Evaluation and Analysis of Regional Economic Growth Factors in Digital Economy Based on the Deep Neural Network

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With the rise of deep learning technology, due to the superior performance of the deep neural network, its application in the digital economy has attracted extensive attention of scholars. Since the beginning of the 21st century, our country’s digital economy has developed rapidly, and its universalization and other characteristics have created favorable conditions for the optimal allocation of resources in underdeveloped regions and the exertion of comparative advantages. The digital economy will play a key role in poverty alleviation, promoting coordinated regional development, narrowing regional gaps, and improving the spatial layout of my country’s reform and opening up. This paper studies the factors that the digital economy based on deep neural networks has on regional economic growth. Simulation experiment conclusions are as follows: (1) the digital economy of Guizhou, Beijing, Chongqing, Anhui, and Tibet is growing rapidly. The central and western regions are in a period of rapid growth. For the gap between major industrial provinces, the coefficient of variation reached about 1 before 2013, then it declined rapidly, and slowed down, and steadily declined after 2019, indicating that the gap in the digital economy in various regions is narrowing in general. (2) From the national level, the digital economy index coefficient is 1.24, that is, for every 1% increase in digital economy investment, GDP will increase by about 0.24%. The labor force increased by 1% and the GDP increased by about 0.22%. This promotion effect is also very obvious. (3) Judging from the above data, the western region urgently needs to promote the construction of the digital economy and introduce high-tech digital economy talents. The talent effect in the Midwest has a significant effect on GDP. (4) From the perspective of the whole country and other regions, the parameter coefficients and signs have not changed significantly, so the original model is robust, and so the conclusion is desirable.

1. Introduction

At present, there is no clear definition of the deep neural network in the field of computer vision. Broadly speaking, it is considered to include specific variants such as convolutional neural networks and recurrent neural networks. In practical applications, deep neural networks often incorporate a variety of known structures \([1, 2]\), for example, restricted Boltzmann machines and long and short-term memory units.

The current level of digital technology development is changing with each passing day in the context of economic globalization. Information technology in various countries is infiltrating and integrating with all walks of life and is constantly injecting new vitality into the global economy. It has become a powerful driving force to promote economic growth \([3, 4]\). The fields involved are not only in manufacturing and business management but also in the fields of population employment, education, and people’s livelihood. It is to promote national economic development and also to promote the smooth advancement of digital transformation in various regions \([5, 6]\).

On the one hand, it encounters challenges such as complex international environment, great downward pressure on the economy, and slow industrial transformation. On the other hand, the country is also in an
environment of major opportunities such as the vigorous rise of new technology revolution and the integration and interconnection of data resources [7–10]. Since the outbreak of the new crown pneumonia epidemic, the traditional manufacturing industry has been greatly impacted, which has brought great challenges to economic development around the world, and has also triggered many people’s thinking about economic growth. The global economy will enter a new cycle of economic growth led by innovation [11, 12].

Economic growth is the basis and premise of regional economic and social development and progress, but there are always differences between and within countries or regions. Developing countries consider how to increase their economic growth rate to approach developed countries; within countries or regions, they consider how to adjust the economic structure, narrow the internal gap, and improve the overall social welfare level [13].

China has continuously created miracles in the history of human development, but the gap in economic strength between regions has always existed. How to gradually reduce the economic gap between regions while maintaining stable economic development is a problem that our government has always attached great importance to. The digital economy is an emerging economic form [14–17]. The digital economy has penetrated into all fields of society and has changed the way of social organization to a large extent. Similarly, the digital economy also has had a certain impact on economic growth in terms of economic theory and policy systems.

The specific aspects are shown in Figure 1.

For the empirical research on the promotion of economic growth by the digital economy, many research results have achieved the world’s advanced level in new development fields. The impact of the digital economy on the economy is mainly manifested in the following aspects: the digital economy puts forward new requirements for energy distribution and environmental protection, the digital economy also presents new challenges for taxation as it affects economic growth, and the digital economy changes business and social behavior. Due to the various characteristics and advantages of deep neural networks, we propose to study the evaluation and analysis of regional economic growth factors in the digital economy based on deep neural networks [18, 19].

2. Basic Theory Related to the Deep Neural Network and the Digital Economy

2.1. Deep Neural Network Model. A deep neural network and its idea come from the human brain’s hierarchical processing mechanism for visual information. Starting from the original data, it automatically learns effective feature expressions through a multilayer structure and realizes classification and recognition at the output layer. Its advantages are that it overcomes the time-consuming and laborious shortcomings of the manual feature design; the primary features of each layer are obtained through layer-by-layer data pretraining; distributed data learning is more effective (exponential); and compared with shallow modeling methods, deep modeling can be more detailed and efficient representation of actual complex nonlinear problems. At present, both the theoretical research on the deep neural network algorithm and its application research have reached a peak. As the core model of deep learning, the deep neural network is often designed for image classification, speech recognition, and other fields, and has achieved good results. The different models differ mainly in their different model structures and have little to do with other parameters.

If the deep structure is regarded as a neuron network, the idea of the deep neural network can be described as follows: the pretraining of each layer of the network adopts unsupervised learning; input to one layer; supervised learning to fine-tune all layers (plus a classifier for classification). The main difference between deep neural networks and traditional neural networks is the training mechanism. The deep neural network adopts the training mechanism of layer-by-layer pretraining as a whole rather than the back-propagation training mechanism of the traditional neural network. The related theory is shown in Figure 2.

The encoder is one of the building blocks of the deep neural network. It is an unsupervised learning algorithm and a nonlinear neural network structure that reproduces the input signal as much as possible. The training difficulty of the convolutional neural network is more difficult, and the design of its network structure is also more complicated. Therefore, when designing a convolutional neural network, it is necessary to optimize its structural design.

2.2. Theories Related to Digital Economy. The digital economy takes digital knowledge and information as the key production factors [20], takes digital technology innovation as the core driving force, takes the modern information network as an important carrier, and deeply integrates Internet technology with the real economy to enhance industrial intelligence, digitization, and speed up the new economic form formed by reconstruction. Among them, industries such as computer manufacturing, electronic equipment manufacturing, radio and television and satellite transmission services, and information technology services are the basic industries of the digital economy. Internet retail, e-commerce, financial service platforms, and logistics services are based on digitalization and can be regarded as the category of digital economy [21].

The digital economy can be divided into digital industrialization and industrial digitization. Digital industrialization transforms scientific and technological innovation achievements into the driving force of economic and social progress through the market-oriented application of modern digital technology. Industrial digitalization means that traditional industries can improve themselves in an all-round and full-chain manner by introducing digital technology and in-depth integration, such as industrial Internet, intelligent manufacturing, and digital agriculture. From the 1990’s to the first decade of the 21st century, the electronic information manufacturing and software industries were booming. The main feature of the digital economy in this
The period was informatization, and information technology began to be widely embedded in the traditional neural network. In the industry, new business models have been conceived, but they are not yet mature. The accumulation of sufficient quantitative changes in the application of information technology began to produce a qualitative leap. After 2010, the main feature of the digital economy changed to digitization. In addition, the digital economy has three major characteristics [22].

First is platformization. The Internet platform makes information flow no longer monopolized by giants in the industry chain, promotes direct communication between suppliers and consumers, and realizes a large-scale division of labor and cooperation systems. Second is data. Data has become a key production factor for the development of the digital economy. The third is universalization. Inclusiveness embodies the concept of “everyone participates and everyone shares,” and representative fields include inclusive technology, inclusive finance, and inclusive trade. Figure 3 shows the three laws of the digital economy [23].

2.3. The Impact of the Digital Economy on Regional Economic Development. The digital economy has become a driving force, one is to promote production innovation. Digital, networked, and intelligently guided production methods are in line with the trends of precise resource allocation, automated production organization, and enterprise interconnection. The second is to promote consumption upgrading. The wide application of information products and information services makes the Internet penetrate into almost every detail of people’s consumption life. Mobile payment, with its convenience and efficiency, lowers the payment threshold and fully releases the consumption potential of urban and rural residents. The third is to change the trade pattern, such as books, audio and video, software, and services, such as R&D, finance, and advertising, can easily and quickly realize cross-border transactions through Internet transmission. Such digital trade products are growing rapidly. Digital trade will lead a world trade into a new stage and become a new economic growth pole.

Secondly, the digital economy has spillover effects on the economic development of other regions [24]. The digital economy not only empowers the economic development of the region but also promotes the economic development of other regions due to the spillover effect of digital technologies such as the Internet. The real-time, shared, and open nature of the Internet, as a core digital technology, connects multiple regions into a whole, breaks geographic barriers, and provides great convenience for the development of economic activities. Zhejiang regards the digital economy as “Project No. 1.” The difference in Shandong’s digital economy policy lies in the inclination towards the primary industry, which proposes to speed up the development of smart agriculture. Guangxi proposes to improve the foundation and governance of the digital economy and create a highland for ASEAN-oriented digital economic cooperation. The Yangtze River Delta region will focus on building key industries and promoting digital economy industrial clusters [25].
3. Basic Theory Related to the Deep Neural Network and the Digital Economy

3.1. Multihidden Layer Multilayer Perceptron. Multilayer perceptron: usually, this model is also called multihidden layer multilayer perceptron. Figure 5 shows the general structure of the multilayer perceptron model.

We deduce the learning process of the network through mathematical formulas. Suppose the input variable is net_i, then we get

$$\text{net}_i = \sum_{j=1}^{M} x_j + \theta_i.$$  \hspace{1cm} (1)

The corresponding output is

$$a_i = f(\text{net}_i).$$  \hspace{1cm} (2)

Sigmoid function is

$$f(x) = \frac{1}{1 + \exp(-x)}.$$  \hspace{1cm} (3)

When the value of the mapping function is in the positive and negative range, the symmetrical function is used as the excitation function:

$$f(x) = \text{tan}(x) = \frac{1 - \exp(-x)}{1 + \exp(-x)}.$$  \hspace{1cm} (4)

General order is

$$a_i = x_i.$$  \hspace{1cm} (5)

Then the input of the jth neuron in the hidden layer net_j is

$$\text{net}_j = \sum_{i=1}^{N} w_{ij} a_i + \theta_j.$$  \hspace{1cm} (6)

The corresponding output is a_j:

$$a_j = f(\text{net}_j).$$  \hspace{1cm} (7)

Then the input of the kth neuron in the output layer net_k is

$$\text{net}_k = \sum_{j=1}^{L} w_{jk} a_j + \theta_k,$$  \hspace{1cm} (8)

where $w_{jk}$ and $\theta_k$ are the weight and threshold, respectively. The corresponding output is $y_k$:

$$y_k = f(\text{net}_k).$$  \hspace{1cm} (9)

3.2. Long Short-Term Memory Network. Long short-term memory network is a special kind of a neural network. This kind of a neural network is different from the general feedforward neural network, LSTM can use time series to analyze the input. Recurrent neural networks learn sequential information through inner loops. The slope obtained by the chain rule is propagated to the activation function, and then the slope becomes very small or very large, which is the problem of vanishing or exploding gradients.

The long-short-term memory network forgetting gate is
\( f_i = \sigma(U_i x_i + W_j h_{i-1} + b_j). \) (10)

The input gate of the long short-term memory network is
\( i_t = \sigma(U_i x_i + W_j h_{i-1} + b_j), \)
\( \tau_t = \tanh(U_c x_i + W_c h_{i-1} + b_c). \) (11)

The current memory cell state is
\( c_t = f_i c_{t-1} + i_t \cdot \tau_t. \) (12)

Then the output gate of the long-short-term memory network is
\( o_t = \sigma(U_o x_i + W_j h_{i-1} + b_o). \) (13)

Then the state of the current hidden layer is
\( h_t = o_t \cdot \tanh(c_t). \) (14)

3.3. Entropy Method. Indicator selection: if there are \( m \) indicators, \( n \) regions, and \( r \) years, then \( x_{ijt} \) is the observed value of the jth indicator in region \( i \) in year \( t \). Then, standardize the indicators as follows:

Positive indicators are
\[ x_{ijt}^* = \frac{(x_{ijt} - m_j)}{(M_j - m_j)}. \] (15)

Negative indicators are
\[ x_{ijt}^* = \frac{(M_j - x_{ijt})}{(M_j - m_j)}. \] (16)

\( M_j = \max \{ x_{ijt} \}, m_j = \min \{ x_{ijt} \}. \)

We determine the proportion of observations of the jth indicator for region \( i \) in year \( t \):
\( p_{ijt} = \frac{x_{ijt}^*}{\sum_t x_{ijt}^*}, p_{ijt} \in [0, 1]. \) (17)

We determine the entropy value of the jth index as
\[ e_j = -\frac{1}{\ln(nT)} \sum_t \sum_{i} p_{ijt} \ln(p_{ijt}), e_j \in [0, 1]. \] (18)

We determine the information utility value of the jth indicator as
\( g_j = 1 - e_j. \) (19)

We determine the weight of the jth indicator as
\( w_j = \frac{g_j}{\sum_j g_j} \) (20)

We determine the index for year \( t \) of region \( i \) as
\( H_{it} = \sum_j w_j x_{ijt}^*. \) (21)

This defines a set of data information entropy as
\[ E_j = -\ln(nT)^{-1} \sum_{i=1}^{n} p_{ijt} \ln(p_{ijt}), \] (22)

where \( p_{ijt} \) is
\[ p_{ijt} = \frac{Y_{ijt}}{\sum_{i=1}^{n} Y_{ijt}}. \] (23)
4. Simulation Experiment

4.1. Experimental Data and the Digital Economy Indicator System. This article selects the national provincial unit data from 2011 to 2021. The constructed digital economy indicator system includes first-level indicators: infrastructure, digital industry, innovation capability, and digital livelihood, and second-level indicators, as shown in Table 1.

According to the formula in Figure 6, this paper calculates the digital economy index of each province, municipality, and autonomous region. The highest ranking province and city in the digital economy index in 2021 is Beijing, which is 0.49. In Beijing, Tianjin, Hebei, and Sichuan, the digital economy index is relatively high. The digital economy indicator system constructed in this paper is relatively robust and suitable for empirical research. The coefficient of variation reached around 1 before 2013, then decreased rapidly, and then slowed down, and decreased steadily after 2019, indicating that the overall digital economy gap between regions is narrowing, and the gap before 2019 is significantly larger than after 2019. The Moran index was stable at 0.2–0.3, and passed the 5% significance test except in 2016 and 2017, as shown in Figure 7 and Table 2.

4.2. Construction of the Digital Economy and Economic Growth Model Based on the Deep Neural Network. Among them, lnY represents the total economic volume, lnL represents the labor force, lnK represents the capital stock, and lnT represents the digital economy index. This paper uses regional per capita GDP data to measure, labor is one of the main endogenous variables in the economic growth model, and the digital economy index uses the above measurement data results. According to the above-mentioned selected variables and methods for calculation, the following data results are obtained. As shown in Table 3 and Figure 8, the following are the statistical description values of the data.

From the results of the regression test values in the above table, the model fitting effect is good. Previous empirical studies have consistently shown that the digital economy index has a positive relationship with GDP, which is confirmed in this paper. At the national level, the digital economy index coefficient is 1.24, which shows that the digital economy has a good role in promoting economic growth, that is, for every 1% increase in the digital economy input, GDP will increase by about 0.24%, the labor force increased by 1%, and the GDP increased by about 0.22%. This promotion effect is also very obvious and are shown in Table 4 and Figure 9.

In the current digital economy era, innovation is the main driving force for development, and talents are the main body of innovation. Among them, including Beijing, Guangdong, and other regions are regions with relatively good digital economy development. The digital economy foundation, digital economy development resources, and digital economy innovation in this region are with the best ability in the country. From the point of view of the digital economy index coefficient, the digital economy grows by 1%, the GDP increases by about 0.30%, the labor input increases by 1%, the regional economy increases by about 0.24%, the capital investment increases by 1%, and the GDP increases

| First-level indicator | Secondary indicators                                      | Weights |
|-----------------------|----------------------------------------------------------|---------|
| Infrastructure        | Mobile telephone exchange capacity per capita            | 0.0501  |
|                       | Length of long-distance optical cable per square kilometer| 0.0507  |
|                       | Telecommunication traffic per capita                     | 0.0701  |
|                       | Computer main business income as a percentage of GDP     | 0.1735  |
|                       | Software main business income as a percentage of GDP     | 0.1702  |
|                       | The proportion of electronic information product exports in total exports | 0.1036 |
| Digital industry      | Number of domestic patent authorizations per 10,000 people | 0.1743 |
|                       | Internal expenditure of R&D funds as a percentage of GDP | 0.0641 |
|                       | Education spending as a share of GDP                     | 0.0456 |
| Creativity            | Internet penetration                                     | 0.0533  |
|                       | The household rate of cable broadcasting and TV          | 0.0336  |

Figure 6: Weight of each indicator.
by about 0.16%. From the perspective of the provinces in the central region represented by Shanxi and Hunan, the basic digital economy has developed well, and the fiber optic laying range basically covers the whole province. The electronic information industry and the software service industry play a significant role in the economic contribution of this region. The digital economy index coefficient of the western region is 1.35, indicating that the digital economy
Investment increases by 1%, and the GDP increases by about 0.35%. The labor coefficient is 1.39, indicating that labor input increases by 1%, GDP increases by about 0.39%, and the capital coefficient is 1.14, indicating that capital investment increases by 1%, GDP increases by about 0.14%. Judging from the above data, and the construction of digital talents and the introduction of digital talents are a solid foundation for further sustainable innovation and development in various regions. Table 5 and Figure 10 shows the F test value and the Hausman test value.
4.4. Robustness Check. In order to ensure the reliability of the research conclusions, this paper does a robustness test on the national, eastern, central, and western data, and removes the explanatory variables one by one. The reason is that when calculating the digital economy index in this paper, these variables may be superimposed with labor and capital stock data. Sex test: Judging from the three models of the national, eastern, central, and western models, the parameter coefficients and signs have not changed significantly, so the original model is robust, and so the conclusion is desirable, as shown in Figure 11.

5. Conclusion

According to the calculation results of the digital economy index, it is concluded through this topic: (1) the digital economy of Guizhou, Beijing, Chongqing, Anhui, and Tibet is growing rapidly, and the central and western regions are in a period of rapid growth. For the gap between major industrial provinces, the coefficient of variation reached about 1 before 2013, and then declined rapidly, and slowed down, and steadily declined after 2019, indicating that the gap in the digital economy in various regions is narrowing in general. (2) From

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| National | East area | Central region | Western region |
|----------|-----------|----------------|----------------|
| F test value | 67.6 | 82.9 | 36.53 | 58.96 |
| Hausman test | 124.9 | 43.5 | 8.96 | 66.75 |

Figure 10: F test value and Hausman test value of each region.

Figure 11: Robustness analysis.
the national level, the digital economy index coefficient is 1.24, that is, for every 1% increase in digital economy investment, GDP will increase by about 0.24%. The labor force increased by 1% and the GDP increased by about 0.22%. This promotion effect is also very obvious. (3) Judging from the above data, the western region urgently needs to promote the construction of the digital economy and introduce high-tech digital economy talents. The talent effect in the Midwest has a significant effect on GDP. (4) From the perspective of the whole country and other regions, the parameter coefficients and signs have not changed significantly, so the original model is robust, so the conclusion is desirable.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding this work.

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