Research on Factors Influencing the Digital Economy Based on Principal Component Analysis: A Case Study of Liaoning Province

Xingyang Chen [1], Yumeng Qi [2, *]

[1] Zhejiang gongshang university school of statistics and mathematics, China

[2] Nanjing University,China

* Corresponding Author Email: MF21140096@smail.nju.edu.cn

Abstract. Exploring the influencing factors of the digital economy plays an important role in the development of Liaoning Province. Therefore, this paper proposes a research model for the influencing factors of the digital economy based on principal component analysis. Firstly, the indicators of the influencing factors of the digital economy in Liaoning Province are constructed. Secondly, Pearson correlation analysis is used to select the indicators. Finally, principal component analysis is used to reduce the dimensionality of the 14 indicators into 2 principal components, and it is identified that per capita GDP, R&D expenditure, and the number of Internet broadband access users at the end of the year are key factors influencing the development of the digital economy in Liaoning Province.

Keywords: Liaoning Province; digital economy; influencing factors; Pearson coefficient correlation analysis; principal component analysis.

1. Introduction

In recent years, the digital economy, as an important engine driving economic and social development, is rapidly changing our production methods, consumption patterns, and social forms. General Secretary Xi Jinping pointed out at the Central Economic Work Conference in December 2022: "We must vigorously develop the digital economy, improve the level of regularized regulation, and support platform enterprises in leading development, creating employment, and competing internationally." This important statement highlights the position and role of the digital economy in the national strategy, and its significance for exploration. By the end of 2022, the scale of China's digital economy reached 50.2 trillion-yuan, accounting for 41.5% of the GDP, making China not only one of the largest digital economies in the world but also providing strong support for promoting economic transformation and upgrading and driving innovation. However, in the development of the digital economy, there are still significant gaps and challenges among different regions. As an important province in the northeast region, Liaoning Province faces unique development problems and opportunities. Although the digital economy in Liaoning Province has continued to grow, there is still a certain gap compared to the more advanced regions in the country. In this era of rapid transformation, how to further promote the development of the digital economy in Liaoning Province and strengthen digital transformation has become an urgent issue before us. Through in-depth research and analysis, this paper aims to provide targeted references and suggestions for promoting the development of the digital economy in Liaoning Province. The intention of this paper is to fill the gap in the research on the influencing factors of the digital economy and contribute academic wisdom and research strength to the realization of digital transformation and the promotion of high-quality development.

This paper first constructs three secondary indicators: economic factors, infrastructure, and talent reserves, and further subdivides them into 14 secondary indicators, to comprehensively evaluate the influencing factors of the digital economy in Liaoning Province. After the construction of the indicators is completed, the Pearson correlation analysis method is used to test the correlation between these indicators and eliminate factors that have a small impact on the dependent variable. Then, the

principal component analysis method is used to reduce the dimensionality of the significant indicators, reducing multiple indicators into two main components, F1 and F2. Finally, recommendations and strategies for the development of the digital economy in Liaoning Province are proposed, providing decision support for the digital economy transformation in Liaoning Province.

2. Literature Review

2.1. Methods for Identifying Factors Influencing the Digital Economy

He et al. (2021) [2] analyzed data from multiple countries to explore the impact of the digital economy on economic growth. The study indicated that the digital economy has played a positive role in enhancing economic growth. Brynjolfsson, Erik (2014) [3], in his work "The Second Machine Age," examined the impact of digital technology on the economy, including its role in employment, progress, and prosperity. The book provides in-depth analysis and case studies, offering a detailed explanation of the importance of the digital economy. Salvi et al. (2021) [4] argued that disseminating information related to digitization has a positive impact on company value. Autor, D. H. (2015) [5], discussed employment in the current digital economy context, providing deep insights into the impact of the digital economy and discussing potential future trends. José Luis Ruiz-Real et al. (2020) [6] explored the impact of artificial intelligence on the economy and businesses from a business perspective. The authors analyzed the rise of digital technology and artificial intelligence and their role in creating value, enhancing productivity, and changing industry dynamics. Shepherd et al. (2020) [7] emphasized the potential of digital agriculture in addressing complex challenges in food production, highlighting the role of science and interdisciplinary research. Acemoglu, D., and Restrepo, P. (2019) [8], provided important insights into the factors influencing the digital economy by analyzing the impact of technological innovation and the digital economy on job tasks. They studied the current development and economic impact of the digital economy in China. Dong, Xinzhi (2022) [9], evaluated the importance of the digital economy in China by analyzing data and trends, and discussed its positive impact on economic growth. Fan, Hejun, Wu, Ting (2021) [10], proposed that strengthening digital construction is an inevitable choice for achieving economic growth and high-quality development.

2.2. The Current Status and Future Development of the Digital Economy

He Da'an (2021) [11] believes that China's digital economy is currently in its early stages, with a relatively high level of digitization in the circulation sector and a relatively low level in the manufacturing sector. The level of data intelligence among manufacturers also varies. At the same time, He Da'an (2021) [11] also believes that the overall trend of China's future digital economy development is that manufacturers' investment and operation will shift from the Internet+ model to the Artificial Intelligence+ model. This requires manufacturers to improve their ability to collect, process, and analyze non-digital data, current data, and future data, as well as expand the coverage of artificial intelligence matching with big data in the manufacturing industry. Li Danyang (2023) [12], from both domestic and international perspectives, has found that countries such as the United States, Japan, and Germany actively promote the development of the digital economy and have introduced a series of policies and strategies focusing on technological innovation, digital transformation, and integrated applications. China's digital economy has rapidly expanded in scale, ranking second in the world. However, it also faces challenges such as insufficient key technological innovation capabilities, data security risks, and intense international competition.

2.3. Literature Review Critique

The above literature review provides an in-depth understanding of different aspects and influencing factors of the digital economy. Scholars from both domestic and international sources have emphasized the positive impact of the digital economy on areas such as economic growth. However, domestic scholars have also pointed out the challenges and issues faced by the digital

economy, such as data privacy and security, intense international competition, and skill requirements. This suggests that the development of the digital economy requires a comprehensive consideration of technological, economic, social, and legal factors, as well as the promotion of interdisciplinary research and cooperation to realize its potential and sustainable development. In the above literature review, scholars from both domestic and international sources extensively discuss the influencing factors of the digital economy, revealing its significant role in areas such as economic growth, employment, enterprise value, and agriculture. However, there are still some gaps in research on the digital economy specific to certain regions or industries, and the timeliness of data is not strong. There is relatively little research on the influencing factors and effects of the digital economy in local economies. Liaoning Province, as an important region in China, deserves in-depth exploration of its digital economy development and influencing factors. Therefore, this study aims to investigate the influencing factors of the digital economy in Liaoning Province and conduct an in-depth analysis of its impact on the local economy by applying the principal component analysis method.

3. Pearson correlation coefficient

In the field of statistics, the Pearson correlation coefficient, also known as the Pearson product-moment correlation coefficient (PPMCC or PCCs), is used to assess the correlation (linear correlation) between variables X and Y. Its values range between -1 and 1. The formula is shown below.

$$r = \frac{\sum\left(X-\overline{X}\right)\left(Y-\overline{Y}\right)}{\sqrt{\sum\left(X-\overline{X}\right)^2 \sum\left(Y-\overline{Y}\right)^2}} \tag{1}$$

Table 1. Pearson correlation coefficient.

	Explanatory Variables	Correlation Coefficients
X_1	Number of Mobile Phone Users at the end of the year	0.825**
X_2	Mobile Phone Penetration Rate	0.817**
X_3	Number of Internet Users	0.834**
X_4	Internet Penetration Rate	0.841**
X_5	Number of Internet Subscribers	0.980**
X_6	Total Telecommunications Services Volume	0.778**
X_7	R&D Investment	0.856**
X_8	Software Business Revenue	0.577*
X_9	Total Fixed Asset Investment in Information Transmission, Software, and Information Technology Services Industry	0.261
X_{10}	Total Foreign Investment	0.948**
X_{11}	Per Capita GDP	0.934**
X_{12}	Employment in Information Transmission, Software, and Information Technology Services Industry	0.894**
X_{13}	Number of Broadband Internet Access Users at the end of the year	0.957**
X_{14}	Number of Employees in Information Transmission, Software, and Information Technology Services Industry	0.891**

Note: * indicates significant correlation at the 0.05 level (two-tailed), ** indicates significant correlation at the 0.01 level (two-tailed).

The results in the table show that the correlation coefficient for the total social fixed asset investment in the information transmission, software, and information technology services industry is below 0.3, and the correlation is not significant. Therefore, it can be considered that its impact on the digital economy is small and can be excluded. The correlation coefficients of the remaining 13 variables are all above 0.5 and the correlation is significant, so they are retained.

4. Principal Component Analysis

Principal Component Analysis (PCA) is a statistical dimensionality reduction method used to transform a set of potentially correlated variables into a set of linearly independent variables through orthogonal transformations. These new variables are called principal components. PCA can reduce the dimensionality of data and extract the most representative information to help us better understand and explain the variability of the data.

4.1. Validity Test

In this study, the KMO test and Bartlett's sphericity test were conducted on the 13 indicators to determine if the variable data is suitable for principal component analysis. The specific results are shown in Table 2.

Table 2. Results of KMO and Bartlett's Test for the Digital Economy.

KMO and Bartlett's Test		
KMO (Kaiser-Meyer-Olkin) measures sampling adequacy		0.813
Bartlett's Test of Sphericity	Approx. Chi-Square	557.871
	Degrees of Freedom	78
	Significance	0.000

The results indicate that the KMO value of the indicator data is 0.813, which is greater than 0.8, indicating a certain level of correlation among the indicators. The approximate chi-square value of Bartlett's test of sphericity is 557.871, with 78 degrees of freedom and a corresponding significance (P) value of 0.000. We reject the null hypothesis, suggesting a significant difference between the correlation matrix and the identity matrix. This indicates a strong correlation among the indicators, indicating that the indicator data is suitable for principal component analysis.

4.2. Principal Component Analysis

4.2.1. Principles of Principal Component Analysis

Principal Component Analysis (PCA) is a method that transforms highly correlated multiple indicators in the original data into a few indicators that can express most of the original information. It aims to eliminate the correlation between data and belongs to the category of unsupervised learning algorithms. Based on this, this study uses the PCA method to reduce the dimensionality of the factors influencing the digital economy in Liaoning Province, to construct a function that combines different types of factors and make the constructed evaluation system more realistic. The following is a brief introduction to the PCA method.

Suppose there are n samples of annual data and p indicators related to the development of the digital economy. The initial sample matrix can be obtained as follows.

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix} = (x_{ij})_{n\times p} \tag{2}$$

Here, the notation $i=(1,2,\cdots,n)$ represents the ith row of the initial sample matrix, and $j=(1,2,\cdots,p)$ represents the jth column. The subsequent interpretation of "i" and "j" in the following text remains the same as stated here.

(1) Calculation of the Correlation Matrix $R=(r_{ij})_{n\times p}$

The formula r_{ij} for calculating is as follows:

$$r_{ij} = \frac{1}{n}\sum_{i=1}^{n}\frac{(x_{ij}-x_i)(x_{ij}-x_j)}{s} \tag{3}$$

Here, "s" represents the variance of the sample.

(2) Calculation of Eigenvalues and Eigenvectors of R

Based on the expression of the characteristic equation $|R-\lambda I|=0$, we can calculate the values of λ. Here, R represents the correlation matrix, and I represent the identity matrix. By arranging the eigenvalues λ in descending order, we obtain $\lambda_1,\lambda_2,\cdots,\lambda_n$. Simultaneously, we can calculate the corresponding eigenvectors a_j.

(3) Calculation of Contribution Rate and Cumulative Contribution Rate.

$$e_i=\frac{\lambda_i}{\sum_{i=1}^{p}\lambda_i} \tag{4}$$

$$E_m=\frac{\sum_{i=1}^{m}\lambda_i}{\sum_{i=1}^{p}\lambda_i} \tag{5}$$

(4) Calculation of Principal Components

$$z_m=a_{mj}x_j \tag{6}$$

(5) Calculating the Number of Principal Components

The number of principal components is determined by examining the cumulative variance contribution. In this study, all principal components with a cumulative variance contribution greater than 90% were selected to complete the extraction of principal components. Finally, based on the obtained indicators, a comprehensive index system of the influencing factors of Liaoning Province's digital economy was constructed.

4.2.2. Empirical Testing

The SPSS 26.0 software was used to perform principal component analysis using the following steps: "Analyze - Dimension Reduction - Factor." The results are shown in Table 3, which presents the explained total variance, and the scree plot is depicted in Figure 1.

Table 3 Explained Total Variance Table.

Component	Initial Eigenvalues			Extraction Loadings		
	Total	Variance Percentage	Cumulative %	Total	Variance Percentage	Cumulative %
1	11.267	86.672	86.672	11.267	86.672	86.672
2	1.311	10.084	96.756	1.311	10.084	96.756
3	0.188	1.446	98.202			
4	0.119	0.918	99.120			
5	0.078	0.600	99.720			
6	0.018	0.136	99.855			
7	0.010	0.077	99.932			
8	0.004	0.030	99.962			
9	0.003	0.023	99.985			
10	0.001	0.007	99.992			
11	0.001	0.005	99.998			
12	0.000	0.002	100.000			
13	2.70E-05	0.000	100.000			

Extraction Method: Principal Component Analysis

From Table 3, the first two principal components explain 96.756% of the total variance. This indicates that the extracted 2 principal components can represent 96.756% of the information from the original 13 indicators of the digital economy. The extraction of principal components provides a certain understanding of the influencing factors of Liaoning Province's digital economy. Therefore, 2 principal components, namely F1 and F2, are extracted.

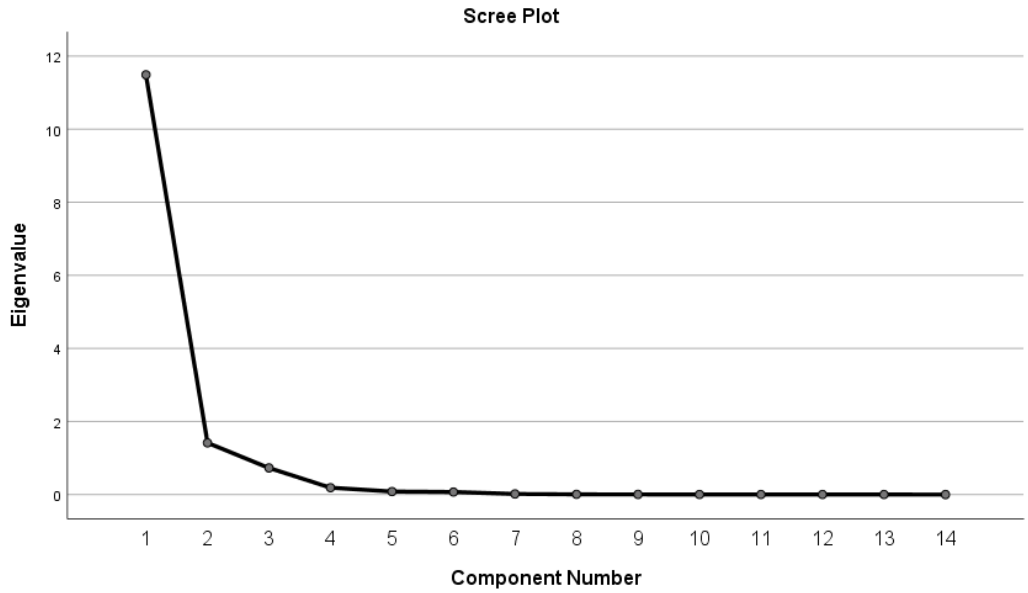


Figure 1. Scree Plot.

From Figure 1, it can be observed that the slope of Component 1 and Component 2 is relatively steep, and their eigenvalues are all greater than 1. On the other hand, the slope of Component 3 to Component 13 is relatively flat. Therefore, it is appropriate to extract 2 principal components.

The final component score coefficient table is presented in Table 4.

Table 4. Component Matrix Table.

Variable	Component	
	F_1	F_2
X_1	0.975	-0.171
X_2	0.971	-0.187
X_3	0.972	-0.146
X_4	0.974	-0.125
X_5	0.953	0.280
X_6	0.625	0.746
X_7	0.978	-0.021
X_8	0.794	-0.565
X_{10}	0.884	0.435
X_{11}	0.995	0.060
X_{12}	0.961	-0.128
X_{13}	0.978	0.163
X_{14}	0.970	-0.137

Extraction Method: Principal Component Analysis

After the extraction of principal components is completed, we obtain the following two formulas:

$$F_1=0.975X_1+0.971X_2+0.972X_3+0.974X_4+0.953X_5+0.625X_6 +0.978X_7+0.794X_8+0.884X_9+0.995X_{10}+0.961X_{11}+0.978X_{12}+0.970X_{13} \quad (7)$$

$$F_2=-0.171X_1+-0.187X_2-0.146X_3-0.125X_4+0.280X_5+0.746X_6 -0.021X_7-0.565X_8+0.435X_9+0.060X_{10}-0.128X_{11}+0.163X_{12}-0.137X_{13} \quad (8)$$

5. Conclusion

(1) According to Table 4, the most important factors influencing the development of the digital economy in Liaoning Province are per capita GDP, R&D expenditure, and the number of internet broadband access users at the end of the year, with loading coefficients of 0.995, 0.978, and 0.978, respectively. Per capita GDP reflects the economic level of the region. The per capita GDP of Liaoning Province directly relates to the purchasing power and consumption capacity of the citizens, which is of great significance to areas such as e-commerce and online services in the digital economy. R&D expenditure is the driving force of innovation and is crucial for the development of the digital economy. It can promote the emergence of new technologies and innovative industries and contribute to the continuous progress of digital technologies. The number of internet broadband access users reflects the level of digital infrastructure development. More broadband users imply a wider range of digital economy applications, such as cloud computing, the Internet of Things, and online media.

(2) Comparatively important factors influencing the development of the digital economy in Liaoning Province include the number of mobile phone users at the end of the year, internet penetration rate, number of internet users, mobile phone penetration rate, information transfer, and the number of employees in the software and information technology services industry, with loading coefficients of 0.975, 0.974, 0.972, 0.971, and 0.970, respectively. The number of mobile phone users reflects the level of communication technology penetration, which is crucial for the development of the digital economy. More mobile phone users imply a broader range of digital communication and mobile applications, which contribute to the growth of areas such as e-commerce and mobile payments. The internet penetration rate reflects the level of network access availability, which is crucial for the development of the digital economy. It supports the growth of areas such as online education, e-government, e-healthcare, and online entertainment. The number of internet users represents the population using the internet. It is a key indicator for digital markets and digital content consumption, directly impacting the development of areas such as online advertising, social media, and digital media. The mobile phone penetration rate is closely related to the development of communication technology. A high penetration rate can support innovation in mobile applications and communication services, positively influencing the growth of the digital economy. The number of employees in the information transfer, software, and information technology services industry reflects the employment situation in the digital technology field. Professionals in the digital technology field are the foundation for the development of the digital economy, driving the growth of innovation and technology application.

(3) General factors that affect the development of the digital economy in Liaoning Province are information transfer, employment in the software and information technology services industry, the number of internet users, and total foreign investment, with loading coefficients of 0.961, 0.953, and 0.884, respectively. The development of the digital economy relies on the support of technical professionals. A higher number of employees in the software and information technology services industry indicates more talent participating in digital innovation and service provision in the region, which contributes to the development and application of digital technologies. The number of internet users reflects the level of internet penetration, which has a direct impact on the development of the digital economy. More internet users imply a broader digital market and online service users, promoting the growth of the digital economy. Foreign investment can bring funds, technology, and market opportunities to the region. It helps drive the internationalization of the digital economy by introducing external resources to promote the development of digital industries.

(4) Factors that have a relatively smaller impact on the development of the digital economy in Liaoning Province are software business revenue and total telecommunications business, with loading coefficients of 0.794 and 0.625, respectively. Although software business revenue plays an important role in the digital economy, it may not be the primary factor influencing the digital economy in Liaoning Province. This may be due to the relatively smaller scale of the software business or other aspects of the digital economy (such as internet penetration and talent development) being more critical to the region's digital development. Total telecommunications business typically reflects the

scale of communication infrastructure, but it may contribute less to the growth of the digital economy itself. The digital economy relies on broader digital applications and innovation, not just the scale of communication infrastructure.

6. Recommendation

6.1. Increasing R&D funding can contribute to the growth of the digital economy

Increased investment in R&D can have the following important impacts: Promoting technological innovation: Increasing R&D funding helps stimulate innovation and drive the development of new technologies and solutions. This contributes to various fields in the digital economy, such as artificial intelligence, blockchain, and big data analytics. Enhancing competitiveness: Having advanced technology and innovation capabilities improves the competitiveness of enterprises in Liaoning Province. This helps attract domestic and foreign investments, promoting local business growth and internationalization. Supporting digital transformation: Increased R&D funding can assist businesses in better addressing the challenges of digital transformation. This includes developing automated processes, improving digital security, and building digital infrastructure. Attracting talent: Investment in R&D attracts talent with high technical knowledge and expertise. This helps expand the talent pool in the digital economy, promoting industry innovation and growth. Driving industrial upgrading: R&D support can guide traditional industries towards digital transformation. This helps improve the efficiency of traditional industries and creates new business opportunities. In summary, increasing R&D funding is one of the key factors driving the development of the digital economy in Liaoning Province. It helps the region better respond to the challenges of the digital age and achieve sustainable economic growth.

6.2. Expanding the number of broadband internet access users and promoting the stable development of the data economy

The importance of increasing the number of broadband internet access users for the development of the digital economy can be seen in the following six aspects: Promoting digital education: By providing broader internet access, the development of digital education can be facilitated. Students can access online learning resources, improve their education levels, and cultivate digital technology skills to prepare for future employment in the digital economy. Driving e-commerce: Increasing the number of internet users contributes to the expansion of the e-commerce market. More online shopping and electronic payment transactions will stimulate digital economic growth and increase the activity of e-commerce platforms and digital markets. Supporting remote work: Remote work is becoming increasingly common globally. Providing broader broadband access enables more people to work from home or remote locations, which helps enhance workforce flexibility and productivity. Encouraging digital innovation: The increase in broadband internet access will encourage digital innovation. Entrepreneurs and innovators can more easily access online resources, collaborate with the global innovation community, and drive development in the field of digital technology. Improving healthcare services: Improving internet accessibility contributes to enhancing remote healthcare and health consultation services. Patients can consult doctors remotely, receive medical advice, and reduce the waste of medical resources. Supporting digital government services: Broader internet access can promote the development of digital government services, improve government efficiency, and provide residents with more online services and information. Overall, increasing the number of broadband internet access users not only contributes to the growth of the digital economy but also improves education, healthcare, work, and public services, thereby enhancing quality of life and social development. This is a crucial step in a digital society.

6.3. Strengthening talent development in the digital field and supporting employment in the software and information technology services industry

Cultivating talent in the digital field is a key measure to promote the development of the digital economy. Specific measures include: Diversified training programs: Introduce diverse training programs that cater to people of different ages and education levels. This includes vocational skills training, online learning, vocational degree courses, etc., to ensure inclusive training opportunities in the digital field. Industry-academia collaboration: Strengthen collaboration between educational institutions and the industry to ensure that the education system keeps up with technological trends. Collaborate with industry partners to develop curriculum, provide practical experiences and internship opportunities, which help students better adapt to professional demands. Technology innovation centers: Establish technology innovation centers to provide students and professionals with opportunities for practical projects and research. These centers can serve as incubators for nurturing talent in emerging technological fields. Digital literacy: Incorporate digital literacy into basic education to ensure that every student possesses basic digital skills. This will cultivate more graduates with digital literacy for the future job market. Online learning resources: Provide online learning resources so that professionals can continue their education and continuously update their skills anytime, anywhere. This helps employees adapt to constantly changing technological and industry demands. Encouraging self-learning: Encourage individuals to independently learn digital skills, including programming, data analysis, and cybersecurity. This will help cultivate self-driven innovators and entrepreneurs. Through these expanded measures, Liaoning Province can establish a stronger talent pool in the digital field, promote innovation and application in the digital economy, enhance competitiveness, and ensure sustained growth in the digital domain. This will contribute to addressing the rapid changes and developmental needs of the digital economy.

6.4. Developing friendly policies for foreign investment is crucial for the internationalization of the digital economy

Developing friendly policies for foreign investment is crucial for the internationalization of the digital economy. Specific measures include: Lowering market entry barriers: Simplify the market entry procedures for foreign investment and reduce the complexity of administrative approvals. This will attract more foreign companies to enter Liaoning Province and promote diversification and competition in the digital economy. Providing tax incentives: Offer tax incentives to foreign investors, such as tax exemptions and preferential tax rates, to reduce their operating costs. This will enhance the region's attractiveness in international competition. Ensuring intellectual property protection: Establish robust mechanisms for protecting intellectual property rights to safeguard the IP of foreign investors. This will increase their confidence in the digital economy sector and encourage the development of IP-intensive industries. Promoting innovation collaboration: Encourage local businesses to engage in innovation collaborations with foreign investors to jointly drive research and development and applications in the digital economy field. This fosters technology exchange and innovation. Providing market intelligence support: Provide market intelligence and research support to foreign investors to help them better understand local market opportunities and demands. This enhances the intelligence of investment decisions. Facilitating talent mobility: Encourage international talent mobility to attract foreign professionals to work in Liaoning Province. An internationalized team and innovation ecosystem contribute to the international competitiveness of the digital economy. By implementing the above suggestions, Liaoning Province can create a more favorable investment environment for foreign investors, attract technology, capital, and market opportunities, promote the internationalization of the digital economy, and stimulate the upgrade and innovation of local industries. This will accelerate the global impact and competitiveness of the digital economy.

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