon, etc., while the representative enterprises of China are Baidu, Tencent, Huawei, Alibaba, byte jumping, etc. However, comparing these enterprises in China and the United States, the innovation ability of China's Internet enterprises has a large gap compared with that of the United States. For example, China's enterprises still retain the traditional model of imitating and catching up with the technological innovation of enterprises, and the business model and technological innovation ability of e-commerce platforms is poor. Therefore, the innovation ability of China's Internet enterprises has yet to be improved.

China and the United States have different ways of expanding the industry chain. The United States take the Internet technology as a universal technology, comprehensive penetration into all areas of life, making the Internet people's production and life play a huge role. Internet technology in the U.S. upstream and downstream industries have been laid out in depth, enhancing the innovation and international competitiveness of enterprises, the overall effectiveness of the Internet can be fully realized, forming a unique advantage. China focuses on the downstream industry of the Internet, the infrastructure of the Internet and other upstream industries is relatively backward compared to the United States, the level of research and development of the Internet is not high, and a large amount of capital and human resources are concentrated in the downstream industry of the Internet.

There are large differences in regulatory approaches between China and the United States. China's large population, regional economic, environmental and cultural differences, because of the faster regional development, digital economic development from the east to the central and western regions showing a ladder-like development trend, the form is more complex, making China in the digital economy regulation convenient cannot synchronize with the pace of economic development. In addition, China's national conditions relative to the United States is more complex, making it more difficult to regulate the digital economy. However, the United States is a developed country, the rule of law is relatively sound. The U.S. regulatory authorities have regulated the dynamics of the operation of the digital economy relatively well, especially in June 2019, the U.S. Department of Justice began to launch an antitrust investigation of four companies, Facebook, Amazon, Apple and Google, and released an antitrust research report called "Digital Market Competition Investigation" in 2020, pointing out that these four companies abused the market economic status that suppressed and stifled competition. These actions show that the U.S. government is strengthening the regulation and governance of monopoly behavior in the digital economy, the regulatory strategy of the U.S. digital economy antitrust, and what is the reference significance for China.

In summary, the development of the digital economy has attracted extensive global attention and has become the core force driving the development of global economic innovation. The United States in supporting the development of digital economy mainly adopts the overall layout of the dominant Internet industry, actively promotes the strategy of big data and cloud computing, promotes the widespread application of the Internet in industry and energy, strengthens the construction of digital infrastructure, attaches importance to technological research and development, patents and intellectual property rights protection, and actively promotes the transformation of laboratory products into market products and other policy measures. Currently, there is a large gap between China's digital economic development in terms of total volume, innovation capacity, industrial development and regulation compared with the United States. Therefore, China needs to increase its investment and pay more attention to top-level design to effectively promote the development of the digital economy.

3 Methods and data

The raw data used in this study were obtained from the National Bureau of Statistics, the China Statistical Yearbook, the Statistical Yearbooks of China's Information Industry provinces and the 2022 China Digital Economy Development Research Report published by the China Institute of Information and Communication Technology (CICT) from 2010 to 2021 in order to more objectively reflect the level of development of the regional digital economy, to guarantee the fairness of the data, and to make the empirical results more accurate, all data are calculated as mean value. These data were used to accurately measure the level of regional digital economy development and to construct a comprehensive digital economy indicator evaluation system from the three dimensions of digital infrastructure, digital industry development, and digitization potential (detailed data in Table 1) (He et al., 2023; Wang D. X. et al., 2023; Yang and Li, 2023; Zhao, 2023).

Digital infrastructure refers to the various hardware, software and network facilities that support the development of the digital economy and digital society. It includes communication

TABLE 1 Comprehensive indicator system for the level of development of the digital economy.

Level 1 indicators	Level 2 indicators	Three-tiered measurement indicators	Unit
Digital infrastructures	Hardware facilities	Mobile telephone exchange capacity	Ten thousand
		Number of ports for internet broadband access	Ten thousand
		Length of long-distance fiber-optic cable lines	Ten thousand kilometers
	Software facilities	Number of internet domain names	Ten thousand
		Number of internet web pages	Ten thousand
Development of the digital industry	Digital industrialization	Total telecommunication services	100 million RMB
		Size of software business revenues	Ten thousand RMB
	Digitalization of industry	Number of enterprises with e-commerce trading activities	Companies
		Share of enterprises with e-commerce trading activities	Percent (%)
		E-commerce sales	100 million RMB
Digitalization potential	Talent environment	Number of talents with bachelor's degree or above	Ten thousand people
	Application environment	Cell phone year-end subscribers	Ten thousand subscribers
		Mobile telephone penetration rate	Percent (%)

networks, data centers, cloud computing, artificial intelligence and many other aspects. The construction and development of digital infrastructure is of great significance in promoting economic growth, improving social efficiency, fostering innovation and enhancing national competitiveness. Digital industrialization, i.e., the core industries of the digital economy, refers to all kinds of economic activities that provide digital technologies, products, services, infrastructures and solutions for the digital development of industries, as well as those that are completely dependent on digital technologies and data elements. The potential of digitization is attributed to three factors: China's large market size and a sizable and relatively young number of Internet users have created the conditions for the rapid marketization of digital business models; China has not only spawned a number of digital giants, but also formed an ever-expanding digital ecosystem; and the government not only provides enough space for digital enterprises to test the waters, but also acts as both an investor and a consumer of digital technologies.

To accurately measure the level of regional digital economy development, a comprehensive digital economy index evaluation system is constructed from the three dimensions of digital infrastructure, digital industry development, and digitization potential to scientifically and reasonably measure the level of digital economy development and regional differences in 30 provinces (Grigorescu et al., 2021; Li et al., 2023; Pang and Wang, 2023; Shen and Zhou, 2023; Wang K. L. et al., 2023). This is used as the basis for calculating the digital economy development level among the four major economic zones of the eastern, western, central, and northeastern regions, as well as within each region. This approach will be used as a basis for calculating the differences in the level of digital economic development among the four major economic zones of East, West, Central, and Northeast, as well as within each region, to understand the differences in the development of the digital economy across the country as well as the trend of regional differences, to analyze the factors affecting the unbalanced development of the digital economy and its causes and to explore policies and suggestions for promoting the coordinated development of the digital economy in the region.

3.1 Entropy value method

In this paper, the entropy method is used to measure the development level of China's digital economy and the development level of three subsystems (Zhang and Shi, 2023; Gao, 2024). The entropy method, as an objective weighting method, is often used in the comprehensive evaluation of multiple indicators. Its principle is to determine the weights based on the size of the indicator data, and the larger the weights, the greater the influence on the evaluation system. Compared with other methods, the entropy method can eliminate the interference of subjective and artificial, and make the results of measurement more scientific and reasonable. Entropy value method belongs to a kind of objective assignment method, which utilizes the size of the information carried by the data to calculate the weights and get more objective indicator weights. Entropy value is a measure of uncertainty, the smaller the entropy, the greater the amount of information carried by the data, the greater the weight; on the contrary, the greater the entropy, the smaller the amount of information, the smaller the weight. The entropy method is widely used in various fields, and it can be calculated for common questionnaire data (cross-section data) or panel data. In practical research, it is usually used in conjunction with other weight calculation methods, such as factor or principal component analysis to get the weight of the factor or principal component, that is, to get the weight of the high dimensionality, and then use the entropy method to calculate, want to get the weight of the specific items.

The entropy value method emphasizes the advantage of assigning values based on objective facts, because the entropy value method is an objective assignment method, which can reflect the utility value of the indicator information entropy, so as to determine the weights, and the subjective weight value derived

TABLE 2 2013–2021 China's digital economy development level composite index DEDCI measurement results.

District		2013	2014	2015	2016	2017	2018	2019	2020	2021	Average annual growth rate (%)
Eastern region	Beijing	0.229	0.294	0.390	0.419	0.459	0.485	0.546	0.571	0.633	13.569
	Tianjin	0.054	0.063	0.064	0.069	0.071	0.078	0.085	0.097	0.093	6.930
	Hebei	0.110	0.121	0.131	0.151	0.164	0.183	0.209	0.226	0.194	7.403
	Shanghai	0.128	0.169	0.191	0.216	0.224	0.230	0.266	0.279	0.285	10.524
	Jiangsu	0.250	0.263	0.275	0.292	0.317	0.370	0.436	0.457	0.410	6.421
	Zhejiang	0.205	0.233	0.269	0.295	0.307	0.333	0.390	0.397	0.365	7.487
	Fujian	0.106	0.124	0.155	0.203	0.259	0.258	0.265	0.225	0.213	9.166
	Shandong	0.235	0.247	0.248	0.272	0.291	0.328	0.349	0.368	0.349	5.058
	Guangdong	0.364	0.399	0.424	0.466	0.491	0.576	0.654	0.674	0.637	7.259
	Hainan	0.021	0.031	0.039	0.042	0.042	0.045	0.055	0.055	0.046	10.452
	Average value	0.170	0.194	0.218	0.242	0.263	0.288	0.325	0.335	0.323	8.333
Central region	Shanxi	0.062	0.067	0.071	0.079	0.083	0.107	0.116	0.126	0.109	7.268
	Anhui	0.082	0.097	0.115	0.122	0.133	0.156	0.190	0.202	0.182	10.404
	Jiangxi	0.053	0.061	0.079	0.080	0.091	0.112	0.139	0.149	0.125	11.428
	Henan	0.123	0.145	0.173	0.190	0.203	0.240	0.276	0.297	0.246	9.056
	Hubei	0.104	0.119	0.146	0.152	0.156	0.173	0.203	0.207	0.177	6.882
	Hunan	0.088	0.101	0.116	0.129	0.140	0.161	0.197	0.208	0.170	8.597
	Average value	0.085	0.099	0.116	0.125	0.134	0.158	0.187	0.198	0.168	8.851
Western region	Inner Mongolia	0.060	0.065	0.072	0.079	0.083	0.090	0.100	0.104	0.091	5.303
	Guangxi	0.055	0.067	0.075	0.084	0.104	0.124	0.148	0.166	0.135	11.897
	Chongqing	0.049	0.063	0.077	0.089	0.095	0.109	0.128	0.141	0.128	12.773
	Sichuan	0.135	0.158	0.187	0.205	0.221	0.256	0.274	0.299	0.251	8.013
	Guizhou	0.046	0.054	0.063	0.072	0.078	0.096	0.121	0.130	0.117	12.370
	Yunnan	0.064	0.076	0.085	0.090	0.095	0.114	0.140	0.153	0.115	7.522
	Shanxi	0.057	0.068	0.080	0.094	0.101	0.117	0.141	0.144	0.121	9.837
	Gansu	0.029	0.034	0.042	0.046	0.053	0.063	0.0730	0.081	0.064	10.394
	Qinghai	0.019	0.023	0.029	0.033	0.033	0.038	0.039	0.042	0.039	9.927
	Ningxia	0.015	0.050	0.024	0.028	0.029	0.035	0.035	0.037	0.032	10.296

(Continued)

10.3389/frevc.2024.1396615

TABLE 2 (Continued)

District		2013	2014	2015	2016	2017	2018	2019	2020	2021	Average annual growth rate (%)
Northeastern part of China	Xinjiang	0.043	0.048	0.054	0.055	0.059	0.069	0.083	0.093	0.079	7.975
	Average value	0.052	0.064	0.072	0.080	0.086	0.101	0.117	0.126	0.107	9.391
	Liaoning	0.122	0.131	0.151	0.131	0.136	0.143	0.159	0.170	0.150	2.668
	Jilin	0.050	0.056	0.061	0.069	0.077	0.087	0.088	0.093	0.079	5.990
	Heilongjiang	0.071	0.080	0.084	0.087	0.093	0.097	0.107	0.113	0.098	4.219
	Average value	0.081	0.089	0.098	0.096	0.102	0.109	0.118	0.125	0.109	3.857
Nationwide	Average value	0.097	0.112	0.126	0.136	0.146	0.164	0.187	0.196	0.177	7.781

from it has a higher accuracy and credibility than the subjective assignment method. This study adopts this metric to measure the degree of the digital economy and calculates the evaluation standard ratio P_{ij} of the i-evaluation object of item j as follows (Equation 1):

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, i = 1, 2, \cdots, n \tag{1}$$

The entropy value E_j for the j^{th} evaluation metric is calculated as follows (Equation 2):

$$E_J = \frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right), j = 1, 2, \cdots, n \tag{2}$$

The weight ω_j of the j^{th} evaluation index is calculated as follows (Equation 3):

$$\omega_j = \frac{1 - E_J}{\sum_{j=1}^{n}\left(1 - E_j\right)}, j = 1, 2, \cdots, n \tag{3}$$

The level of digital economy development in each region is measured as follows (Equation 4):

$$Z_I = \sum_{j=1}^{n} \omega_j y_{ij}, j = 1, 2, \cdots, n \tag{4}$$

From this equation, we can derive an aggregate value DEDCI (The Composite Index of Digital Economy Development is an indicator that measures the development of the digital economy. The index allows us to see the level of development and the strengths and weaknesses of each economy in the field of the digital economy, as well as the relationship between the development of the digital economy and economic efficiency.) that ranges from 0 to 1. Notably, if the value of an indicator corresponds to its maximum or minimum allowable value, its value changes to one or zero during the normalization process. A higher DEDCI value represents a superior state of development in the digital economy. Conversely, a lower DEDCI reflects poor performance in the digital economy.

3.2 Analysis of the measurement results

Based on the calculation steps of the entropy method, we calculated the Digital Economy Development Composite Index (DEDCI) for 30 provinces in China. We categorized China's 30 provinces and regions into four economic zones, namely, the eastern, western, central, and northeastern regions, to more accurately understand the state of digital economy development. The mean values and annual growth rates were calculated for these four regions (detailed data in Table 2). Based on the results of our Digital Economy Development Composite Index (DEDCI) calculations from 2013 to 2021, it is clear that the country's development of the digital economy shows significant variability across regions and time.

Overall, China's digital economic growth improved from 0.0969 to 0.1765, with an annual growth rate as high as 7.781%, with some regions showing significant progress. Specifically, Beijing,

Shanghai, Jiangsu, Guangdong, Shandong and Zhejiang provinces are the leading echelons in the digital economy. On the other hand, the annual growth rates in Hainan, Guizhou, Anhui, Jiangxi, Guangxi, Gansu, Chongqing, Ningxia, and Jilin are at the top of the echelon, exceeding 10%, with the momentum of development remaining very strong. Overall, these regions continue to play a follow-up role in the development of the national digital economy.

However, differences between provinces are still evident, with Guangdong's DEDCI (0.6367) being 19.65 times greater than that of the Ningxia Hui Autonomous Region's DEDCI (0.0324) in 2021. For example, this finding shows that the problem of disparity between provinces still exists, but that there is a strong willingness to catch up. Considering the four major economic regions, the DEDCI status of the four economic regions shows continuous growth year after year. The western region has the highest average annual growth rate of 9.391%, the central region has the second highest growth rate of 8.851%, the eastern region has a growth rate of 8.333%, and the northeastern region has a growth rate of 3.857%. However, when analyzing the level of digital economy development, the DEDCI of the eastern region in 2021 was 0.3226, that of the central region was second at 0.1682, that DEDCI of the northeast region was third at 0.1089, and that of the western region was 0.1065. This indicates that the eastern area of the eastern region has a larger stock of the digital economy, but the growth rate is relatively slow. However, other regions had lower DEDCIs and faster growth rates.

Thus, studying the differences in the development of China's digital economy in major regions, upgrading the standard of digital economic progress in lagging regions, reducing the divergence of regional digital economic progress, and eliminating the digitalization gap are key strategic and forward-looking steps for promoting the synergistic development of China's digital economy among regions. Currently, the first and foremost task is to promote the synergistic development of the digital economy and clarify the exact route for the quality development of China's economy.

3.3 Theil index

The Theil index has been widely used as an important index for calculating the difference in income between regions. Regional disparities can be directly understood by calculating the Theil index (Liu and Hong, 2022; Su et al., 2022). In this study, we use the Theil index to study the differences in the level of digital economic development between and within regions. The Theil index was calculated as follows:

$$T = \frac{1}{n}\sum_{i=1}^{n}\frac{y_i}{y}\log\left(\frac{y_i}{y}\right) \tag{5}$$

where T represents the Theil index of digital economy development and $_{T\varepsilon}[0,1]$. The greater T *is* the greater the regional differences; otherwise, the smaller T *is* the smaller the regional differences. y_i represents the growth level of the digital economy in region i, and $\bar{y}$ represents the average level of development of the regional digital economy. We need to analyze the differences between groups and within groups, which is why the dismantling of the Theil Index is particularly important. The following equation was obtained:

$$T = T_b + T_w = \sum_{k=1}^{k} y_k \log\frac{y_k}{\frac{n_k}{n}} + \sum_{k=1}^{k} y_k \left(\sum_{i\in g_k}\frac{y_i}{y_k}\log\frac{\frac{y_i}{y_k}}{\frac{1}{n_k}}\right) \tag{6}$$

where $T_{\mathbf{b}} = \sum_{k=1}^{k} y_k \log\frac{y_k}{\frac{n_k}{n}}$ is the difference between regions, $T_w = \sum_{k=1}^{k} y_k \left(\sum_{i\in g_k}\frac{y_i}{y_k}\log\frac{\frac{y_i}{y_k}}{\frac{1}{n_k}}\right)$ represents intraregional differences, and $T_k = \sum_{i\in g_k}\frac{y_i}{y_k}\log\frac{\frac{y_i}{y_k}}{\frac{1}{n_k}}$ indicates the intragroup gap of group k, k=1,…, K. The contribution rates of the intragroup and intergroup gaps were as follows:

$$D_k = y_k \times \frac{T_k}{T}_{K=1\ldots,k} \tag{7}$$

$$D_k = \frac{T_b}{T} \tag{8}$$

3.4 Analysis of the measurement results

The Tel index calculated according to Equations (5–8) can assess the overall gap, internal differences, and mutual differences in the degree of digital development of the four major regions of China during 2013–2021 and further analyze its influence on the districts. Using the Theil index and corresponding calculation methods (5–8), we carefully analyzed and summarized the general trends in the development of the digital economy in the four regions of China, comparisons among geographic regions, and their influencing factors from 2013 to 2021. The detailed results of the measurements are presented in Table 3. First, the gap in China's level of digital economy development is highlighted, but overall, this difference gradually decreases. The Tel. index, which was 0.267 in 2013, decreased to 0.224 in 2020, nearly doubling over a short period. This finding verifies the effectiveness of the coordinated development policy of the regional economy and the realization of full prosperity implemented by China. Second, in terms of the construction of gaps in digital economic development, there was a major shift in 2017. In 2013, 2014, 2015, and 2016, the overall differences in digital economic development came mostly from inter-regional differences, while infra-regional differences were relatively small. Since 2017, however, the overall gap in digital economic development has come mainly from intraregional and interregional differences, which are at almost the same level. These findings illustrate that the differences in China's DEDCI have evolved into inter- and international differences.

However, when exploring the underlying reasons, we can see that the problem of the varying pace of development between regions has been somewhat alleviated and the problem of imbalanced development within regions is still becoming increasingly prominent. Most regions exhibit the concept of a key city as the core of development; for example, Xi'an is in the northwest, Nanjing is on the southeast coast, Hangzhou is in eastern China, and Wuhan is in south-central China. Therefore, we must attach great importance to developmental imbalances within these regions. Finally, in terms of the four major regions, the differences within the Northeast and Central regions were smaller than those within the Eastern and Western regions were.

TABLE 3 Theil index and contribution to the development of the digital economy in four regions, 2013–2021.

Particular year	Overall discrepancies	Intraregional differences values and contributions (%)	Interregional differences values and contributions (%)	Eastern region value and contribution (%)	Central region value and contribution (%)	Western region value and contribution (%)	Northeast region value and contribution (%)
2013	0.267	0.122 (45.77)	0.145 (54.40)	0.104 (71.42)	0.007 (4.55)	0.029 (20.23)	0.006 (3.79)
2014	0.239	0.112 (46.65)	0.128 (53.44)	0.093 (72.52)	0.007 (5.69)	0.023 (18.19)	0.005 (3.60)
2015	0.245	0.11 (45.05)	0.135 (54.94)	0.092 (68.48)	0.008 (6.14)	0.029 (21.34)	0.005 (4.05)
2016	0.244	0.116 (47.66)	0.128 (52.44)	0.089 (69.40)	0.009 (6.65)	0.028 (22.09)	0.002 (1.86)
2017	0.245	0.117 (47.66)	0.128 (52.15)	0.089 (69.53)	0.008 (6.03)	0.029 (22.96)	0.002 (1.49)
2018	0.236	0.106 (44.98)	0.13 (54.97)	0.091 (70.36)	0.007 (5.24)	0.03 (23.25)	0.001 (1.15)
2019	0.233	0.103 (44.16)	0.13 (55.64)	0.091 (70.50)	0.007 (5.35)	0.029 (22.71)	0.002 (1.44)
2020	0.224	0.094 (41.82)	0.13 (58.16)	0.091 (69.57)	0.007 (5.28)	0.031 (23.66)	0.002 (1.49)
2021	0.261	0.121 (46.22)	0.141 (53.95)	0.105 (74.82)	0.006 (4.28)	0.027 (19.40)	0.002 (1.51)

The contribution rate of the eastern region gradually increased from 71.42% in 2013 to 74.82% in 2021, followed by that of the western region, from 20.23% in 2021 to 23.66% in 2020, while the contribution rate of the central region increased and then decreased. However, the contribution rate in the northeast region decreased annually.

Consequently, the development of China's digital economy is becoming increasingly differentiated between regions, but the level of digital economic development within each region is decreasing annually. The degree of coordination in the development of the digital economy is gradually increasing, suggesting that the regional synergistic development policies adopted by local governments under the national innovation-driven strategy have been effective in promoting balanced development of the digital economy in these regions and preventing the widening of the regional digital gap.

3.5 Moran's index

Spatial correlation analysis in the process of dealing with spatial data is a very important step in the process of digital economic development in various regions, and it is obvious that spatial distribution is incoherent (Wei and Chen, 2020; Guo et al., 2023). To verify whether these differences are affected by the relationships between regions, it is necessary to explore their spatial correlations in-depth. Spatial correlations primarily include both global and local correlations. The Moran index is by far the most commonly used spatial correlation detection tool and is often used to analyze correlations between areas. The local Moran's index is primarily used to evaluate the interrelation of each element, reflecting the similarity degree of the unit attribute values in the adjacent regions of the space. This study uses the local Moreland Index to explore the correlation characteristics among the provinces. The formula used is as follows (Equation 9):

$$I_i = \frac{y_i - \bar{y}}{\frac{1}{n}\sum (y_i - \bar{y})^2} \sum_{j \neq 1}^{n} w_{ij} (y_i - \bar{y}) \tag{9}$$

where w_{ij} is the spatial weight value, n is the total number of regions (30 provinces), I_i is the local moreland index, y_i is the regional digital economy index, and $\bar{y}$ is the average level of the regional digital economy. The Moreland Index can be divided into four regions: the high-high (HH) regions in the first quadrant. The second quadrant included the low-high (LH) region, the third region included the low-low (LL) region, and the fourth region included the high-low (HL) region. Therefore, the development of the digital economy can be divided into four spatial correlation models. HH is a promotion zone, and the level of the digital economy of the region itself is highly and positively correlated with its surroundings. LH is a transition region, and the level of digital economy development in this region is low. However, development in the surrounding regions is high, indicating a negative correlation. LL indicates a low-level area; the development level of the digital economy in and around the area is low and has a positive correlation; HL is a radiation zone, and the development level of the digital economy in this region is high. However, the surrounding levels were low, indicating a negative correlation.

3.6 Analysis of the measurement results

To further analyze the spatial correlation of the development of the digital economy, which is conducive to the implementation of policies according to local conditions, and the realization of the coordinated and sustainable development of China's regional digital economy, this study uses Moran's index to measure the level of interprovincial development of the digital economy in the 30 provinces and cities, which is divided into four steps (Table 4). (1) The first step was to create a low-level area. (2) The second step involves a low- to medium-level area. (3) The third step was to define high- to medium-level areas. (4) The fourth step involves a high-level area.

China's digital economic growth is closely related to spatial factors, and its development pattern exhibits obvious agglomeration characteristics. The southeastern coastal area is mainly located in the promotion zone (HH), whereas the western inland area is mainly located in the low-level zone (LL) and has a significant positive correlation. Tianjin, Anhui, Jiangxi, Hunan, Guangxi, and Hainan are transition zones, and Beijing, Guangdong, and Sichuan focus on the fourth quadrant, which comprises radiation zones, with a negative correlation between the two types of areas. Overall, most of China is located in a low-level zone, and has not shown a clear evolutionary trend over time. Therefore, there is a strong imbalance in the development of the digital economy in each region of China; comprehensively promoting the coordinated development of regional digital economic development and narrowing the gap in regional digital economic development are important measures for enhancing digital vitality and sharing digital dividends. Promoting the high-quality development of China's economy at the present stage is an important strategic task.

4 Discussion

Against the backdrop of the new round of the scientific and technological revolution and the transformation of the industrial revolution, a new generation of digital technologies represented by the Internet, cloud computing, big data, artificial intelligence, and blockchain has developed in full swing. The rise of digitization, networking, and intelligence as its main features has accelerated the integration and innovation of digital technologies in all fields and industries of the economy and society and has pushed the globe into the era of the digital economy (Qi and Du, 2024). In general, digital economy refers to a new economic form that takes digitized knowledge and information as the key production factors, takes digital technology innovation as the core driving force, takes modern information network as the important carrier, and through the deep integration of digital technology and the real economy, continuously improves the digitalization and intelligence level of the traditional industries, and accelerates the reconfiguration of the mode of economic development and governmental governance (Wang, 2024).

In terms of the level of digital economy development, China's digital economy development level has continued to grow steadily, but there is a large gap between regions in the level of digital economy development, and there are problems such as imbalance (Yang and Li, 2024). In order to further analyze the spatial characteristics of regional differences and spatial distribution of China's digital economy development level, the country's provinces are divided into four regions: the eastern region, the central region, the western region and the northeastern region. The average value of digital economy development in the four regions, in descending order, is in the eastern region, central region, northeastern region, and western region, and the central region, northeastern region, and western region are all lower than the national average level.

Overall, the gradient between east, central and west is characterized by a decreasing gradient. Provincial and regional economic ties are increasingly close, and the mobility of digital factors has increased; the spatial correlation is positive, with low-low agglomeration dominating; the direction of spatial distribution is northeast-southwest, and the center of economic gravity has shifted to the southwest. The growth of China's digital economy is closely related to spatial factors, and its development pattern shows obvious agglomeration characteristics. From the point of view of regional differences in the digital economy, the dominant factor in the unbalanced development of China's digital economy comes from inter-regional differences, and the trend of intra- and inter-regional differences over time is not obvious. The level of digital economy development is unevenly distributed among provinces, with the overall spatial distribution characterized by high in the east and low in the west.

From the current development situation, although there is a big gap between China and the United States in the development of digital economy, due to China's increasing comprehensive national strength, complete industrial system and broad consumer market, the development of digital economy maintains a strong momentum, especially in a series of high-tech industries, the gap between the United States and the United States has gradually narrowed, and in some areas has been in the world's leading level. Especially with the increase in investment in science and technology innovation, in the medium and long term, China's digital economy technology base will be stronger, the development trend will be further improved, and the economic resilience will continue to strengthen. The United States, as the world's largest developed country, has a large digital economy and a more comprehensive industrial layout, and with its economic, political, scientific and technological, cultural and other advantages, it is in an absolute leading position in the field of digital economy, and in the short term, it is difficult to shake its overall dominant position.

5 Conclusion

This study uniquely establishes and quantifies an assessment system for the current development of China's digital economy and utilizes the entropy weighting method, Tyrell index, and Moran index to analyze and outline the characteristics of the temporal and spatial changes in the development of China's digital economy. This study revealed the following.

First, China's digital economic development clearly reflects the spatial and temporal heterogeneity of the four major regions. The overall level of digital economy development in the eastern coastal economic zone is high, and it is in the leading echelon. The central and western regions have strong digital economy development

TABLE 4 Localized Moran's regional distribution, 2013–2021.

Particular year	Promotion area (high-high) quadrant I	Transition zone (low-high) quadrant II	Low-level zone (low-low) quadrant III	High-low quadrant IV
2013	Fujian, Hebei, Shanghai, Jiangsu, Zhejiang, Shandong, Henan	Tianjin, Anhui, Jiangxi, Hunan, Guangxi, Hainan	Shanxi, Inner Mongolia, Jilin, Heilongjiang, Chongqing, Guizhou, Yunnan, Gansu, Shaanxi, Qinghai, Ningxia, Xinjiang	Beijing, Liaoning, Hubei, Guangdong, Sichuan
2014	Fujian, Hebei, Shanghai, Jiangsu, Zhejiang, Shandong, Henan	Tianjin, Anhui, Jiangxi, Hunan, Guangxi, Hainan	Shanxi, Inner Mongolia, Jilin, Heilongjiang, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang	Beijing, Liaoning, Hubei, Guangdong, Sichuan
2015	Fujian, Shanghai, Jiangsu, Zhejiang, Shandong, Henan	Tianjin, Hebei, Anhui, Hunan, Guangxi, Hainan, Jiangxi	Shanxi, Inner Mongolia, Jilin, Heilongjiang, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang	Beijing, Liaoning, Hubei, Guangdong, Sichuan
2016	Hebei, Fujian, Shanghai, Jiangsu, Zhejiang, Shandong, Henan	Tianjin, Anhui, Jiangxi, Hunan, Guangxi, Hainan	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang	Beijing, Hubei, Guangdong, Sichuan
2017	Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong	Tianjin, Anhui, Jiangxi, Hunan, Guangxi, Hainan	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Hubei, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang	Beijing, Henan, Guangdong, Sichuan
2018	Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Henan	Tianjin, Anhui, Jiangxi, Hunan, Guangxi, Hainan	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Hubei, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang	Beijing, Guangdong, Sichuan
2019	Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Henan	Tianjin, Anhui, Jiangxi, Hunan, Guangxi, Hainan	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang	Beijing, Hubei, Guangdong, Sichuan
2020	Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Henan	Tianjin, Anhui, Jiangxi, Hunan, Guangxi, Hainan	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Hubei, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.	Beijing, Guangdong, Sichuan
2021	Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong	Tianjin, Anhui, Jiangxi, Hunan, Guangxi, Hainan	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Hubei, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang	Beijing, Henan, Guangdong, Sichuan

momentum and are in the catching-up echelon. The development of the digital economy in the northeast region is slower, in the slow echelon (Wang et al., 2024).

Secondly, the overall gap in China's digital economic development is more prominent than in other regions, but the gap shows a trend of gradual regional narrowing, indicating that the national implementation of the policy of coordinated development and common prosperity of economic regions is extremely effective. Overall, the gap in the level of digital economic development between provinces is shrinking.

Thirdly, the development of digital economy in all regions of China has significant spatial correlation, and the development of digital economy in all regions shows strong clustering characteristics (Gou and Liu, 2023). The southeastern coastal region is mainly located in the upgrading area, and the western inland region is mainly located in the low-level area, and there is a significant positive correlation between the two.

At this stage, the world economy is in the process of accelerating full integration, and the digital economy has greatly accelerated the digital transformation of all sectors, including agriculture, industry and services. Digital transformation has had a profound impact on the development of these three industries. In order to seize the opportunities brought about by the digital economy, companies are increasingly investing in digital technologies to enhance the digital literacy and competence of their employees and improve their profitability (Kherbachi, 2023).

6 Policy recommendations

Undoubtedly the digital economy has become a key driver of economic development in China. China seeks to build globally competitive digital industry clusters, promote the deep integration of the digital economy with the real economy, reshape its economic structure, and promote coordinated development. At present, the rapid pace of development of the digital economy, wide range of radiation, and depth of influence promote profound changes in the mode of production, way of life, and management. In addition, the Chinese government strives to promote the development of the digital economy, advocate the in-depth integration of digital

technology with the real economy, promote the digitalization of traditional industries, and actively strengthen international dialog and cooperation in the field of the digital economy. Therefore, China should fully grasp the new opportunities of the new round of scientific and technological revolution and industrial revolution in the era of the digital economy, promote the coordinated regional development of the digital economy, and create a socialist digital economy development path that is suitable for China's national conditions. Policy recommendations compatible with the healthy development of the digital economy should be tailored to local conditions, as described below.

(1) Improve the innovation system for healthy development of the digital economy and tackle core digital technologies. First, the government should establish a modern science and technology innovation talent training base, vigorously build high-quality vocational and technical colleges and universities, strengthen the construction of key disciplines, increase investment in scientific research, improve the treatment of high-end talent to create an all-round digital talent team conducive to development, and promote the focus on new high-quality digital economy innovation talent in China. Second, domestic regions have strengthened international cooperation, absorbing the advanced digital technology development experience of developed countries in Japan and the United States in a steady stream and significantly improving their level of technological innovation.

(2) Optimizing and improving the policy framework to enhance vitality in the digital economy's development. The outbreak of the new coronavirus epidemic in 2020 further reflects the special advantages of the digital economy and has had a profound impact on its development trend and competitive landscape. During this period, countries launched important initiatives to promote economic recovery and sustainable development, with enhancement of the competitiveness of the digital economy as a key objective. During the pandemic, the country introduced a rich and favorable set of policies aimed at promoting the digital economy. This series of policies has not only effectively optimized China's economic structure but also contributed to the expansion of the country's digital economy to RMB 50.2 trillion in 2022, accounting for 41.5% of the country's GDP and ranking second in the world behind the United States. Therefore, in the future, China must enhance its policy innovation, which provides an important guarantee and strong vitality for comprehensive, coordinated, and sustainable development of the digital economy.

(3) Encountering practical difficulties in the digital transformation of enterprises and promoting the digital transformation of traditional industries on all fronts. Digital technology must be leveraged to achieve complete digital transformation in traditional industries. Combined with current practical problems, enterprises continue to increase the construction of science and development of digital technology, comprehensively improve their level of intelligent productivity and cultivate skilled personnel in line with the development of enterprises.

(4) Comprehensively strengthen infrastructure development in all regions and promote the common building and sharing of digital infrastructure. Currently, local and provincial administrations are increasing their efforts into implement innovative infrastructure projects driven by technologies such as big data, the Internet, blockchain, the IoT, and artificial intelligence. Development plans for 5G base stations, technology parks, big data centers, and tech cities are rationalized to enable digital innovations to play out in breadth and depth, thus opening new paths for the growth of the digital economy.

(5) Strengthen the construction of digital government and comprehensively enhance the level of government governance. The construction of a digital government is supported by digital technology, realizing the comprehensive integration of business and technology and enhancing the effectiveness of government performance. Promoting the penetration of digital technologies such as big data, blockchain, cloud computing, the Internet of Things, the mobile internet, artificial intelligence and other digital technologies in the field of government governance can, on the one hand, improve the government's ability to govern and promote the intelligence of government governance processes.

(6) Optimize the layout of the digital economy and create a synergistic regional polar core development model. Owing to the significant differences in the development of the digital economy in the four major economic regions of China, each region should use a specific central city as a digital economic growth pole—a new engine—and utilize its diffusion influence to enhance the effect of promoting digital economic activities. A regional core development strategy should be used so that the more developed regions of the digital economy, such as the eastern region, can pull the central, western, and northeastern regions to increase their degree of development. Similarly, the capital cities of provinces with a more advanced digital economy should be regarded as new sources of economic energy, maximizing their effectiveness in promoting their surrounding areas, enhancing their resilience, further optimizing the structure of the regional economy, and promoting healthy and stable development of the digital economy.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

WW: Data curation, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Belozyorov, S., Sokolovska O., and Kim, Y. (2020). Fintech as a precondition of transformations in global financial markets. *Foresight STI Govern.* 14, 23–35. doi: 10.17323/2500-2597.2020.2.23.35

Chen, C., Zhang, Y., and Wang, S. (2023). Digital transformation and firm performance: a case study on China's listed companies in 2009–2020. *DESD.* 1:18. doi: 10.1007/s44265-023-00018-x

Chen, S., Yang, Y., and Wu, T. (2023). Digital economy and green total factor productivity—based on the empirical research on the resource-based cities. *Environ Sci Pollut Res.* 30, 47394–47407. doi: 10.1007/s11356-023-25547-y

Gao, L. (2024). Industrial productive efficiency nexus with energy poverty and energy transition in digital economy: findings of Chinese transport and energy development industries. *Econ. Change Restruct* 57:48. doi: 10.1007/s10644-024-09642-9

Gou, X.M., and Liu, X. (2023). Measurement of digital economy level and difference analysis of provincial areas in China. *Modern Indust. Econ. Informatizat.* 12, 27−33.

Grigorescu, A., Ion, A. E., Pelinescu, E., and Dutcas, M. F. (2021). Human capital in digital economy: an empirical analysis of central and eastern european countries from the European Union. *Sustainability* 13, 1–21. doi: 10.3390/su13042020

Guo, C., Huang, X. J., and Qin, Z. Y. (2023). Research on the coupled and coordinated development of the digital economy and digital finance. *Modern Finance Econ.* 43, 19–33.

He, J., Zhao, X. Z., and Qi, Q. (2023). A study on the measurement of the development level of china's digital economy, spatial and temporal patterns, and regional differences. *Indust. Technol. Econ.* 42, 54–62.

Jallouli, R., Tobji Mohamed, A. B., Soares, A. M., Casais, B., and Belkhir, M. (2024). Editorial: Emerging technologies and innovation for digital economy and transformation. *J. Telecommun. Digit. Econ.* 12, 113–123. doi: 10.18080/jtde.v12n1.945

Jing, G., Meng, S., and Yu, M. (2023). Digital economy and the domestic supply chain network. *DESD.* 1:3. doi: 10.1007/s44265-023-00002-5

Kherbachi, S. (2023). Digital economy under fintech scope: evidence from african investment. *Fintech.* 2, 475–483. doi: 10.3390/fintech2030027

Komala, A. R., and Firdaus, D. W. (2023). Improving the quality of financial statements and the survival of MSMEs through digital economy: the case of Indonesia and Malaysia. *J. East. Eur. Central Asian Res.* 10, 753–763. doi: 10.15549/jeecar.v10i5.1435

Li, Y., Jiang, R., Zhang, M., and Luo, L. (2023). Measurement of the level of high-quality development of China's digital economy and analysis of its spatial and temporal evolution. *Statist. Deci. Making* 39:90.

Li, Y., and Wang, F. (2023). The corporate path to green innovation: does the digital economy matter? *Environ. Sci. Pollut. Res.* 30, 79149–79160. doi: 10.1007/s11356-023-27818-0

Liu, B., and Hong, X. J. (2022). Measuring and analysing the degree of digitalization of Chinese industries. *Statist. Res.* 10, 3–18.

Liu, Q., and Lu, L. (2023). Regional status of spatial dynamic evolution of China's digital economy. *Sci. Manage.* 44, 85–94.

Luo, W., Tang, G., Yang, P., Jia, C., and Yang, R. (2023). Examining digital economy's role in urban green development: a study of the Yangtze river delta region. *J. Knowl. Econ.* 2023:e12875. doi: 10.1007/s13132-023-01532-1

Nguyen, T. H. (2023). Cooperation between universities and businesses in developing human resources to participate in the digital economy. *J. Knowl. Econ.* 5, 1396–1413. doi: 10.1007/s13132-023-01357-y

Ozgun, F. (2023). Dijital Ekonomi ve Türkiye'nin Dijital Ekonomi Göstergelerinin Seçilmiş AB Ülkeleri ile Karşılaştirmali Analizi. *Bilgi Sosyal Bilimler Dergisi.* 25, 140–182. doi: 10.54838/bilgisosyal.1329680

Pang, R. Z., and Wang, H. G. (2023). A study on the efficiency and regional differences in china's science and technology innovation supporting economic development in the context of digital economy. *Contemp. Econ. Sci.* 45, 70–85.

Qi, Y.D., and Du, B. (2024). digital economy, high-quality development and advancing Chinese-Style modernization. *J. Shand. Univers.* 01, 108–124.

Rodríguez, T. (2021). The background of the Digital Services Act: looking towards a platform economy. *ERA Forum* 22, 75–86. doi: 10.1007/s12027-021-00654-w

Salykov, A., Aimbetov, A., and Yesmagulova, N. (2024). Factors and trends in the development of the space industry in the context of the digitalization of the economy of the Republic of Kazakhstan. *Environ. Dev. Sustain.* 26, 6703–6718. doi: 10.1007/s10668-023-02983-x

Shen, Y., and Zhou, P. F. (2023). Measurement of China's digital economy development level and analysis of spatial and temporal patterns. *Statist. Deci. Making* 39, 5–9.

Shevchenko, I., Lysak, O., Zalievska-Shyshak, A., Mazur, I., Korotun, M., and Nestor, V (2023). Digital economy in a global context: world experience. *Int. J. Prof. Busin. Rev.* 8, 1–16. doi: 10.26668/businessreview/2023.v8i4.1551

Su, B. J., Lu, F. Y., Zhu, F., and Li, Y. L. (2022). China's digital economy development level: spatio-temporal characteristics, dynamic evolution and influencing factors. *Operat. Res. Manage.* 09, 161–168.

Tang, X. Y., Lu, B. K., Xing, M. Y., and Meng, X. L. (2023). Measurement of the development level of China's digital economy and dynamic evolution analysis. *Mathem. Statist. Manage.* 3, 9–12.

Wang, D. X., Peng, Z. Q., and Li, L. L. (2023). Measuring and evaluating the level of integrated development of digital economy and agriculture in China. *China Rural Econ.* 06, 48–71.

Wang, J. T. (2024). Theoretical logic, connotation characteristics and optimization path of digital economy. *Contemp. County Econ.* 06, 42–44.

Wang, K. L., Li, X. R., He, C. C., and Wu, J. (2023). A study on measuring the level of digital economy development and spatial differentiation in urban agglomerations. *Statist. Deci. Making* 39, 127–131.

Wang, L., and Chen, L. (2022). Resource dependence and air pollution in China: do the digital economy, income inequality, and industrial upgrading matter? *Environ. Dev. Sustain.* 26, 2069–2109. doi: 10.1007/s10668-022-02802-9

Wang, X., and Chen, J. (2023). An empirical study on the indirect empowerment of economic development by the digital economy-based on the perspective of China's domestic economic cycle. *J. Knowl. Econ.* doi: 10.1007/s13132-023-01445-z

Wang, X., and Zhong, M. (2023). Can digital economy reduce carbon emission intensity? Empirical evidence from China's smart city pilot policies. *Environ Sci Pollut Res.* 30, 51749–51769. doi: 10.1007/s11356-023-26038-w

Wang, Y.Q., Xue, J.X., and F, J.H. (2024). Spatial and temporal evolution of China's digital economy development level and analysis of regional differences. *Busin. Econ.* 05, 1–5.

Wei, P., and Chen, X. W. (2020). Digital economy, spatial spillover and rural-urban income gap - a study based on spatial durbin model. *J. Shand. Univer. Sci. Technol.* 22, 75–88.

Xie, Z., Ma, J., Huang, S., and Zhu, J. (2023). Digital economy and inclusive green growth: the moderating effect of government environmental regulation. *Environ Sci Pollut Res.* 30, 107938–107955. doi: 10.1007/s11356-023-29934-3

Xin, C., Fan, S., Mbanyele, W., and Shahbaz, M. (2023). Towards inclusive green growth: does digital economy matter? *Environ Sci Pollut Res.* 30, 70348–7037. doi: 10.1007/s11356-023-27357-8

Xu, X. (2024). Examining the impact of global uncertainty shocks on the digital economy's role in China's energy transition and green economic recovery. *Econ. Change Restruct.* 57:78. doi: 10.1007/s10644-024-09653-6

Xu, Y., Chen, Y., and Shi, X. (2023). Does the digital economy empower the green development of foreign trade? *Environ. Sci. Pollut. Res.* 30, 110395–110416. doi: 10.1007/s11356-023-30076-9

Yang, C.J., and Li, Z.X. (2024). Level of development, regional differences and distributional dynamics evolution of China's digital economy. *Statist. Decis. Making.* 09, 5–10.

Yang, C. J., and Li, Z. X. (2023). The level of digital economy development, regional differences, and the dynamic evolution of distribution in China. *Statist. Deci. Making* 39, 5–10.

Yang, G., Yao, S., and Dong, X. (2023). Digital economy and wage gap between high- and low-skilled workers. *DESD*. 1:7. doi: 10.1007/s44265-023-00009-y

Zhang, C., Liu, B. and Yang, Y. (2024). Digital economy and urban innovation level: a quasi-natural experiment from the strategy of "Digital China". *Humanit Soc. Sci. Commun.* 11:574. doi: 10.1057/s41599-024-03122-1

Zhang, W., Song, L., and Ilyas, M. (2023). Can the digital economy promote fiscal effort? Empirical evidence from Chinese cities. *Econ. Change Restruct*. 56, 3501–3525. doi: 10.1007/s10644-023-09540-6

Zhang, X. Q., and Shi, X. D. (2023). A study on the measurement and spatial and temporal evolution of the digital economy development in Yangtze River Delta cities. *Finan. Econ. Theory Res*. 1,19–34.

Zhao, Y. B. (2023). An exploration of the current situation of china's digital economy development and regional differences. *Modern Busin. Indust*. 44, 16–19.

Zheng, Z., Xu Y., and Chen, J. (2023). Digital economy, industrial structure upgrading and green innovation efficiency of family enterprises. *Int. Entrep. Manag. J*. 20, 479–503. doi: 10.1007/s11365-023-00854-5