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UNLOCKING EFFICIENCY: AN EMPIRICAL APPRAISAL OF DIGITAL ECONOMY DEVELOPMENT IN HUZHOU

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Abstract: This article presents an empirical analysis of the efficiency of digital economy development in Huzhou using the DEA-BCC model and the Malmquist index model. The study covers the period from 2016 to 2021 and examines the utilization of digital economic resources in Huzhou from both static and dynamic efficiency perspectives. The results indicate that the input of digital economic resources in Huzhou has not been fully utilized in some years, and PTE is the main factor limiting the efficiency of digital economy development. Additionally, the TFP of the digital economy of Huzhou has shown a trend of fluctuation, which is mainly driven by TC. The study also reveals a significant disparity in the effectiveness of digital economic development among counties/districts in Huzhou.

Based on the findings, the article suggests several measures for enhancing the efficiency of digital economy development in Huzhou. These include the need for government departments to make a master plan and rationally allocate resources, accelerate digital technology innovation, optimize talent services, and focus on the complementary and coordinated development of each county/district. Overall, the study provides insights into the challenges and opportunities facing digital economy development in Huzhou and highlights the importance of taking a comprehensive and integrated approach to achieve high-level efficiency.

Keywords: digital economy, efficiency, input-output analysis, DEA-BCC model, Malmquist index model, Huzhou.

Introduction

As the worldwide situation is currently complex and unstable, and the global epidemic continues to ravage, economic recovery remains sluggish. Along with the accelerated iteration of technological empowerment and industrial change represented by 5G, quantum information science, and artificial intelligence, the digital economy has restructured factor resources, reshaped economic structures, and altered the competitive landscape, thereby becoming the driving force of the world's economic development. As reported by the China Academy of Information and Communication Technology, the value of digital economy in China grew from CNY 9.5 trillion to CNY 45.5 trillion, and its proportion of GDP increased from 20.3% to 39.8% during the period 2011-2021. With continuous growth and the total volume ranking second in the world, the role of the digital economy as a "stabilizer" and "driver" of highquality economic development has been further highlighted.

The added value of the core industry of the digital economy in Huzhou was CNY 12.64 billion in 2021, with an increase of 22.3%, of which growth rate joined top three in Zhejiang Province. In terms of the development of digital economy in Huzhou, progress has been made, however, there are still flaws and issues. A correct understanding of the efficiency of digital economy development of Huzhou is crucial in order to further increase the effectiveness of the policy implementation and deployment of digital economy development, further improve the necessity and level for cooperation and reference among regions, and ensure that the digital economy can truly serve as the primary driver of the highquality economic development of the city.

The key areas of domestic and international research on the digital economy currently are its meaning and its measurement. Since the term "digital economy" was first used in the 1990s, there hasn't been a consensus on what it means domestically or internationally. However, Kim (2002) noted that the essence of digital economy was related to the exchange of commodities and services using digital technology.[1] E-commerce was seen by Moulton (2000), Liu (2002), and Gaoua (2014) as one of the key components of the digital economy.[2-4] According to Pang et al. (2013), the digital economy consisted of digital activities that make it possible for people to transact, communicate, and collaborate via technology.[5] The Statistical Classification of the Digital Economy and its Core Industries (2021), published by the National Bureau of Statistics in June 2021, defined the digital economy as a set of economic activities where data resources serve as the essential production inputs, modern information networks serve as the significant carrier and the efficient use of information and communication technologies (ICT) servers as a fundamental driver behind improving productivity and optimizing the economic structure[6]. Quantitative analysis of the digital economy has been steadily growing both domestically and internationally in recent years. To assess the growth of China's digital economy, Zhang et al. (2017) created an index system for measuring digital economy development.[7] The level of digital economy development and the degree of industrial integration between China and the major developed nations were experimentally analyzed and contrasted by Liu et al. (2019).[8] Anatoly et al. (2020) provided a detailed index model of the development of the digital economy in regions of various sizes.[9] Through cluster analysis, Bilozubenko et al. (2020) examined the digital economy development indicators of EU nations.[10] The model was employed by Cai et al. (2020) and Li (2021) to assess the output efficiency of provincial digital economies in China, respectively.[11,12]

There is a lot of scholarly interest in measuring the input-output efficiency of digital economy at the moment. The input-output theory, which was initially put forth by the Russian American economist Wassily Leontief in the 1930s, is the theory that intricately intertwined relationships within the economy of a country can quantitatively reflect the technical structure of the entire economy. According to the input-output theory, inputs are the consumption and use of various resource variables during the society's production process, and outputs are the outcome of that production process. Based on an input-output perspective, Wan et al. (2019) developed an evaluation index system for digital economy development.[13] According to Li (2021), the quantitative measure of the effectiveness of digital economy development was the ratio of output to input in digital economy activities.[14]

In summary, there are plenty of research findings from both domestic and international scholars measuring the input-output perspective of efficiency of digital economy development, but there are considerable differences in the indicators chosen. Moreover, there are hardly any research findings in the literature currently available exploring the efficiency of digital economy development of individual cities, leaving room for the research in this paper. Therefore, based on the input-output perspective, this paper constructs an indicator system for the efficiency of digital economy development of Huzhou.

Then, it uses the DEA-BCC and the Malmquist index models to conduct an empirical analysis of the efficiency of digital economy development of Huzhou. Finally, it explores the specific situation of efficiency of digital economy development of the city including different counties/districts from 2016 to 2021, examines the issues and causes associated with the inputs and outputs of the digital economy, discusses the bottlenecks encountered in advancing the construction of digital economy and proposes appropriate suggestions and countermeasures, to provide theoretical support and policy reference for enhancing the output effectiveness of the digital economy and fostering its high-quality development.

1. Materials and Methods

1.1. Selection of Model

1.1.1. DEA Model

Data Envelopment Analysis (DEA), created by A. Charnes and W.W. Cooper et al. in 1978, is a linear programming tool to assess the relative efficiency of Decision Making Units (DMU) with multiple inputs and multiple outputs. The CCR model, which assumes constant returns to scale (CRS), and the BCC model, which expects variable returns to scale (VRS), are the two that are most frequently applied. Since the returns of scale in the digital economy are not yet clear, this paper uses the DEA-BCC model to assess efficiency, which can measure the technical efficiency (TE) of a decision unit and breakdown it into pure technical efficiency (PTE) and scale efficiency (SE). TE represents the level of overall technical skill of a decision unit, i.e. the number of results produced per unit of resources used. PTE reflects the efficiency generated by technical factors, while scale efficiency refers to the efficiency brought about by the scale of the industry. PTE and SE evaluate how well the technical level and scale level have reached their respective optimum states.

Assuming that there are n $DDDDDD_j (1 \le jj \le nn)$, each decision unit has m input indicators $XX_{jj} =$
TT TT
$XX_{1jj}, X_{2jj}, \cdots\cdots, XX_{mmjj}$, and q output indicators $YY_{jj} = YY_{1jj}, YY_{2jj}, \cdots\cdots, YY_{qqjj}$, the BCC model of $DDDDDD_{jj}$ is obtained as follows.

$$mmmmmmm\{\theta\theta\}$$

$$ss.\ tt.$$

$$\begin{cases} \sum nnjj{=}1 XXjj\lambda\lambda jj + SS- = XX0 \\ \sum_{j=1}^{n} YY_{jj}\lambda\lambda_{jj} - SS^{+} = \theta\theta YY_0 \qquad (1) \\ \sum nnjj{=}1 \lambda\lambda jj = 1 \\ \lambda\lambda_{jj} \ge 0,\ SS^{-} \ge 0,\ SS^{+} \ge 0 \end{cases}$$

where $\theta\theta$ denotes the technical efficiency value of $DDDDDD_{jj}$, $\theta\theta \in [0, 1]$, $\lambda\lambda_{jj}$ denotes the linear combination coefficient of $DDDDDD_{jj}$, and SS^{-}, SS^{+} denote the slack variables of input redundancy and output deficiency, respectively. When $\theta\theta = 1$ and $SS^{-} = SS^{+} = 0$, the evaluated decision unit $DDDDDD_{jj}$ is strongly efficient, and when $\theta\theta \ne 1$, $DDDDDD_{jj}$ is non-efficient, indicating poor input-output efficiency.

1.1.2. Malmquist Index Model

By measuring the Malmquist index by the change in productivity from one period to the next, the Malmquist index model provides a dynamic examination of the effectiveness of the decision unit over time. Using the t-period distance function $DD^{t}(mm^{tt}, yy^{tt})$, the Malmquist index for the evaluated decision unit $DDDDDD_{jj}$ from period t to period t+1 is obtained as follows.

$\frac{1}{2}$

$tt, \quad yyjjtt, \quad mmjjtt+1, \quad yyjjtt+1 \quad =$

$DDjjttDDxxttjjtt+1xxjjtt,,yyyjjjjtt+1tt \times DDjjtt+1DDjjtt+1xxjjtt+1xxjjtt,,yyyyjjjjtt+1tt$ (2)

$DDmmjj$

jj

$DDjjtt+1xxjjtt+1,yjjtt+1 \quad DDjjttxxjjtt+1,yyjjtt+1DDjjttxxjjtt,yyjjtt \frac{1}{2}$

$= \quad jjttxxjjtt,yjjtt\times \; DDjjtt+1xxjjtt+1,yyjjtt+1 \times DDjjtt+1xxjjtt,yyjjtt$

(3)

DD

When M>1, it indicates that productivity in period t+1 tends to increase compared to period t. M=1 means that there is no change in productivity, and when M<1, productivity tends to decrease. The Malmquist Total Factor Productivity Index (TFP) reflects the overall productivity of the production factors in a decision unit over a period of time. It can be decomposed into Efficiency Change (EC) and Technical Change (TC). EC can be further decomposed into Technical Efficiency Change (TEC) and Scale Efficiency Change (SEC).

1.2. Construction of the Indicator System of Efficiency of Digital Economy Development

1.2.1. Selection of indicators

Table 1: Evaluation indicator system of efficiency of digital economy development.

Target layer	Criterion layer	Indicator name
Input Indicators	Capital	Fixed asset investment in information transmission, software, and information technology services (million CNY)
	Labor	Employees in the information transmission, software, and information technology services sector (person)
	Infrastructure	Number of internet broadband access subscribers (billion)
Output Indicators	Level of the Digital Economy	The added value of the digital economy (billion CNY)
	Labor Productivity	GDP/total employment (billion CNY per 10,000 people)

The selection of indicators is a key task. At present, there is no unified standard for the indicator system of efficiency of digital economy development in domestic and international research. According to Classical economics notion of “the Three Factors of Production", three aspects should be included in input indicators: capital, labor, and land. The "land" factor in the digital economy, as opposed to the traditional agricultural and industrial economies where land is a factor of production, can be understood as a contemporary information network that enables digital empowerment and transformation for data collection, storage, sensing, computing and transportation for various industries, driven by both hardware facilities and software technology. In addition, the output of the digital economy is defined as the added value created by promoting the optimization of the traditional economic structure and the improvement of labor productivity in the Statistical Classification of the Digital Economy and its Core Industries (2021) released by the National Bureau of Statistics. Based on these findings, this paper explores input indicators in terms of capital, labor, and infrastructure for the development of the digital economy, as well as output indicators in terms of both the level of the digital economy and labor productivity. Each secondary indicator is chosen by collecting and analyzing the previous research and considering the measurability and availability of data. The final evaluation indicator system of efficiency of digital economy development is constructed based on the input-output perspective, as shown in Table 1.

1.2.2. Data collection and processing

The research object of this paper is the efficiency of digital economy development of Huzhou (including the counties and districts), and the sample years chosen are 2016-2021, with relevant data obtained from the Statistical Yearbook of Chinese City, the Statistical Yearbook of Huzhou, the Statistical Bulletin of Huzhou and the counties/districts, as well as database such as EPS. The findings of descriptive statistics for the relevant indicators are presented in Table 2.

Table 2: Descriptive statistics for the relevant indicators.

Indicator name (Unit)	**Min**	**Max**	**Mean**	**Std Dev**
Fixed asset investment in information transmission, software, and information technology services (million CNY)	0.42	2128.56	324.688	417.203
Employees in the information transmission, software, and information technology services sector (person)	8	5664	1722.278	1985.847
Number of internet broadband access subscribers (billion)	1.76	22.30	6.216	5.968
The added value of the digital economy (billion CNY)	10.50	145.07	35.39	34.505
GDP/total employment (billion CNY per 10,000 people)	1.15	2.04	1.549	0.216

The minimum and maximum values for each indicator are varied significantly, as shown in Table 2, and further analysis of the reasons for the variation is necessary.

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2. Results and Analysis

Based on the DEA-BCC model and the Malmquist index model and in accordance with the above input-output indicator system which evaluates the efficiency of digital economy development, the DEAP2.1 software is used to conduct an empirical analysis on the efficiency of digital economy development of Huzhou from 2016 to 2021 from both static and dynamic perspectives.

2.1. Analysis of static efficiency

Table 3 displays the efficiency and decomposition results of the digital economy of Huzhou in 20162021, as obtained based on the DEA- BCC model with the assumption of VRS.

Table 3: Efficiency and decomposition results of the digital economy of Huzhou, 2016-2021.

Year	2016	2017	2018	2019	2020	2021	Mean
TE	1	0.953	1	0.92	1	1	0.979
PTE	1	0.953	1	0.934	1	1	0.981
SE	1	1	1	0.984	1	1	0.997
Slack variable, S^-	0	302.829	0	106344.19	0	0	-
Slack variable, S^+	0	0	0	76.943	0	0	-
Returns to scale	fixed	diminishing	fixed	incremental	fixed	fixed	-

According to Table 3, the average value of TE of the digital economy in Huzhou from 2016 to 2021 is 0.979, which is close to the DEA effective condition. In 2017 and 2019, DEA validity was not met, indicating that there was potential for improvement in the allocation of input resources for the digital economy over these two years. With TE values of 1 and slack variables of 0 in 2016, 2018, and 20202021, the efficiency of digital economy inputs and outputs attained DEA strong validity, indicating that digital economy resources inputs in Huzhou were fully utilized and maximum output was attained during the majority of years of the study period.

TE is divisible into PTE and SE. PTE refers to the efficiency gained by technological and management upgrades for a given scale of inputs. SE reveals whether the input and output scales are optimally matched under a particular set of technical conditions. PTE of the digital economy in Huzhou exhibited DEA inefficiency in 2017 and 2019, whereas SE exhibited DEA inefficiency only in 2019. Thus, in 2019, TE of the digital economy in Huzhou was restrained by both PTE and SE, whereas in 2017, PTE was the primary factor determining the DEA ineffectiveness of TE.

In terms of returns to scale, diminishing in 2017 and increasing in 2019, it approached a constant optimum after 2019, whereas PTE and SE reached a state of strong continuous effectiveness. This is mainly due to the fact that since 2020, Huzhou Municipal Government has issued a series of policies that gave full play to government guidance, including "Several Policies for Accelerating the Development of New Format of Digital Economy in Huzhou ", "Three-Year Action Plan for Accelerating the "Smart Connection of Everything" to Promote the Development of Digital Economy of Huzhou

(2020-2022)", and "14th Five-Year Plan of Digital Economy Development of Huzhou", encouraged enterprises to innovate and develop, improved the level of technology and scale management, and achieved a reasonable allocation and use of resources.

2.2. Analysis of dynamic efficiency

2.2.1. Longitudinal analysis of TFP of digital economy development

On the basis of the DEA-Malmquist index model, Table 4 displays TFP changes in the digital economy in Huzhou from 2016 to 2021 along the time dimension, as well as their decomposition.

Table 4: TFP changes of the digital economy in Huzhou and decomposition, 2016-2021.

Year	EC	TC	TEC	SEC	TFP
2016-2017	1.016	0.801	1.000	1.016	0.813
2017-2018	1.001	1.056	1.000	1.001	1.057
2018-2019	0.977	0.488	1.000	0.977	0.477
2019-2020	0.991	1.870	1.000	0.991	1.852
2020-2021	1.062	1.050	1.000	1.062	1.115
Mean	1.009	0.959	1.000	1.009	0.967

As can be seen from the data in Table 4, TFP of the digital economy development of Huzhou generally fluctuated around 1 during the study period, with two periods of decline, an 18.7% decline in 2016-2017 and a 52.3% decline in 2018-2019, primarily due to the impact of declining TC. In the other years, TFP was more than 1, as a result of the combined effect of EC and TC, suggesting that the digital resources were rationally allocated and the output of the digital economy was more efficient in Huzhou during this period.

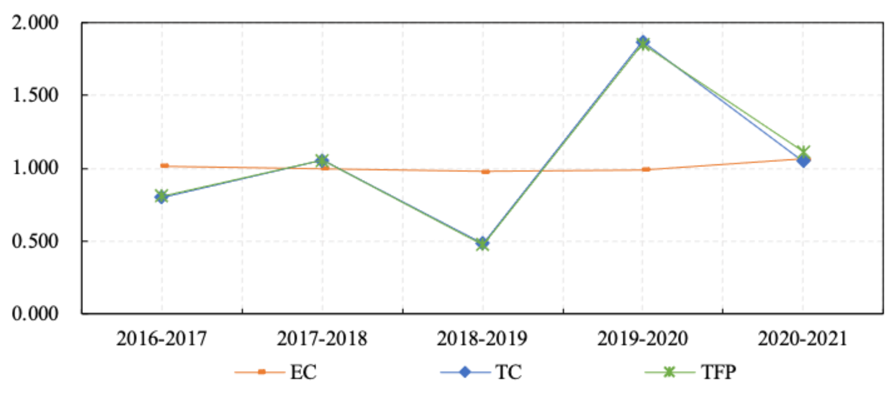

Figure 1: Trends in the Malmquist index of the digital economy of Huzhou and its decomposition, 2016-2021

Further analysis of Figure 1 reveals that the EC index exhibited a downward trend from 2018 to 2020 and an upward trend in the other years; moreover, the fluctuation trend of TC index from 2016 to 2021 was fully consistent with the TFP index, and the TC index fluctuated noticeably more than EC index. It implies that the technical efficiency of digital economy industry in Huzhou improved modestly over the past several years and that the improvement of total factor productivity was primarily dependent on technological advancement. Large projects with budgets of tens of billions or five billion, such as Taijia Optoelectronics, Fulande Communication, Jimaike Microelectronics, Yuanyang Data Centre, and Chaoyue CNC et al., have provided a significant technological impetus for the development of the digital economy in Huzhou.

2.2.2. Horizontal analysis of TFP of digital economy development

Based on the geographical dimension, Table 5 depicts the change in TFP of the digital economy and its decomposition for each county and district in Huzhou as per the DEA-Malmquist index model.

Table 5: TFP of the digital economy and its decomposition for each county and district in Huzhou, 2016-2021

Region	**EC**	**TC**	**TEC**	**SEC**	**TFP**
Wuxing District	1.003	0.865	1.000	1.003	0.868
Nanxun District	1.009	1.209	1.000	1.009	1.219
Deqing County	1.004	0.990	1.000	1.004	0.994
Changxing County	1.039	0.926	1.000	1.039	0.962
Anji County	1.000	0.866	1.000	1.000	0.866
Mean	1.009	0.959	1.000	1.009	0.967

As shown in Table 5, the average TFP of the digital economy in the counties/districts of Huzhou dropped by 3.3% during 2016-2021. By decomposing the data, it is evident that the growth in SEC positively contributed to the EC of the counties/districts. However, the increase in the EC was considerably less than the decrease in the TC, and thus the path of the TFP index was highly comparable to that of the TC index. This indicates that the efficiency of digital economy industry in all counties/districts of Huzhou has increased in recent years, but the growth rate is minimal, while the decline in technological progress was so pronounced that it has offset the positive impact of the enhanced agglomeration effect of the digital economy industry, improved management and optimal allocation of resources, and hindered the development of total factor productivity of the digital economy.

A comparison of the counties/districts reveals that Nanxun District was the only county/district in which both the EC index and the TC index were greater than1, resulting in a substantial rise in TFP of digital economy, with a growth rate of 21.9%, whereas TFP of digital economy in other counties/districts was declining. Whether in terms of technology management or technological innovation, it has attained a pretty advanced level of development in Nanxun District. This is consistent with the findings in the "Comprehensive Evaluation Report of Digital Economy Development of Zhejiang Province in 2022", stating that Nanxun District led the city in terms of the comprehensive index of digital economy development, published by Zhejiang Provincial Leading Group Office of Digital Economy, the Provincial Department of Economy and Information Technology, and the Provincial Bureau of Statistics. In recent years, the provincial smart factory (digital workshop) of Nanxun District achieved a triple flip. Deep processing projects of G8.5 ultra-thin glass substrate by Zhejiang Taijia Optoelectronics Technology Co., Ltd., with a total investment of RMB 29 billion by the

Economic Development Zone of Nanxun District, filled the blank in the field of Zhejiang Province, thereby building momentum for the development of the digital economy. However, the TFP indexes of the digital economy of other counties/districts in Huzhou were all constrained by TC, which is a common issue. It also means that once these counties/districts have a breakthrough in the level of technological progress, they will be able to achieve a growth of total factor productivity in the digital economy.

3. Conclusion

Based on the input-output indicator system for the efficiency of digital economy development, this paper used the DEA- BCC model and the Malmquist index model to empirically analyze the efficiency of digital economy development of Huzhou from both static and dynamic perspectives, explored the specific situation of the efficiency of digital economy development of the city and each county/district from 2016 to 2021, and drew the following conclusions. First, TE of the digital economy in Huzhou attained the DEA effective condition during the majority of the study period. The DEA ineffectiveness of TE was primarily determined by PTE in 2017, whereas it was restrained by both PTE and SE in 2019. Second, the TFP index of digital economy development of Huzhou generally fluctuated around 1 during the study period, with the TC index showing greater influence on the TFP index. Third, Nanxun District was the only county/district in which both the EC index and the TC index were larger than 1, resulting in a substantial rise in TFP of digital economy.

In terms of static efficiency, resource inputs of digital economy in Huzhou have not been effectively utilized in some years. By decomposing TE, it was found that PTE was the main factor limiting the efficiency of digital economy development of Huzhou, indicating that the digital economy in Huzhou had a problem with limited technological innovation and insufficient management level and that there was considerable room for improving the efficiency of resource allocation. As both knowledge technology and industrial structure are required for technological innovation, firstly, government departments should strengthen the top-level design of establishing a sound synergy mechanism, enhancing the exchange of information and reasonably allocating resources during the development of the digital economy. Concurrently, it is also required to improve the basic R&D of digital technology, accelerate cutting-edge digital technology innovation and data elements utilization mechanism innovation, and strive to overcome the core technology of the digital economy to strengthen the positive promotion effect of PTE on the efficiency of digital economy. Secondly, the introduction of leading talents and teams in the digital economy industries should be accelerated through talent-related programs such as “the Southern Tai Lake Elite Program” and “the Southern Tai Lake Special Support Program”, and the introduction and production of high-level and highly skilled digital talents should be bolstered by increased investment in education and the construction of a series of talent incentive systems and diverse talent evaluation systems. Also, it is necessary to promote the mutual recognition of talents across provinces and cities, optimize talent services, and to provide a guarantee of highly skilled talents for enhancing core technology R&D and achieving digital technology innovation. Lastly, it is suggested to improve the business environment for the development of the digital economy, continue to deepen the integration of the digital industry with the real economy, stimulate the value of data elements, build an industry ecology of innovative applications, promote the development of new business forms, comprehensively stimulate market vitality, and to promote a high-level improvement of the efficiency of digital economy.

In terms of dynamic efficiency, the TFP index of digital economy development of Huzhou showed an overall trend of fluctuation and improvement during the study period. SEC had a limited effect on the digital economy industry, while TC was mainly responsible for the improvement of TFP. In addition, there was a significant disparity in the efficiency of digital economy development in the counties/districts of Huzhou. Except for Nanxun District, the inability of the majority of counties/districts to accomplish technological breakthroughs severely hindered the enhancement of total factor productivity. To develop "digital Huzhou" comprehensively, government departments should improve market construction, cultivate and expand digital industrial clusters, and maximize the scale effect of the digital economy, through the design of a rational master plan and pertinent policies. In addition, in the process of development of the digital economy, it is advised that the complementarity of resource advantages of each county/district be bolstered and synergistic development be emphasized, for instance, maximizing the benefits of industrial agglomeration such as "the National Beidou and Geomatics Industry Base" and "the National New Generation Artificial Intelligence Innovation and Development Pilot Zone" in Deqing County, "the Provincial Emerging Base of Integrated Circuit" and "the New Energy Resources and Intelligent Networking Centre of Yangtze River Delta" in Changxing County, "the Cloud Data Centre of Yangtze River Delta" in Anji County and other related industrial clusters to build a solid foundation of high-quality development of digital economy. Last but not the least, participating in the joint research and development of core and key technologies of the digital economy by leveraging the regional advantages of relevant districts of Huzhou which are included in "the Science and Innovation Corridor of western Hangzhou", deeply engaging in the construction of the digital Yangtze River Delta and the provincial digital bay area, actively integrating into the regional cycle of digital industry, and bridging the "digital divide" between urban and rural areas are also recommended to better promote high-quality development of digital economy and common prosperity in Huzhou.

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