

A study on the level of digital economy development and influencing factors in Chinese coastal provinces - based on EWM and ANN algorithm

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Abstract. Focusing on the high-quality regional economic development of 11 coastal provinces in China in the new era, this article constructs a multi-level evaluation system of digital economy development level composed of 12 indicators and uses the EWM analysis method to measure the development level of the digital economy in the region. At the same time, 13 indicators are selected as regional economic endowment conditions, and the ANN algorithm is used to study the impact of regional economic endowment conditions on the development of the digital economy. The evaluation system of this study is relatively comprehensive, and the machine learning method is used to make the results more accurate. Taking coastal provinces as the specific research object, more concrete and targeted conclusions will be produced, providing cutting-edge theoretical support for the economically developed regions such as the Yangtze River Delta and the Pearl River.

Keywords: Digital economy; Quality development; Regional differences; ANN; E-commerce.

1. Introduction

With the advancement of information technology such as cloud computing, Internet of Things and blockchain, and the improvement of infrastructure construction such as industrial Internet, data centers and 5G networks, the quantity, quality and capacity of human beings to process information have been greatly enhanced, and the economic form of human beings has gradually shifted from industrial economy to information economy and smart economy. In the Digital Economy Development Report 2021, the United Nations points out that China and the United States stand out in terms of data collection and use while benefiting most from digital economy development. More than 50% of the world's hyper-scale data centers are located in China and the US, with 70% of the world's top AI researchers and 94% of AI startups funded in the last five years. It manifests that no traditional North-South divide exists in the digital economy. In addition, through the growth of the digital economy, China will be motivated to become competitive with developed countries, promoting an economic development shift from high growth to high quality development, towards a smart economy where value is the central concept, quality is over quantity, and the GDP is water-free.

According to the China Digital Economy Development Report (2022), China's digital economy reached RMB 45.5 trillion in the past 2021, accounting for 39.8% of GDP, more than double the size of the early part of the 13th Five-Year Plan. According to a forecast by the Sadie Research Institute, by 2025, the value added of China's core digital economy industries will contribute to 10% of GDP, while the global share of data volume related to the digital economy will reach 30%. By then, China will be one of the richest countries in terms of data volume and data types, suggesting that the digital economy is set to have an increasing impact on general macroeconomic growth.

During the 13th Five-Year Plan, the digital economy grew at a rate of over 16.6% per capita in terms of development results. In terms of promoting employment, the number of jobs in industries related to the digital economy accounted for 32.6% of all jobs and 24.2% of the total number of recruits. As for industrial transformation and upgrading, the digital economy penetration rate in China's three industries reached 8.9%, 21% and 40.7%, respectively. Among the three industrial employment sectors, the employment absorbed by industrial digitalization is mainly concentrated in the tertiary sector. Therefore, the digital economy plays a positive role in adjusting industrial

proportions, promoting the development of new industries, and facilitating industrial transformation and upgrading.

The 14th Five-Year Plan for the Development of the Digital Economy identifies eight major objectives, eight tasks, and eleven special projects for digital economy development. In the context of the new epidemic, China advocates a "double cycle" development strategy to establish a large domestic cycle in the domestic market. At the internal cycle level, low demand for natural resources and the trans-regional nature of the digital economy lead to inter- and intra-regional linkages that are not limited by natural resource endowments. At the same time, the 14th Five-Year Plan states that the digital economy should provide substantial benefits for the general public, and also contribute to shared and inclusive development while achieving sustained and general growth.

There is no denying that the differences in China's regional economies will also result in the differences in the development of the digital economy. At present, only a few studies have focused on whether regional and digital economies should maintain a coordinated manner of development. Therefore, this paper firstly figures out the development level and the shortcomings in the long-term development of the digital economy in each province of China at the current stage by constructing a digital economy development level indicator system, and divides the development echelon of the digital economy. Afterward, 11 representative regional economic indicators of China's coastal provinces are selected to explore the impact of different characteristics of the regional economy on the development of the regional digital economy using machine learning algorithms, which will provide a theoretical basis for the coordinated development and mutual promotion of the regional and digital economies.

2. Literature review

2.1 Research on the level of development of the digital economy

With the development of the digital economy, academic research on measuring the development level of the digital economy has also gone through germination, development and refinement. Kang [1] argues that the scale of the digital economy is measured in terms of network transactions, enterprise and market structure, individuals and employees, price factors as well as ICT infrastructure construction. Since digital activities of the non-digital industry are involved in the accounting process, the calculated value added by the digital industry contains can only be counted as an estimated value.

Subsequently, Zhang and Jiao [2] focused on how the external environment affected digital economy development. First, he selected the main indicators of ICT primary and advanced applications, ICT infrastructure, enterprise digital development and ICT industry development, and subdivided the main indicators. He concluded that the average growth rate of the digital economy in China from 2007 to 2015 was as high as 36%. However, the selected indicators are centred on the external environment. Wen[3] selected two aspects of infrastructure and penetration degree for indicator selection and model building, reflecting the degree of penetration of the digital economy to other industries. Wan[4] observed the damage to the development environment of the digital economy, such as information leakage, and included digital knowledge talent and digital governance in the measurement of development level. In Wang's [5] study, four level 1 indicators were selected: digital economy development carrier, digital industrialization, industrial digitalization, and digital economy development environment, which are more comprehensive to measure the current level of development of digital economy, rather than just emphasizing a single perspective.

2.2 Research on the mechanism of the role of the digital economy

The difference between the digital economy and other previous economic forms lies in that it has the potential to facilitate increasing marginal benefits despite its already large economic scale, and has key characteristics such as strong diffusion, high growth and low cost, which can promote high-quality economic development at different levels and depths. The mechanism of the role of the digital economy is analyzed in three main dimensions: micro, meso and macro. At the micro level, the

essence of the digital economy is informatization. As the input of data production factors increases, marginal output will not decrease, but may also rise. As a result, enterprises tend to expand the scale of production to achieve lower costs, thereby forming economies of scale in society to provide consumers with a diverse consumption environment in terms of price, quantity and variety, while stimulating vitality at both production and consumption ends. From a meso perspective, the digital economy plays a role in market expansion, while positively affecting industrial productivity. For example, Internet technology can significantly improve total factor productivity in the equipment manufacturing industry[6]. At the macro level, with the support of digital technology, producers can transform from the traditional "production-determined sales" to new "sales-determined production", and diversified consumer preferences will reflect comprehensive and scientific production decisions by producers through relevant information elements, forming a virtuous cycle of mutual promotion of production and consumption, so as to promote supply-side structural reform[7].

2.3 The digital economy will either widen or narrow geographic disparities

The digital economy offers new opportunities for less developed regions, given that the main contradiction in society is the problem of unbalanced and insufficient development. First, backward regions will enjoy the advantage of a latecomer to knowledge and technology imitation. With lower investment costs required by digital development compared to traditional industries, digital information is shared and spillover, which guarantees that lagging regions can achieve economic catch-up through successful practices such as infrastructure rehabilitation needed for informatization and digital industrial upgrading[8]. Second, the digital economy will not only help promote the digital upgrading of industries in each region, but also reduce production and transaction costs and create unique regional comparative and competitive advantages. Duan[9] proposes that the digital economy can solve long-standing problems of segmentation and disconnection in China's market, and can lead to the extension of industrial chains and the establishment of new industries in latecomer regions, increasing the endogenous power of their own development. At the same time, backward regions can enhance their information acquisition and integration capabilities through the digital economy, participate more deeply in globalization and modular division of labor, produce products with unique regional advantages, seek new economic growth points and narrow the regional gap[10]. Finally, the dividends of digital economy development can be freed from time and space constraints, ensuring residents and enterprises in remote areas enjoy deeper benefits than those brought by other industries. Digital information service parity is the easiest of all infrastructure service parties to achieve, and with the promotion of smart livelihood tasks, the efficiency of services in education and healthcare in plenty of backward regions has been significantly improved[11].

Therefore, in the context of digital economy development, the only approach for lagging regions to receive the dividends brought by integrated markets and national and global value chains, and to discover new drivers of economic growth, is to excavate their own core competencies and develop their relative advantages. Only in this way, can the development gap between regions be narrowed. Otherwise, regions may face an ever-widening digital divide and even the development divide.

While all of the above studies have examined the development and role of the digital economy in detail, the existing literature about the role of the regional economy on the digital economy is relatively scarce. It is true that the digital economy will contribute to the development of the regional economy to a certain extent, but whether and how the regional economy can have an impact on the development of the digital economy is a question worth exploring by scholars. At the same time, when exploring the role of the digital economy on regional economy, scholars have often adopted traditional economic models, which is a complicated and lengthy process. Therefore, this paper summarizes the shortcomings of the existing literature and makes the following innovations: (1) Based on the summary of the existing literature, this paper constructs an evaluation system covering four aspects of digital economy development carrier, digital industrialization, industrial digitization, and digital economy development environment, which is more comprehensive and reasonable. (2) Using machine learning algorithms, this article studies the influence of regional economic endowment

conditions on the development of the digital economy. A more advanced method is used to train a model with a better fit. Hence, the accuracy and credibility of the results are higher. (3) In the relationship between the digital economy and the regional economy, a new role direction study is explored as a way to adjust the regional economic development strategy and promote the development of the digital economy to achieve a benign process of two-way action. For the development of the digital economy, there proposed targeted opinions, so as to achieve the strategic goal of high-quality development of China's economy in the new era.

3. Construction of an indicator system for the regional economy and the digital economy

3.1 Regional economy

As China enters a new era of socialism, the economy has changed from high-speed development to high-quality development, which requires corresponding adjustments of the indicator system to measure the level of regional economic development so as to conform to the new characteristics and development direction of the times. Therefore, this paper is concerned with regional economic development, and the indicator system includes both quantitative expansion and development effectiveness. The former reflects the economic growth rate of each region, revealing the economic volume of each region. The latter emphasizes the quality of economic development, paying more attention to whether the economic development of each region is healthy and truly beneficial to human capital, social equity and the sprouting of new industries in each region. In the meantime, high-quality development requires the realization of industrial transformation and the transformation of development dynamics. Therefore, this paper establishes three primary indicators: economic structure, economic volume and economic efficiency, as well as corresponding 13 subordinate secondary indicators. The economic structure is measured by the output value of the three industries, which not only reflects the proportion of the three industries, but also explores whether the scale of each industry exerts an impact on digital economy development. In the total economic volume, considering the economic peculiarities brought about by the geographical location of coastal provinces, this paper selects the actual utilization of foreign direct investment and total import and export to reflect. Secondly, GDP is chosen as the basic indicator, the number of employees in the three industries as the human capital measure, and the amount of social fixed asset investment and total retail sales of social consumer goods as the indicators of regional investment and consumption capacity. In terms of economic efficiency, the paper measures the level of government macro-control based on local fiscal revenue, and adopts the Thiel index, per capita disposable income and CPI to measure residents' living standards. In summary, the regional economic indicator system constructed in this paper is shown in Table 1.

Table 1. Regional economic evaluation system

Tier 1 indicators	Secondary indicators	Unit	Reference
Economic structure	Primary sector output (X_1)	billion	[12]
	Secondary sector output (X_2)	billion	[13]
	Tertiary sector output (X_3)	billion	[14]
	GDP (X_4)	billion	[14]
Total economy	Total retail sales of consumer goods (X_5)	billion	[15]
	Number of people employed in the three sectors (X_6)	10,000 people	[16]
	Total social fixed asset investment (X_7)	billion	[17]
	Actual utilization of foreign direct investment (X_8)	US\$ billion	[18]
	Total imports and exports (X_9)	billion	[19]
	Local revenue (X_{10})	billion	[20]
	Thiel's Index (X_{11})	None	[21]
Economic benefits	Disposable income per capita (X_{12})	Yuan	[22]
	CPI (X_{13})	None	[23]

3.2 The digital economy

Based on existing research, this paper measures the level of digital economy development from four perspectives: digital economy development carrier, digital industrialization, industry digitization as well as digital economy development environment. Digital economy development carrier is regarded as the basis for the long-term development of the digital economy. In this paper, traditional hardware facilities and emerging network resources are measured. Hardware facilities contain the number of Internet domain names per 100 people and Internet broadband access ports per square kilometer. Emerging network resources include mobile phone penetration and the number of mobile power station base stations per square kilometer. Digital industrialization and digitization of industry focus on measuring the adoption of the digital economy. Digital industrialization involves two main businesses: telecommunications and software, specifically speaking total telecommunications business and software revenue. Digitalization of industry is represented by e-commerce, measured by e-commerce sales, e-commerce purchases and e-commerce transaction size. The digital economy development environment is mainly measured by governance environment and innovation capability. Governance environment is selected from the Online Government Service Capability Index in the Government e-Service Capability Index Report. Innovation capability focuses on R&D investment and human capital, so the proportion of R&D expenditure to GDP and the number of general undergraduate and tertiary students per 10,000 people are selected. Based on the above four primary indicators and 12 secondary indicators, the digital economy indicator system constructed in this paper is introduced in Table 2.

Table 2. Evaluation system for the level of development of the digital economy

Tier 1 indicators	Secondary indicators	Unit	Reference
Digital Economy Development Vehicle	Number of Internet domain names per 100 people (Y1)	million	[24], [25], [26]
	Internet broadband access ports per square kilometer (Y2)	million	
	Mobile phone penetration rate (Y3)	Parts per 100 population	
	Number of mobile power station base stations per square kilometer (Y4)	million	
Digital Industrialization	Total telecommunications business (Y5)	billion	
Digitalization of industry	Software industry revenue (Y6)	million	
	E-commerce sales (Y7)	billion	
	E-commerce purchases (Y8)	billion	
	E-commerce transaction size (Y9)	billion	
Digital Economy Development environment	Online Government Service Capability Index (Y10)	None	
	R&D expenditure as a proportion of GDP (Y11)	Percentage	
	Number of general undergraduate and tertiary students per 10,000 population (Y12)	People	

4. EWM analysis and ANN algorithms

4.1 EMW principle

The EWM itself is a measure of the magnitude of differences between indicators and has analytical value in revealing the regional variability of specific indicators. The entropy method comprehensive evaluation model and steps are as follows.

STEP1: Determine the weights of both primary and secondary indicators using the entropy value method.

The share of the i -th province under indicator j in this indicator is

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^n X_{ij}} \quad (1)$$

The information entropy value of the j -th indicator is

$$e_j = -\left(\frac{1}{\ln(n)}\right) \sum_{i=1}^n p_{ij} \ln(p_{ij}) \quad (2)$$

The information utility value is $g_{ij} = 1 - e_j$. A higher information utility value indicates that the more important the indicator is, the more important it is for evaluation.

The entropy value, i.e., the weight, of the j th indicator is

$$W_j = \frac{g_j}{\sum_{j=1}^m g_j} \quad (3)$$

STEP2: Calculate the overall evaluation score using the composite index method.

$$F = \sum_{j=1}^m w_j \times A_{ij} \quad (4)$$

4.2 Principle of ANN algorithm

ANN is a mathematical algorithm that simulates the operation of human brain. It consists of a large number of interconnected neurons forming a complex network structure, which can form a non-linear mapping of inputs and outputs, with the unknown mechanism between the inputs and outputs considered as a "neural network". Neurons are divided into an input layer, an implicit layer, and an output layer. The input and output layers are determined by the number of dimensions of the input and output data. The number of neurons and implicit layers in each layer is not fixed, so it is necessary to constantly adjust the weights of each node by the neural network to optimize it to achieve the effect of repeated training. After the input data is given, the trained network will calculate the corresponding output based on the weights of the trained nodes. The calculation includes online judgment and offline learning. Offline learning means that neurons receive data and are trained to continuously adjust the weights, while online judgment calculates the output based on the trained network. The artificial neural network applied in this paper is a multilayer perceptron (MLP).

The hyperbolic tangent sigmoid function is the activation function of the hidden layer of the MLP neural network. Its expression is:

$$f_{(x)} = \frac{2}{1+e^{-2x}} - 1 \quad (5)$$

The Softmax function is the activation function for the output layer. Its expression is:

$$\text{Softmax}_{(z_i)} = \frac{e^{z_i}}{\sum_{c=1}^C e^{z_c}} \quad (6)$$

5. Empirical analysis

5.1 Selection of research subjects and data collection

A total of 11 coastal provinces in China are selected for this study, from north to south, including Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi and

Hainan (excluding Hong Kong, Macao and Taiwan). With the extension of China's economy from a land-based economy to a maritime economy, these coastal provinces, with a superior location, trade environment, shipping and transportation and other endowments, play an important role in leading and supporting economic development, talent employment and industrial transformation. Their open and strong hardware and software support, such as attracting foreign investment, will significantly impact the level of development of the digital economy and regional economy. With the promotion of the "One Belt, One Road" and the requirements of high-quality economic development, these 11 provinces should play a greater role in promoting and leading regional economic development.

The data in this paper are selected from 2015 to 2020 as the sample period. The new development concept of innovation, coordination, green, openness and sharing was clearly put forward at the Fifth Plenary Session of the 18th Central Committee in 2015. Data sources are from the official website of the National Bureau of Statistics, China Digital Economy Development Report, China Statistical Yearbook, China Information Yearbook, China Information Industry Yearbook, Government e-Service Capability Index Report, China Industrial Statistics Yearbook, China Science and Technology Statistics Yearbook, China High Technology Statistics Yearbook and Wind Financial Database.

5.2 Measurement of the digital economy based on EWM

Based on the entropy analysis method above, the corresponding weights of 12 secondary indicators (Table 3) and the overall digital economy scores of 11 coastal provinces between 2015 and 2020 (Table 4) are derived.

Table 3. Entropy values of the variables and their weights

Serial number	Variable name	Entropy value	Weighting	Properties
Y ₁	Number of Internet domain names per 100 people	0.888	0.112	+
Y ₂	Internet broadband access ports per square kilometer	0.949	0.051	+
Y ₃	Mobile phone penetration rate	0.972	0.028	+
Y ₄	Number of mobile power station base stations per square kilometer	0.953	0.047	+
Y ₅	Total telecommunications business	0.904	0.096	+
Y ₆	Software industry revenue	0.828	0.172	+
Y ₇	E-commerce sales	0.876	0.124	+
Y ₈	E-commerce purchases	0.859	0.141	+
Y ₉	E-commerce transaction size	0.872	0.128	+
Y ₁₀	Online Government Service Capability Index	0.983	0.017	+
Y ₁₁	R&D expenditure as a percentage of GDP	0.937	0.063	+
Y ₁₂	Number of general undergraduate and tertiary students per 10,000 population	0.980	0.020	+

Table 4. Composite score of digital economy development level by province

	2015	2016	2017	2018	2019	2020
Hebei Province	0.076	0.097	0.128	0.137	0.170	0.189
Tianjin	0.118	0.112	0.111	0.128	0.152	0.175
Liaoning Province	0.122	0.118	0.129	0.151	0.176	0.189
Fujian Province	0.130	0.178	0.239	0.243	0.265	0.223
Shandong Province	0.216	0.283	0.333	0.392	0.387	0.410
Zhejiang Province	0.219	0.254	0.260	0.299	0.373	0.399
Jiangsu Province	0.272	0.297	0.334	0.388	0.448	0.495
Shanghai	0.281	0.337	0.343	0.376	0.432	0.495
Guangdong Province	0.441	0.518	0.579	0.704	0.833	0.868
Hainan Province	0.034	0.035	0.039	0.048	0.060	0.060
Guangxi Province	0.053	0.057	0.064	0.086	0.123	0.140

According to the entropy analysis, the software industry revenue dominates the most important position of the digital economy evaluation system, with a weight of 17.2%, followed by e-commerce procurement, transaction scale and sales, with a weight of 14.98%, 12.84% and 12.39% respectively. Thus, the main components of the digital economy evaluation system that determines the development level of the regional digital economy are the application segments of the digital economy: digitization of industries and digital industrialization. The fifth-largest weighting is the number of Internet domain names per 100 people, at 11.16%, followed by total telecoms business and R&D expenditure to GDP, at 9.5% and 6.34%, respectively. The remaining indices of Internet broadband access ports per square kilometer, number of mobile power stations per square kilometer, mobile phone penetration rate, number of general undergraduate students per 10,000 people and online government service capability account for 5%, 4.7%, 2.8%, 2.0% and 1.68% respectively, all of which are less than 5%, having a smaller impact on the development of the digital economy.

The digital economy development scores by province demonstrate all provinces show a fluctuating upward trend in the digital economy. Guangdong Province has been the best-developed and fastest growing province in terms of the digital economy, with a score soaring from 44 to 86 points between 2015 and 2020, ranking first in the sample. Jiangsu and Shanghai follow, with the same growth rate and close to the initial and final periods, scoring from 27 and 28 to 49 points. The third echelon includes Shandong and Zhejiang, both close in the initial and final periods, but with faster development in Shandong Province in the first and middle periods and Zhejiang Province in the later period. The fourth echelon covers Tianjin, Liaoning and Fujian, of which Fujian achieves the best development, with the highest starting point, but shows a decline in 2019-2020; Tianjin mainly develops from 2018 to 2020, and Liaoning maintains an even, fluctuating growth trend. The fifth echelon contains Hebei, Hainan and Guangxi, all of which have low starting points, with Hebei and Guangxi both growing continuously and Hainan Province growing slowly.

5.3 Calculation of the ANN

Based on multiple ANN training, the results (Table 5) are as follows: the comparison in terms of mean square error and goodness of fit is performed.

Table 5. Training results of ANN model

Number of hidden layers	Mean Square Error	Goodness of fit
10	0.0026	0.9732
11	0.0044	0.9548
12	0.0026	0.9732
13	0.0018	0.9815
14	0.0047	0.9523
15	0.0039	0.9599
16	0.0042	0.9575
17	0.0013	0.9869
18	0.0023	0.9770
19	0.0009	0.9909
20	0.0016	0.9838

It can be concluded that with the artificial neural network training, the goodness of fit is generally higher than 0.95, proving the chosen method is correct. The comparison between the mean square error and goodness of fit reveals that at the 10th training, i.e., when the hidden layer is 19 layers, the most accurate prediction value is obtained, with the mean square error of 0.0009 and the goodness of fit of 0.99. Therefore, this paper utilizes this group of data to analyze the contribution of each indicator of regional economy to the comprehensive score of the digital economy.

5.4 Contribution analysis

According to the results of SPSS neural network analysis (shown in figure 1), the number of people employed in the three industries and the total imports and export of the regional economy has the greatest positive contribution to the regional economic development, both above 90%. Disposable income per capita and the output value of tertiary industry are more than 70% important, while the contribution of the Thiel index and total retail sales of consumer goods is close to 60%, and the importance of FDI is 40%. The contribution of output value of primary and secondary industries, GDP, local fiscal revenue, CPI and total social fixed asset investment are all below 30% and shows a decreasing trend in order.

Therefore, this paper concludes that labor force, total imports and exports, disposable income and output of the tertiary sector all significantly impact the development of the regional digital economy.

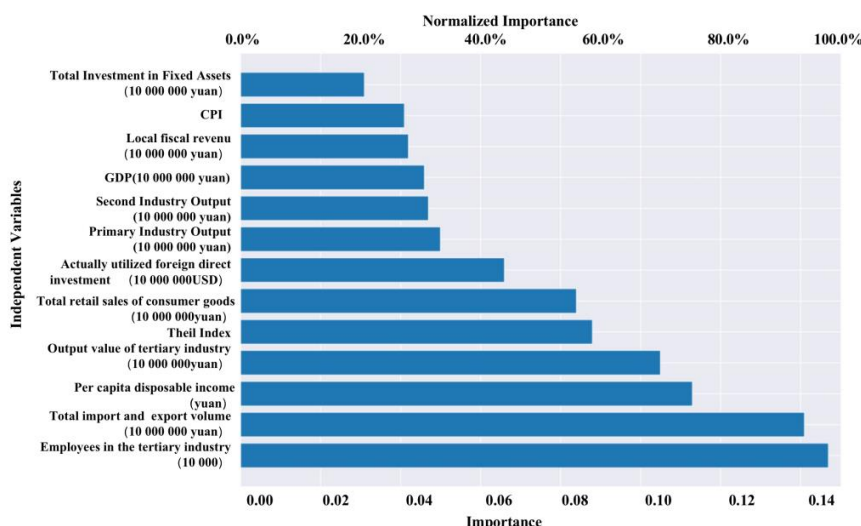


Fig. 1 Contribution degree ranking of regional economic endowment to digital economy

6. Conclusion

(1) Active policy formulation and implementation of digital economy applications. China should promote the contribution of the digital economy industry to economic growth so that the digital economy and economic growth become coordinated in both directions. In this regard, the state should formulate and implement policies and regularly publish annual reports on ICT and e-commerce to stimulate the practical application of the digital economy.

(2) Increase the intensity of investment in core information technology such as blockchain and artificial intelligence, with a focus on the depth of Internet construction. The government should fully use fiscal policy and macro-regulation to enable social resources to nurture the growth of the digital economy.

(3) The large regional differences exposed in the development of the digital economy in 11 coastal provinces cannot be ignored. Therefore, it is of significance to formulate a more comprehensive digital economy development mission and plan to improve the level of regional digital economy development. The Yangtze River Delta and the Pearl River Delta regions have witnessed brighter results in digital economy development, and the Guangdong region should become a leader and practitioner of the new trend of digital economy development and actively innovate and practice the new direction of digital economy development.

(4) Improve regional policies for the introduction of talents, encourage active employment, increase the disposable income of employees, and moderately guide the growth of the tertiary sector workforce. Governments should improve talent introduction policies, while paying attention to the employment rate of the regional workforce, and actively provide sufficient human capital to construct the digital economy.

(5) Take advantage of the excellent coastal business environment to develop import and export businesses and encourage the development of cross-border e-commerce. Coastal provinces should actively make use of the location factor to attract foreign investment and promote frequent exchanges of maritime e-commerce to create a favorable business environment.

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