Technological and Economic Development of Economy
ISSN: 2029-4913 / eISSN: 2029-4921
2023 Volume 29 Issue 2: 518–538
https://doi.org/10.3846/tede.2022.18018

CHINA'S DIGITAL ECONOMY DEVELOPMENT: INCENTIVES AND CHALLENGES

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Received 19 April 2022; accepted 17 October 2022; first published online 30 November 2022

Abstract. The development of the digital economy has become a new way to respond to the epidemic impact effectively. With the innovative breakthrough of information and communication technology, the digital and real economies are deeply integrated. The digital economy has become an important driving force for the transformation of economic momentum and development. Panel data from 31 provinces in China from 2010 to 2019 were selected for analysis. In the first stage, the study constructed the evaluation index system of digital economy development. Then, the quality development index of the digital economy is calculated by using the entropy method. Finally, the main factors of digital economy development are analysed by spatial measurement. The research results prove that: (1) the development of China's digital economy in 2010–2019 has gradually increased; (2) the development of the digital economy has a positive correlation between regions and has a spatial spillover effect; (3) the level of economic development, urbanisation, government support, industrial structure, and the level of opening will promote the development of the digital economy.

Keywords: digital economy, entropy method, index, influencing factors, spatial measurement, sustainable development.

JEL Classification: E26, D83, F63, L86, O1, Q01.

Introduction

The digital revolution and Industry 4.0 provoke the penetrating of digital knowledge and information technology in all economic spheres. Besides, they become the core element of economic growth among different countries (Carlsson, 2004; Zhang & Chen, 2019; Tkachenko et al., 2019; Kwilinski, 2019; Kostetskyi, 2021). Through the deep integration of digital

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technology, informatization, networking and intelligence, digital technology and the real economy are deeply integrated to speed up the reconstruction of a new economic development model and governance model (Tapscott & Agnew, 2000; Linkov et al., 2018; Zhao et al., 2015; Korcsmaros et al., 2021). At present, the development of digital economy (DDE) in China is showing a rapid trend, maintaining the status of a global digital economy power. The DDE plays a crucial role in promoting China's economic growth, and economic growth also provides a continuous driving force for the DDE (Yin et al., 2019; Zhang & Chen, 2019; Jiang, 2020). The experts and scientific networks (Tapscott & Agnew, 2000; Korcsmaros et al., 2021; Yin et al., 2019) intensify the investigation of the landscape of the DDE, defining the core dimensions of the development, analysing the relationship between economic, social, environmental and digital development, and forecasting the transformation of the economy structure depending on digital development, analysing of the optimal ratio of resources for DDE.

Considering the Report of United Nations (United Nations Conference on Trade and Development [UNCTAD], 2019) China and the USA are the leader in information technology development, more than 40% of world market are generated by those countries. Furthermore, the penetration of digital technologies boosts the modernisation of economic infrastructure due the providing of proactive innovation policy. The digital economy has become a field of high economic value created by China. The digital economy is the name of a new economic form that will appear or has appeared after scientific and technological progress and economic development reach a higher stage. It is the direction of traditional industrial economic reform and transformation.

With the strong DDE itself, the level of economic development, urbanization, government support, industrial structure and opening to the outside world will be improved, the pace of renewal will be accelerated, and the integration of traditional industries and current digital industries will be faster and faster. Therefore, digital technology has made a significant breakthrough, and the digital industry has become the most important factor in national economic growth. In 2003, the scale of China's digital economy was 1565.8 billion yuan (Figure 1). In 2005, the scale of the national digital economy reached 2600 billion yuan (Woetzel et al., 2017a, 2017b). In 2019, the digital economy increased significantly, and the DDE to 35.8 trillion yuan. In 2020, the scale of the digital economy was 39.2 trillion yuan (China Academy of Information and Communication Technologies [CAICT], 2020). The digital economy's share in GDP has been increasing year by year: from 10.3% in 2003 to 36.2% in 2019, and then to 38.6% in 2020. The pic of the Chinese digital economy is in 2020 (39.2 trillion yuan, which is 38.6% of GDP). Furthermore, in 2020 the growth rate of overall size of the digital economy increases by 3.3 trillion yuan (2.4 percentage points of GDP) compared to the previous year.

The findings showed that the annual growth rate of digital economy highly exceed the annual growth of GDP per capita. Compare to the previous period in 2020 growth of GDP per capita was 2.61%. However, overall size of the digital economy – 9.37% (Figure 2). Compare to 2003 in 2020 the growth of overall size of the digital economy exceeds by 3 times the similar GDP indicator.

At the same time, during the studied period, the findings confirmed the permanent declining growth rate of GDP per capita and overall size of the digital economy. Zhang and Chen (2019), Pradhan et al. (2019), Wu and Yu (2022), Li and Liu (2021) proved that digitalization allowed restrain the declining growth rate of GDP under the economic development.

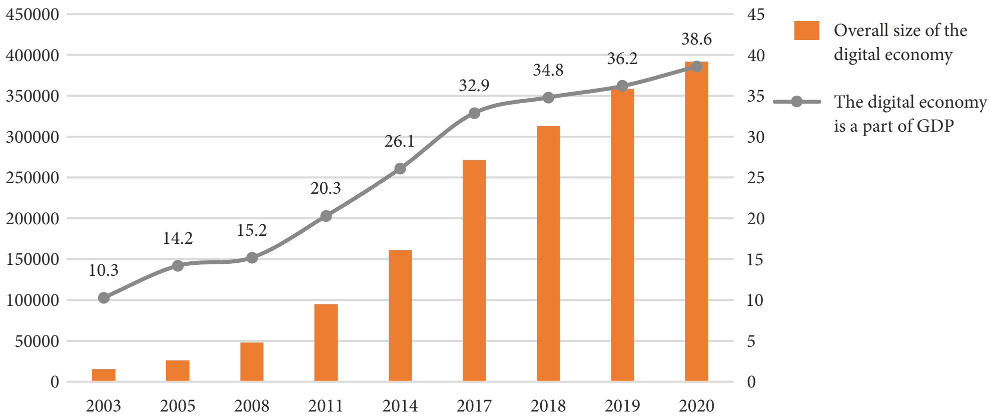

Figure 1. Overall scale and proportion of Chinese digital economy in GDP in 2003–2020

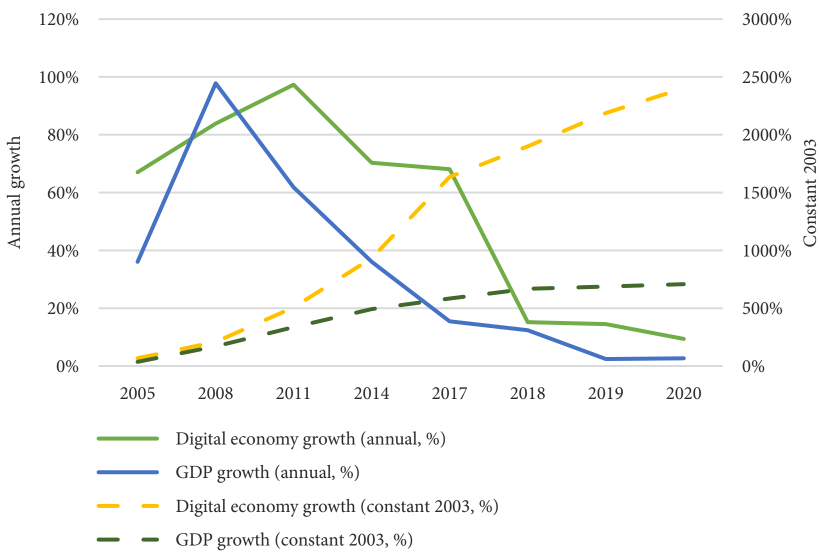

Figure 2. Overall scale and proportion of Chinese digital economy in GDP in 2003–2020

The aim of the paper is to analyse the relationship between digital and economic development. Based on the DDE in China, this paper uses the entropy method and spatial measurement model to predict the DDE. The paper applies a spatial measurement model to analyse the factors affecting the DDE and highlight the recommendation for digital policy improvement in China.

The paper has the following structure: literature review – analysis of the theoretical backgrounds on role of digital economy in economic development of the country; methodology – explained the methods to achieve the paper's aim; results – description of the findings on the relationship between digital and economic development; conclusion and discussion – presented the core outputs, discussed them with previous investigations, the highlighting the suggestions for the future investigations based on the defined limitations.

1. Literature review

1.1. Digital economy

The research on the digital economy focuses more on the connotation definition of the digital technologies. The USA government and research institutions define the digital economy as the following four parts:

- Electronic enterprise infrastructure (electronic enterprise process and operation basis of e-commerce transactions), includes hardware, software, communication network, support services, and human capital;
- Electronic enterprise (any workflow performed by an enterprise or organisation on a computer network), enterprise processes that include production, customer, and internal management;
- E-commerce (transactions in goods or services conducted on a computer network), transactions occurring in a specific electronic enterprise process (such as sales);
- Computer network (components of electronic devices controlled by a computer) includes the hardware, software used, and control commands from the user (Carlsson, 2004).

More scholars began to focus on the development of digital technology, and it began to play a positive role in economic growth (Akimov et al., 2021; Kryshtanovych et al., 2021; Shpak et al., 2020; Vyshnevskyi, 2019; Molchanova, 2021; Trushkina, 2019). Jorgenson et al. (2000) believes that affordability the price of digital products and technologies promote and enhance the Internet products. According to the characteristics of Metcalfe's law and Moore's law, Internet technology conducive the economic development. Datta and Agarwal (2004) uses 22 OECD national data as samples to analyse the positive effect of digital infrastructure on the ratio of fixed capital stock to GNP. Thompson et al. (2013) pointed out that digital factors of production characterise the digital economy. Enterprises can use big data and artificial intelligence technologies to save costs, shorten the supply chain, improve production efficiency, which is conducive to increasing profits, and then stimulate enterprises to release a large number of idle resources that could be used for independent research and development. Turcan et al. (2014) suggested that the development of the network changes the way of social information dissemination, and the change in the speed and way of information transmission will bring new economic growth points to the society. Pee (2016) researched B2C e-commerce. Considering the results found that enterprises are using network platforms to promote consumers directly participating in new product research and development design in the digital economy era. Besides, it allows simplified communication and interaction with consumers, provides relevant improvement opinions, and positively impacts the development of new products, which could further improve the success rate of enterprises in new product development. Teece (2018) compares the digital economy with the traditional economy, pointing out that the DDE has changed the traditional model of labour and provides a favourable development environment for the business development. On the one hand, enterprises realise digital development through the penetration of information technology. On the other hand, it improves the innovation ability to inject new vitality into the development of enterprises.

1.2. Approach to measure digital economy

In recent years, more and more scholars have clarified the connotation of the digital economy, measured the scale of the digital economy and measured DDE. In 2014, OECD (2014) released "Measuring Digital Economy: a New Perspective", which added ICT usage at the enterprise and individual level and rerevised the measurement tools to measure the digital economy from a wider dimension. Jiankui et al. (2016), based on the information economy index of 31 provinces from 2005 to 2013 released by the National Information Center, verified the impact on the quality of economic growth and concluded that narrowing the regional economic differences will reduce the quality gap of regional economic development. Liu and Chen (2017) Based on the relationship between the Internet and the regional economic development level and development structure of 31 provinces and cities in China from 2007 to 2015, the space panel empirical results show that the Internet penetration rate increased by 0.742% per 1%, while the tertiary industry increased by 0.067%; analysed the connotation and mechanism of the digital economy and put forward policy suggestions.

From the 2010 to 2021 year, the findings of a bibliometric analysis of 5000 documents published in the Web of Science, CNKI (China National Knowledge Infrastructure) indexed scientific journals revealed that scientists from China, Korea, Africa, the European Union, and the United States of America and so on (Figure 3). These countries were the first to start investigating the digital economy issues.

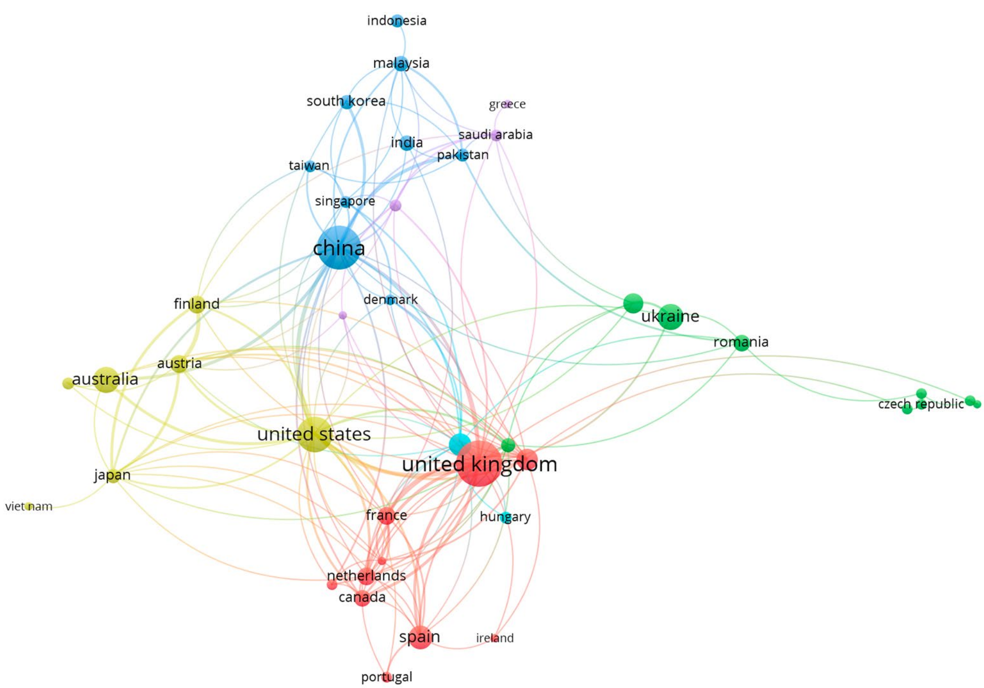

Figure 3. The visualization network of co-authorship analysis in researching DDE by the country

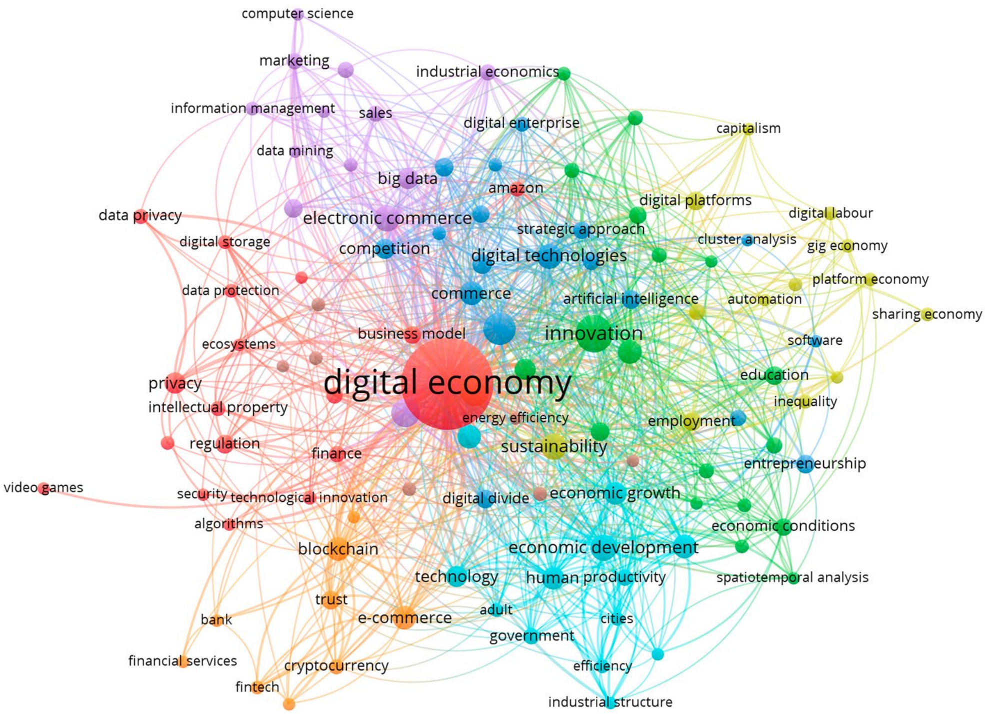

Figure 4. The visualization network of co-occurrence analysis in researching digital economy

The meta-analysis results confirmed that DDE was investigated under intellectual property rights, innovation, and digital information technology (red, navy blue and green cluster), digital economy, cryptocurrency, blockchain and e-commerce (orange, blue and purple cluster). The findings of the co-occurrence analysis are presented in Figure 4.

1.3. Relationship between digital and economic development

Since 2019 (Figure 5), many researchers have begun to focus on the development measures and influencing factors of the digital economy, which could boost the country's development. Using a spatial measurement model, Zhong and Mao (2019) analysed the digital economic development of the Yangtze River economic belt cities. He found that the geographical distribution difference was significant. The downstream urban development level was higher than the upstream cities, digital hot areas, including Shanghai, Suzhou, Jiaxing and other cities. Zhong Yexi suggested that the poor economic foundation could be adopted to improve information infrastructure and promote industrial upgrading to achieve rapid economic growth. Haiyan and Yu (2020) build a digital economic measurement index system, applying the entropy method and Tobit model. They selected 16 secondary indicators from the development of the telecom industry, information and technology-related industry development, electronic enterprise, and social innovation ability in four dimensions. Haiyan and Yu (2020) analysed digital economic development levels among 11 Zhejiang provinces from

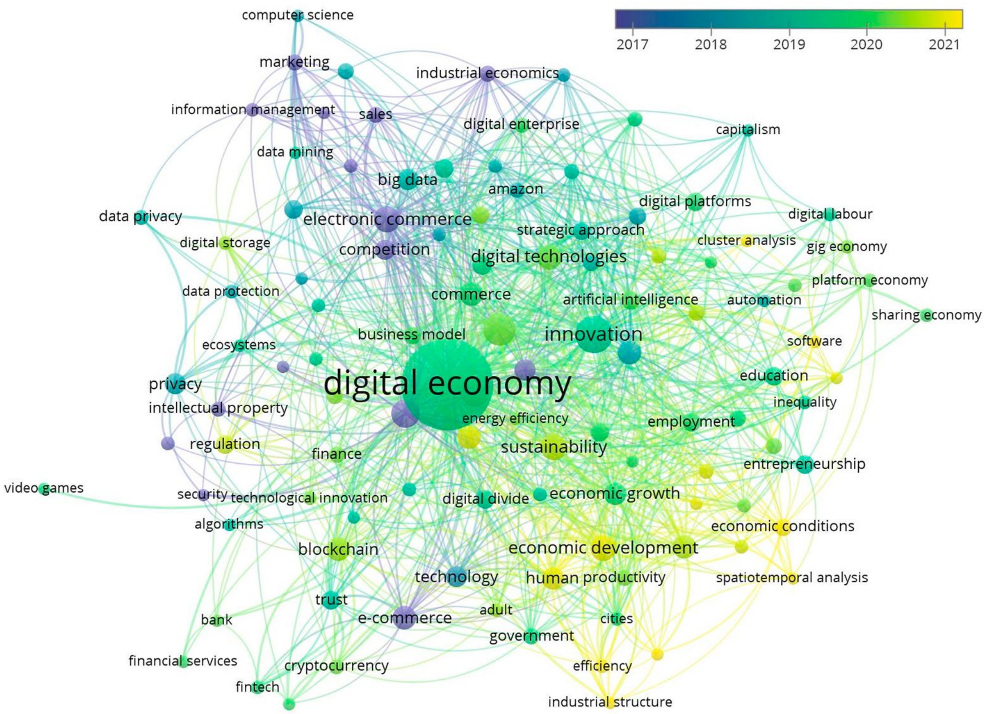

Figure 5. The overlay visualization map of core scientific clusters in researching DDE

2009 to 2018. The results found a positive relationship between economic development and the DDE. Chen et al. (2021a) measured the DDE from 2012 to 2018 through the CRITIC method. They used the fixed-effect model to study the relationship between the DDE level and the industrial structure level.

The results show that the DDE can help to improve the level of industrial structure. Chen et al. (2019) analysed countries from the "Belt and Road" to build models using panel data. The results found that the DDE in these regions can effectively promote economic growth, and open economic conditions will further promote the impact of the DDE on economic growth.

2. Methodology

2.1. Data

The study used the data of 31 provinces in China (excluding Hong Kong, Macao and Taiwan) from the "China Statistical Yearbook", "China Science and Technology Statistical Yearbook", "Chinese and Employment Statistics Yearbook", "China Information Yearbook", "China Information Industry Yearbook", provincial statistical yearbooks and China's DDE reports over the years. The data is for the period from 2010 to 2019.

The DDE is a multi-dimensional and multi-level complex coordination relationship. In this case, it is actual to provide a more objective multi-dimensional analysis index to evaluate the importance of world economic development accurately. The index system is an essential basis for a comprehensive evaluation. It is based on the following principles: scientificity, practicality, systematicness and data availability. By combing and analysing Corrocher and Ordanini (2002), Moroz (2017), Jovanović et al. (2018), Afonasova et al. (2019), Fernández-Portillo et al. (2020), Cosmulese et al. (2019) this paper constructs the indicators of DDE. Table 1 explains the core elements of the DDE Index.

Table 1. Digital economic index system

Sub-indicators	Basic indicators	Measured	Unit	Metric properties
The foundation for digitalization	Internet penetration rate	Internet broadband access users / permanent resident population at the end of the year	%	Positive
	Long-distance optical cable line density	Long-distance optical cable line length / urban area * 10,000	%	Positive
	Internet infrastructure	Total assets of the information transmission, computer services, and software industries	Million yuan	Positive
	The proportion of Internet users	Internet access number / permanent resident population at the end of the year	%	Positive
Digital industry scale	Software business revenue	Total software business revenue	Million yuan	Positive
	Number of Internet-related employees	Information transmission, software and information technology services employment personnel	Thousands of people	Positive
	The proportion of high-tech products in the export of commodities	Exports of high-tech products / total commodity exports	%	Positive
Digital R & D investment	Computer and office equipment manufacturing industry investment	Total expenditure for the computer and office equipment manufacturing industry	Million yuan	Positive
	Electronic and communication equipment manufacturing industry investment	Total expenditure for the electronic and communication equipment manufacturing industry	Million yuan	Positive
	Investment in introducing high-tech industries	Total funds for the introduction of high-tech industries	Million yuan	Positive
	Investment in the transformation of high-tech industries	Total funds for the transformation of high-tech industries	Million yuan	Positive

The study applied the entropy method to measure DDE in 31 provinces in China from 2010 to 2019. Sun et al. (2021) confirmed that the subjective weight method would be interfered with by human factors and deviate from the calculation results, and it will not reflect the authenticity at the appropriate level.

The calculation steps are as follows:

Step 1. Standardize the data:

Positive indicator:

$$x_{ij}^{*} = \frac{x_{ij} - m_j}{M_j - m_j}. \tag{1}$$

Negative indicator:

$$x_{ij}^{*} = \frac{M_j - x_{ij}}{M_j - m_j}, \tag{2}$$

where $M_j = \max\{x_{ij}\}$, $m_j = \min\{x_{ij}\}$.

Step 2. Calculate the indicator weight:

$$p_{ij} = x_{ij} / \sum_{i=1}^{n} x_{ij}. \tag{3}$$

Step 3. Calculate the information entropy of each component based on the specific gravity:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right). \tag{4}$$

Step 4. Evaluate of the information entropy redundancy:

$$d_j = 1 - e_j. \tag{5}$$

Step 5. Estimate the weights of each indicator:

$$w_j = d_j / \sum_{i=1}^{n} d_j. \tag{6}$$

Step 6. Calculate the final overall score.

w_j is represents the comprehensive development index of j province, between 0 and 1.

Explained variable: Digital economy development (DDE): Based on the connotation of DDE, the digital economy index calculated by the comprehensive evaluation system containing 1 primary index, 3 secondary indicators and 11 tertiary indicators represents the DDE, and the variables are logarithmically processed. Table 2 contains the explanatory variables.

2.2. Empirical model

Despite the numerous investigations on the relationship between DDE and economic development, most of them are based on the single equation or multi-equation econometric techniques (Carlsson, 2004; Sui & Rejeski, 2002; Hojeghan & Esfangareh, 2011; Zhao et al., 2015; Semenova & Tarasova, 2017; Chen et al., 2021b). This study applied a spatial autoregressive model (SAR), a spatial error model (SEM) and a spatial Durbin model (SDM). The study determines the most suitable model for empirical analysis based on the test findings.

Table 2. The explanatory variables

Explanatory variables	Measure	Symbol	Unit
Transportation infrastructure	Highway mileage	Tra	KM
Economic development level	GDP per capita	Eco	CNY
Financial support	Fiscal expenditure / fiscal revenue	Fis	%
Science and technology input	Technology R & D investment / regional GDP	Tec	%
Industrial structure	The output value of the tertiary industry accounts for the GDP of prefecture-level cities	Ei	%
Urbanization	Urbanization rate	Urb	%
Consumption structure	Consumption expenses / total expenses	Cs	%
Open level	Total import and export volume / regional GDP	Open	%

For each of China's regions, the relationship could be written:

– Spatial autoregression model (SAR)

$$y = \lambda Wy + X\beta + \varepsilon, \tag{7}$$

where y – dependent variables which represents digital economic development; W – the spatial weight matrix, the X – independent variables Tra, Eco, Fis, Tec, Ei, Urb, Cs, Open.

– Spatial Error Model (SEM).

Spatial dependence could also be reflected by error terms, which builds a spatial error model (SEM)

$$y = X\beta + \varepsilon,\ \mu = \rho M\mu + \varepsilon,\ \varepsilon \sim N\left(0, \sigma^2\ I_n\right), \tag{8}$$

where M – the spatial weight matrix, representing the spatial error coefficients, x, y, and above.

– Spatial Durbin Model (SDM)

$$y = \lambda Wy + X\beta + WX\delta + \varepsilon, \tag{9}$$

where $WX\delta$ – the effect of variables in adjacent regions, x, y means above.

To determine whether to use spatial metrology methods, the spatial relevance of the study object should first be tested (Shi et al., 2021; Jinya et al., 2020). If there is a spatial correlation, the spatial measurement method can be used. Therefore, the spatial correlation between China's high-quality economic development and DDE is first examined.

The global Moran's Index is used to test the spatial correlation to investigate the digital economy's spatial interaction and a spillover effect on high-quality development (Eq. (4)).

$$\text{Moran's } I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}(Y_{it} - \overline{Y})\left(Y_{jt} - \overline{Y}\right)}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}}, \tag{10}$$

where $w_{i,j}$ – the weight matrix defined above, $\overline{Y}$ is the mean of the development level, Y_{it}, Y_{jt} – the development level of i and j provinces respectively.

The local Moran index is calculated as follows:

$$\text{Local Moran's } I_i = \frac{\left(Y_{jt} - \overline{Y}\right)}{S^2} \sum_{j=1}^{n} w_{i,j} \left(Y_{jt} - \overline{Y}\right). \tag{11}$$

The value range of Moran's Index is [–1,1]. If the index is positive, there is a positive spatial correlation; otherwise, there is a negative.

Waldo Tobler proposed the first law of geography, which holds that things are not isolated and are related to each other. Standard weights matrices fall into four categories: adjacency matrices, geographic distance matrices, economic distance matrices, and nested matrices. The adjacency and geographic distance matrix measure the spatial effect between regions from the perspective of geographical location, and the economic distance matrix reflects the regional spatial effect from economic attributes. The nested matrix considers both geographical and economic factors. This article uses nested matrices as spatial weights W (Eq. (6)).

$$W = \begin{bmatrix} \frac{1}{d_{11}} & \cdots & \frac{1}{d_{1n}} \\ \vdots & \ddots & \vdots \\ \frac{1}{d_{n1}} & \cdots & \frac{1}{d_{nn}} \end{bmatrix} \begin{bmatrix} \frac{x_{11}}{x} & \cdots & \frac{x_{1n}}{x} \\ \vdots & \ddots & \vdots \\ \frac{x_{n1}}{x} & \cdots & \frac{x_{nn}}{x} \end{bmatrix}. \tag{12}$$

3. Results

3.1. Measurement results and analysis of DDE

The findings of descriptive statistics of the explanatory variable showed in Table 3.

The DDE shows the characteristics of temporal and spatial dynamics and heterogeneity. The analysis of DDE from 2010 to 2019 will be carried out at the national and provincial levels, respectively, fully reflecting the development level of the digital economy.

Considering findings (Figure 6), China's DDE index is increasing year by year, and the growth rate is also accelerating.

Table 3. The findings of the descriptive statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
Dde	310	0.1457	0.157	0.024	0.836
Tra	310	51652.66	26179.59	9030.6	164000
Eco	310	49.0644	20.07751	6.651	93.137
Fis	310	0.0198	0.0146	0.003	0.068
Tec	310	115.41	64.806	49.960	516.924
Ei	310	56.079	13.390	22.67	89.60
Urb	310	39.407	7.347	22.718	64.34
Cs	310	25.883	31.275	0.001	182.374
Open	310	145282.2	77664.4	11974	337095

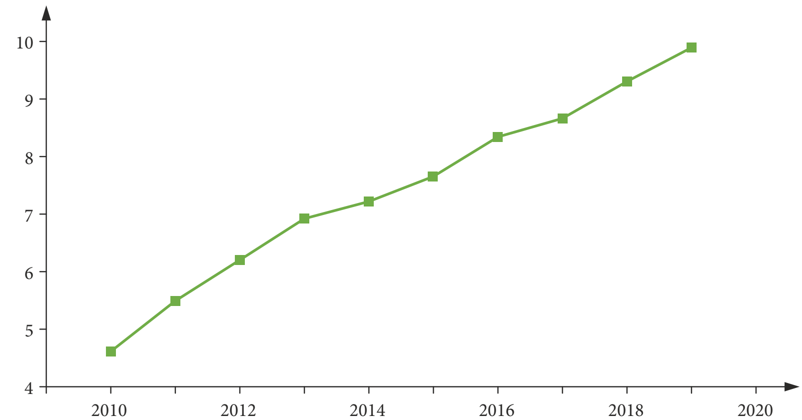

Figure 6. Change trend chart of the digital economy index in 2010–2019

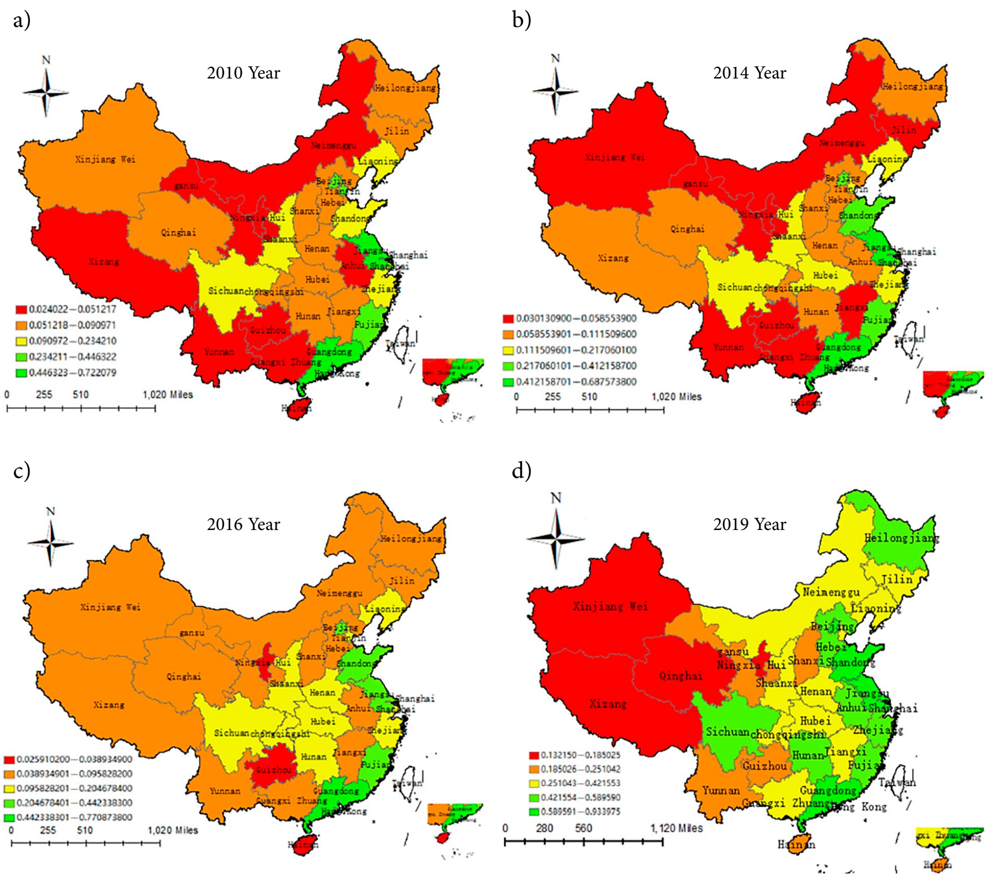

Figure 7. Spatial map of China's DDE: a) – 2010 year; b) – 2014 year; c) – 2016 year; d) – 2019 year

In order to further analyse whether the inter-regional DDE will present the "Matthew effect", the regional maps for 2010, 2014, 2016 and 2019 were drawn with the help of ArcGIS 10.8 software. The findings showed in Figure 7.

From the provincial map of the above four years, we find that the development scale of the digital economy is gradually decreasing from the southeast coast to the west inland, which is basically in line with the pattern of the Hu Huanyong line. The top five provinces in the DDE are Guangdong, Shanghai, Jiangsu, Zhejiang, and Beijing, and the last five provinces are Gansu, Tibet, Guizhou, Ningxia, and Qinghai. We can also see that the DDE in China's provinces shows an apparent imbalance between the East and the West. The development level of eastern coastal provinces is higher than in the western inland provinces, in line with China's current economic development pattern.

Due to its geographical location, the level of social and economic development in the eastern coastal area is generally higher than in the central and western regions. Due to the weak economic foundation, geographical location and historical factors in the central and western regions, the current level of DDE lags behind the eastern coastal areas. It indicates that the digital economy industry is not considered a dominant industry in these areas. The level of DDE between regions is different. It justifies that further analysis of the influencing factors of DDE and the identification of the main factors affecting the DDE in China could promote the rapid DDE.

3.2. Correlation testing

Based on the DDE level index measured by the entropy method and the nested weight matrix, the global Moran's Index of the DDE in 2010–2019 was calculated respectively, as shown in Table 4.

The global Moran index has a range of [–1,1]. It should be noted that positive and negative values confirm the positive and negative spatial correlation, respectively. From 2010 to 2019, although the Moran's Index fluctuated, it was all positive with significance at 1%, indicating that the level of DDE has significant spatial positive correlation characteristics,

Table 4. Global Moran's Index of the level of DDE

Variables	I	E(I)	sd(I)	z	p-value*
2010	0.424	–0.033	0.088	5.266	0.000
2011	0.401	–0.033	0.092	4.947	0.000
2012	0.352	–0.033	0.088	4.37	0.000
2013	0.319	–0.033	0.086	4.075	0.000
2014	0.319	–0.033	0.087	4.328	0.000
2015	0.271	–0.033	0.082	3.700	0.000
2016	0.342	–0.033	0.079	4.753	0.000
2017	0.356	–0.033	0.079	4.944	0.000
2018	0.266	–0.033	0.068	4.399	0.000
2019	0.227	–0.033	0.067	3.895	0.000

Note: * – indicates significant at a level of 1%.

which is manifested explicitly as the agglomeration of high-level provinces and the spatial dependence is relatively stable. The findings allow apply the spatial econometric model.

In order to further investigate the agglomeration characteristics of the spatial distribution of DDE, this paper draws a partial Moran map of the DDE. Due to space, only the 2010 and 2019 biennium results are reported (Figure 8).

The findings (Tables 5–6) allowed concluding that the vast majority of provinces are in 1st and 3rd quadrants. It proves that the provinces have a robust positive promotion effect in local area. Thus, the obtained results are indistinguishable with the Global Moran Index test results. Therefore, the positive correlation characteristics of local space are significant, and the spatial econometric model should be selected due to the influence of spatial factors.

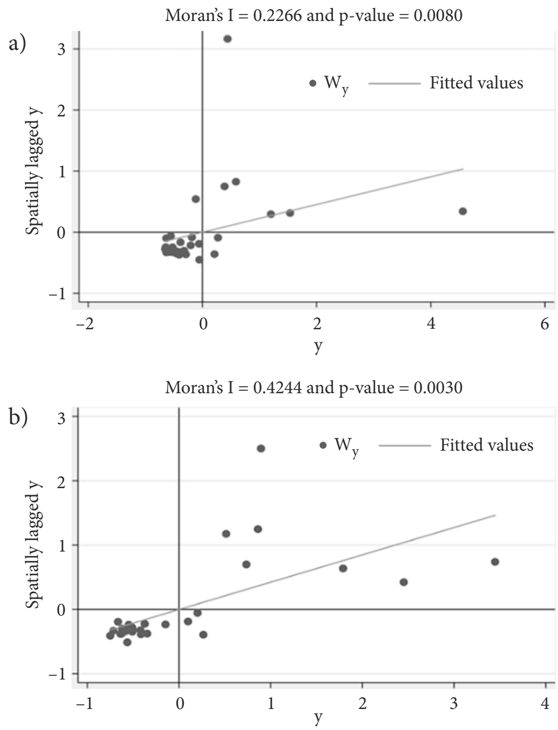

Figure 8. Local Moran scatter plot of DDE in 2010 (a) and 2019 (b) years

Table 5. Characteristics of DDE space in 2010 (source: compiled by the authors)

Quadrant	Spatial features	Province	Number
One	H-H	Beijing, Shanghai, Guangdong, Jiangsu, Zhejiang, Tianjin, Shandong	7
Two	L-H		0
Three	L-L	Hebei, Henan, Hubei, Hunan, Shanxi, Shaanxi, Anhui, Fujian, Jiangxi, Hainan, Sichuan, Chongqing, Inner Mongolia, Yunnan, Guizhou, Gansu, Heilongjiang, Liaoning, Jilin, Xinjiang and Guangxi	21
Four	H-L	Ningxia, Qinghai and Tibet	3

Table 6. Characteristics of DDE space in 2019

Quadrant	Spatial features	Province	Number
One	H-H	Beijing, Shanghai, Guangdong, Jiangsu, Zhejiang, Tianjin	6
Two	L-H	Shandong	1
Three	L-L	Hebei, Henan, Hubei, Hunan, Shanxi, Shaanxi, Anhui, Fujian, Jiangxi, Hainan, Sichuan, Chongqing, Inner Mongolia, Yunnan, Guizhou, Gansu, Heilongjiang, Liaoning, Jilin, Xinjiang, Guangxi and Ningxia	22
Four	H-L	Qinghai, Tibet	2

3.3. Spatial measurement model test

In order to obtain the best regression results for fitting, before performing model analysis. As can be seen from Table 7, LM_test_lag and robust LM_test_lag failed the 10% significance test, while LM_test_sem and robust LM_test_sem passed the 5% significance test, indicating that the spatial lag model is the preferred choice for the spatial dependence test.

The Hausman test on the SDM model (Table 8) allows determining whether to use a fixed or random-effect model. The findings show a chi2(6) value of 0.58 and a p-value of 0.00, indicating that the SDM model should be analyzed using a fixed effect. Secondly, LR is used to determine which fixed-effect model to use (time-fixed, region-fixed, double-fixed effect), and finally, using the LR test and the Wald test, whether the SDM model will degenerate into an SEM, SAR model.

The findings (Table 8) showed that rejecting the SDM model could degenerate into the null hypothesis of the SAR model and the SEM model, and the SDM model should be used for analysis by accepting the SDM model.

Table 7. The findings of dependency test

Statistics	Value	P value
LM_test_lag	8.858	0.003
robust LM_test_lag	0.275	0.600
LM_test_sem	23.655	0.000
robust LM_test_sem	15.072	0.000

Table 8. Hausman, LR and Wald test results

<table>
<tr><th>Test</th><th colspan="3">Summary results</th></tr>
<tr><td rowspan="2">Hausman tests</td><td>–</td><td>chi2(6)</td><td>0.58</td></tr>
<tr><td>–</td><td>Prob>chi2</td><td>0.000</td></tr>
<tr><td rowspan="4">LR tests</td><td>Likelihood-ratio test</td><td>LR chi2(15)</td><td>24.03</td></tr>
<tr><td>(Asumption: sar nested in sdm)</td><td>Prob>chi2</td><td>0.000</td></tr>
<tr><td>Likelihood-ratio test</td><td>LR chi2(15)</td><td>24.03</td></tr>
<tr><td>(Asumption:sem ested in sdm)</td><td>Prob>chi2</td><td>0.000</td></tr>
<tr><td rowspan="4">Wald tests</td><td rowspan="2">Wald Test for SAR</td><td>chi2(8)</td><td>32.56</td></tr>
<tr><td>Prob>chi2</td><td>0.000</td></tr>
<tr><td rowspan="2">Wald Test for SEM</td><td>chi2(8)</td><td>31.72</td></tr>
<tr><td>Prob>chi2</td><td>0.000</td></tr>
</table>

3.4. Regression analysis of spatial Durbin model

Before the empirical analysis using the spatial autoregression model (SDM), the multicollinearity test was conducted for each variable, and the variance expansion factor (VIF) of the explanatory variables was between 1.18 and 5.93 (Table 9). The maximum value was less than 10, so the multicollinearity interference was excluded.

Table 9. The findings of Multicollinearity test results

	X1	X2	X3	X4	X5	X6	X7	X8
VIF	4.3	5.1	4.24	1.82	5.93	1.18	3.47	1.59
1/VIF	0.233	0.196	0.236	0.548	0.169	0.850	0.288	0.630

Table 10. SDM regression results

Main	Del 1	Del 2	Del 3
Tra	–0.000311	0.000117**	0.000444*
	(–1.66)	(2.60)	(2.36)
Eco	0.00146*	–0.000329	0.00172**
	(2.30)	(–0.50)	(2.80)
Fis	1.514***	1.104	1.380***
	(3.81)	(1.79)	(3.50)
Tec	0.000333	0.000129	0.000366**
	(0.28)	(0.12)	(0.35)
Ei	–0.00103	–0.00367***	0.00149**
	(–0.61)	(–4.51)	(0.32)
Urb	0.000184	–0.00131	0.000363**
	(0.46)	(–1.73)	(0.88)
Cs	–0.000204	0.00386***	0.00167**
	(–1.17)	(12.43)	(0.93)
Open	0.000424*	0.000310***	0.00412**
	(2.01)	(3.34)	(1.91)
Spatial rho	–0.0865	0.130	0.0279**
	(–0.85)	(1.47)	(0.30)
Variance sigma2_e	0.00547***	0.00495***	0.00590***
	(12.42)	(12.42)	(12.45)
Individual fixed	Yes	No	No
Time fixed	No	Yes	No
Double fixed	No	No	Yes
N	310	310	310
R^2	0.968	0.898	0.986

Note: Del 1 – test the regional, Del 2 – time, Del 3 – double fixed effects.

Table 11. SDM model effect decomposition

	Direct	Indirect	Total
Tra	–0.00318	0.00135*	0.00453*
Eco	0.00142*	0.00120**	0.00262*
Fis	1.548***	0.0664*	1.6144***
Tec	0.000415**	0.000487	0.000902
Ei	0.00119 *	0.0123***	0.01349***
Urb	0.000219**	–0.000986	0.001205**
Cs	–0.000207	0.000133**	–0.000074
Open	0.00398**	0.00986**	0.01384**
N	310		
R^2	0.890		

Considering the findings of the regression, the spatial Durbin model was applied to test the regional, time and double fixed effects. The symbols of each explanatory variable were positive under the two-way fixed-effect model (Table 10). It shows that the proportion of transportation infrastructure, urbanization improvement, government fiscal expenditure in GDP, trade openness, industrial structure adjustment, and scientific and technological investment level is conducive to developing the interprovincial digital economy. The spatial correlation coefficients are tested by the significance levels of 10%, 5%, and 1%, respectively. The coefficients are positive. It allows confirming the positive spatial spillover effect.

After the spatial SDM regression, the spatial SDM fixed effect decomposition is calculated based on the nested matrix. It allowed explaining the spatial effect of the DDE. The decomposition and calculation results are shown in Table 11.

According to the results of the effect decomposition of the SDM model, it could be concluded that the changes in transportation infrastructure and consumption structure could not promote the DDE in the region, and the level of economic development, financial support, industrial structure, urbanization, and opening up to the outside world has a role in promoting the DDE. The transportation infrastructure, economic development level, financial support, scientific and technological investment, industrial structure, urbanization, and the level of opening up could promote the DDE in the surrounding areas. Through the saliency test, the change in consumption structure plays a role in inhibiting the DDE.

Discussion and conclusions

According to the actual level of the DDE in 31 Chinese provinces from 2010 to 2019 (estimated using the comprehensive index evaluation system of the digital economy), the study obtained the following conclusions:

1. From 2010 to 2019, China's digital economy has been rising yearly, and the development gaps between regions are also declining.
2. There is a positive correlation in the DDE between regions, and there is a spatial spillover effect between regions. Such results are corresponded to the findings in the papers (Jiao & Sun, 2021; Liu & Chen, 2017).

3. The DDE requires the effective coherent policy on economic development, urbanisation, government support, industrial structure, and economic openness. It also provokes the scaling cross-sector effect of digitisation among all regions. The similar contributions on digital technologies in economic development were defined by (Haiyan & Yu, 2020; Chen et al., 2021).

The digital economy is the main driving force for promoting the high-quality development of China's economy. Thus, considering the findings, the following suggestions could be realised to boost the DDE:

1. Increase investment in scientific research and technological innovation in the digital economy. Strengthen the cultivation of digital economy talents and vigorously encourage research departments (research institutes and universities). Furthermore, it is necessary to simplify the examination and approval of research projects for front-end scientific and technological innovation. It should be developed and implement a comprehensive layout of digital technology innovation, increase funding for scientific research investment, and ensure that cutting-edge scientific and technological innovation should be implemented.
2. Continuously expand the breadth and depth of industrial digitalisation. Traditional industries must be deeply integrated with digital technology. Besides, the traditional industries should accelerate the integration with digital technology to promote the DDE in China and improve the efficiency of production, circulation and sales of traditional industries.
3. Promote the deep integration of digital technology with the traditional primary, secondary and tertiary industries, and vigorously develop new digital economy models (such as smart agriculture, online education, smart travel, and digital finance). Furthermore, it is necessary comprehensively improve the digital management and operation of traditional industries, promote the transformation and upgrading of traditional industrial chains, optimise the efficiency of resource allocation in traditional industries, reduce human, material and financial costs, and comprehensively improve the economic benefits of traditional industries.

It is necessary to promote the economic opening up to the outside world. It requires continuously strengthening technical exchanges and cooperation with the outside world to promote the DDE in China. Besides, China's government should lead the industrial structure to move toward upgrading and continuously optimizing and upgrading the traditional industrial structure.

It should be noted that the study has few limitations. Thus, in the future research, it would be actual to analyse the convergence between digital development among Chine's regions. Besides, it would be better to enlarge the number of factors which impacted on digital development. Consequently, it allows to indicate significant drivers for digital development.

Funding

Ministry of Education and Science of Ukraine under Grant [number 0121U100468].

Author contributions

YC, SX, OL, TP – conceptualisation; YC, SX, OL, TP – methodology and investigation; OL, TP – writing-review and editing. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

The authors don't have competing financial, professional, or personal interests from other parties.

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