# Analysis and Research of the Temporal and Spatial Evolution of Digital Logistics Development in China Under Environmental Regulation

Zheng Yang, Fangsen Xue *

School of Marketing Management, Liaoning Technology University, Huludao, Liaoning 125105, China

yzxxfe@163.com; *632595283@qq.com

**Abstract.** Based on the provincial data of China from 2011 to 2021, this paper constructs the provincial digital development level evaluation system under environmental regulation, uses the entropy right method-TOPSIS to calculate its digital development level, and finally uses the broken analysis layer to analyze its spatial and temporal evolution characteristics. The results show that: (1) the development level of digital logistics in various regions of China is on the upward trend, but it is still at a low level, and there are obvious unbalanced development problems.(2) There are spatial differences in the development of digital logistics in China, from high to low, in the east, showing the spatial distribution pattern of "high east, middle and low west"; the agglomeration of high level in the eastern coastal areas has been solidified, and the low level mainly turns to the southwest and northwest regions.

**Keywords:** digital logistics, time and space evolution, TOPSIS, kernel density estimation

## 1 INTRODUCTION

In 2023, the total carbon emissions of China's express delivery industry reached 55.65 million tons, and the environmental pressure increased year by year. Energy consumption in transportation, excessive use of packaging materials and unreasonable construction of logistics centers seriously restrict the high-quality development of the logistics industry. At the same time, the implementation of environmental regulation policies in the Environmental Protection Law, the Air Pollution Prevention and Control Law and other laws force China's economy to develop with higher quality. The improvement of carbon productivity in the logistics industry represents the "decoupling development" of the level of the logistics industry and carbon emissions, and is also an important embodiment of the implementation of the new development concept in the industry.

Environmental regulation refers to the policy formulated by the government by considering both environment and economy. With the deepening of the research, the research is mainly divided into the influence of environmental regulation on carbon


V. Vasilev et al. (eds.), *Proceedings of the 2024 5th International Conference on Management Science and Engineering Management (ICMSEM 2024)*, Advances in Economics, Business and Management Research 306,
https://doi.org/10.2991/978-94-6463-570-6_85

productivity in different dimensions, the influence mechanism and effect of environmental regulation on industrial upgrading, and the relationship between environmental regulation and green technology innovation[1].Li Sufeng and Yang Lei studied green finance and environmental regulation found that environmental regulation can significantly improve the high-quality economic development level of the Beijing-Tianjin-Hebei region. Mou Hongliang, Yu Kunlian and others studied the impact of environmental regulation and green innovation technology on carbon productivity in China's logistics industry, and found that environmental regulation had a double threshold effect and showed a U-shaped curve trend on the whole. At the same time, Zhou Jiewen [2]and Gao Xiang found that environmental regulations were regional heterogeneous by studying the impact of environmental regulations on China's green and low-carbon transformation and development in China[3].

The above research shows that environmental regulation has a great impact on the high-quality development of China's logistics industry, but the current research on environmental regulation mainly focuses on industrial upgrading and green technology innovation[4]. Few studies combine digital logistics with environmental regulation, and considering that logistics carbon productivity is one of the main quantitative indicators of low-carbon and green logistics, this paper is namely.

# 2 INDICATOR SYSTEM CONSTRUCTION

## 2.1 Index Selection

Digital logistics index selection for reference, for digital logistics, this paper refers to Cui Liang [5] to logistics capacity, logistics output capacity, digital development level three aspects development level of digital logistics, capacity for logistics investment in fixed assets, logistics industry employees' number two level 3 index to describe. For the logistics output capacity to freight volume, transportation, storage and postal industry added value, freight turnover, express volume Four three-level indicators to describe it. The measure of the digital development level is the Internet penetration rate, the mobile phone penetration rate, Optical cable line length, e-commerce sales, e-commerce procurement amount of five three-level indicators to describe (Table 2).

Environmental regulation indicates the intensity of a region's investment in its environmental governance. In this paper, scholars Cui Lizhi and other authors use the proportion of the GDP total amount of environmental pollution control investment consists of the actual amount of industrial pollution source treatment investment, the investment of industrial pollution source treatment and the investment of the environmental protection acceptance project in the same year.

The measure of carbon productivity in logistics industry, the carbon productivity of logistics industry is an "index of carbon productivity of undesired output", and the measurement of its $CO_2$ emissions is the key to calculate its carbon productivity. [6] There are no direct official data on $CO_2$ emissions. Carbon emissions can be measured by using the parameters provided by the China Energy Statistical Yearbook and the IPCC National Greenhouse Gas Inventory Guidelines prepared by the IPCC Panel on Climate Change (IPCC). The total carbon emissions of the logistics industry can be obtained from the $CO_2$ emissions generated by the logistics industry consuming various energy sources. The calculation formula is as follows:

$$\sum CO_{2,i} = \sum E_i \times NCV_i \times CEF_i \times COF_i \times 44/12 \tag{1}$$

$$LCP_{it} = x_{it}/\sum CO_2 \tag{2}$$

Among them, i is the final energy consumption type (fossil fuel). This paper selects eight energy sources of raw coal, gasoline, kerosene, diesel, fuel oil, liquefied oil, natural gas and electricity in the final energy consumption of China Energy Statistical Yearbook as the main sources of energy consumption in the logistics industry. $E_i$ Represents the consumption of the first I fossil fuel; $NCV_i$ means that the low calorific value of the first I fossil fuel $CEF_i$is the carbon content of the first I fossil fuel; $COF_i$is the oxidation rate of the first I fossil fuel; 44 and 12 represent the molecular weight of carbon dioxide and carbon respectively; Carbon productivity is closely related to regional environmental cost, with the ratio of regional GDP to total carbon dioxide emissions; $LCP_{it}$ is the logistics carbon productivity in $t$ in $i$ province, $x_{it}$ is the total logistics volume in $i$ province; according to IPCC carbon emission calculation guide, the calculation formula is as follows(Table 1):

**Table 1.** Carbon emission index and coefficient

| Energy name | raw coal | gasoline | kerosene | diesel oil | fuel oil | LPG | gas | power |
|---|---|---|---|---|---|---|---|---|
| CE/t | 0.7143 | 1.4714 | 1.4714 | 1.4571 | 1.4286 | 1.7143 | 1.215 | 0.404 |
| CEF | 1.9003 | 2.9251 | 3.0179 | 3.0959 | 3.1705 | 3.1013 | 2.1622 | - |

The energy consumption is derived from China Energy Statistical Yearbook, and the discount standard coal coefficient and carbon emission coefficient refer to the 2006 IPCC National Greenhouse Gas List Guide Catalogue, General Rules for Comprehensive Energy Consumption Calculation and Guidelines for provincial Greenhouse Gas List Compilation.

## 2.2 Indicator System Construction

**Table 2.** Evaluation index system of digital logistics development level

| Level 1 indicators | Secondary indicators | Three-level index (unit) | Indicator type | weight |
|---|---|---|---|---|
| Digital logistics | Logistics input capacity | Logistics industry fixed assets investment (100 million yuan) | + | 0.0522894 |
| | | Number of employees in the logistics industry (ten thousand people) | + | 0.0576448 |
| | Logistics output capacity | Freight volume (RMB 100 million) | + | 0.047501 |
| | | Value-added value of transportation, storage and postal services (billion yuan) | + | 0.0514243 |
| | | Freight turnover (ten thousand tons) | + | 0.0815555 |

| | | | | |
|---|---|---|---|---|
| | | Express delivery volume (ten thousand pieces) | + | 0.2167631 |
| | | The Internet penetration rate is (%) | + | 0.0196935 |
| | | Mobile phone penetration rate (department / 100 people) | + | 0.0231293 |
| | Digital development level | Optical cable line length (km) | + | 0.0577215 |
| | | E-commerce sales volume (RMB 100 million yuan) | + | 0.1275455 |
| | | E-commerce purchase amount (100 million yuan) | + | 0.1343141 |
| Environmental regulation | Environmental regulation intensity | Completed investment in industrial pollution control per 1,000 yuan of industrial added value | + | 0.086381 |
| Carbon productivity | Logistics industry carbon productivity | Ratio of regional GDP to total CO2 emissions | - | 0.044037 |

Based on previous studies, this paper selected 30 provinces, autonomous regions and municipalities directly under the Central Government (except Hong Kong, Macao, Taiwan and Tibet) based on data availability. The data are from China Statistical Yearbook 2011-20121 China Statistical Yearbook, China Energy Statistical Yearbook and provincial statistical yearbooks.

# 3 SELECTION OF RESEARCH METHODS

## 3.1 Entropy Weight-Topsis Method

Entropy weight method is an objective evaluation method of empowerment according to the information quantity of index data, which can avoid the defects of subjective empowerment method. TOPSIS According to the comprehensive distance between the measurement object and the optimal solution and the worst solution, it obtains the relative quality of the evaluation target. Combining the two, we can make the measurement results more reasonable. The calculation steps are performed as follows:

（1）Index standardization

Forward pointer:

$$Z_{aij} = \frac{x_{aij} - x_{min}}{x_{max} - x_{min}} \tag{3}$$

Negative indicators:

$$Z_{aij} = \frac{x_{max} - x_{aij}}{x_{max} - x_{min}} \tag{4}$$

Where $x_{max}$ and $x_{min}$ represent the maximum and minimum values of the item j index, respectively, $x_{aij}$ and $Z_{aij}$ represent the values before and after normalization of the index, respectively.

（2）Indicators were normalized：

$$P_{aij} = \frac{Z_{aij}}{\sum_{a=1}^{m} \sum_{i=1}^{k} Z_{aij}} \tag{5}$$

Where, m represents the year，k represents the province (autonomous region, municipality directly under the Central Government), $Z_{aij}$ is the normalized value, $\sum_{a=1}^{m}\sum_{i=1}^{k} Z_{aij}$is the sum of the observed data of all provinces (autonomous region, municipality) and year directly under the Central Government in item j, and $P_{aij}$ is the normalized value of the index.

(3) Calculate the information entropy of the *j* indicator (Where: k is the sample size):

$$E_j = -K_1 \sum_{a=1}^{m}\sum_{i=1}^{k} P_{aij} \ln P_{ij} \tag{6}$$

$$K_1 = \frac{1}{ln(m \times k)} \tag{7}$$

(4) Difference coefficient and calculation weight of each index：

$$D_j = 1 - E_j \tag{8}$$

### 3.2 Moran Index

Global spatial autocorrelation. Global spatial autocorrelation is used to reflect the spatial agglomeration characteristics of all objects in the study area, measured using the global Moran Index I, with the following formula:

$$\mathrm{I} = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x}) / S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \tag{9}$$

### 3.3 Nuclear Density Estimation Method

The kernel density estimation method can analyze the dynamic characteristics of China's digital logistics in China more intuitively and vividly by comparing the kernel density estimation curves of different time nodes. The calculation formula is provided as follows:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{X_i - x}{h}\right) \quad 10)$$

$$\mathrm{K(x)} = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \tag{11}$$

## 4 ANALYSIS OF THE SPATIAL AND TEMPORAL EVOLUTION OF PROVINCIAL DIGITAL LOGISTICS

### 4.1 Spatial Distribution Pattern

The natural breakpoint method of ArcGIS was used to analyze the spatial distribution characteristics of digital logistics development level in 30 Chinese provinces, autonomous regions and municipalities (except Hong Kong, Macao, Taiwan and Tibet). The representative years are 2011,2013,2015,2017,2019 and 2021, which are specifically divided into five categories: low and low level, medium level, medium level, medium and high level and high level.

As can be seen from Figure 1, from 2011 to 2021, low level areas and medium and low-level areas kept decreasing, while medium and high-level areas increased significantly. The proportion of high-level areas and medium and high-level areas increased from 33% in 2011 to 66% in 2021, which indicates that the logistics industry in the Yellow River Basin has developed greatly in the past ten years. From the perspective of spatial evolution pattern, the logistics development level of the Yellow River Basin in 2011 generally showed a distribution pattern of low in the north and high in the south, and in 2021, it showed a distribution pattern of low in the west and high in the east.

On the whole, the development of provincial digital logistics in China is significantly unbalanced. The eastern region represented by Jiangsu and Zhejiang benefits from its superior geographical position, strong mobility of market, science and technology and other factors, relatively perfect logistics service system, and a leading position in the digital development. Mongolia, Qinghai region may be due to the geographical environment, serious brain drains, the most backward. Chengdu, Chongqing development is more obvious.

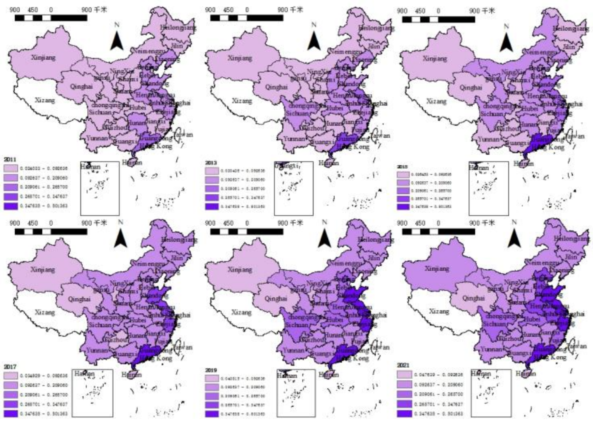


**Fig. 1.** Spatial distribution pattern diagram of provincial digital logistics level

## 4.2 Spatial Association Characteristics

The global Moran index I is calculated according to the comprehensive evaluation score of the provincial digital logistics development level in China from 2011 to 2021, and the results are shown in Table 3. As can be seen from Table 3, all Z values were greater than 2 during the study period, indicating that this test is valid and credible. P values did not exceed 0. 05, indicating that the data all passed the significance level test of 1%. The global Moran index I is all positive, indicating that there is a positive spatial correlation between the logistics development level of each province and region, but the agglomeration effect is constantly weakening over time.

**Table 3.** Global Moran index statistics

| time | 2011 | 2013 | 2015 | 2017 | 2019 | 2021 |
|---|---|---|---|---|---|---|
| Moran’s I | 0.107 | 0.074 | 0.070 | 0.042 | 0.047 | 0.057 |
| Z | 3.600 | 2.480 | 2.743 | 2.065 | 2.239 | 2.495 |
| P | 0.000 | 0.002 | 0.003 | 0.019 | 0.013 | 0.006 |

In order to explore the spatial correlation of logistics development level between provinces and neighboring provinces, the data from 2011 and 2021 were selected to divide the spatial agglomeration mode of provincial digital logistics development level in China into four quadrants (Table 4). On the whole, the phenomenon of high value agglomeration and low value agglomeration is relatively stable, the number of high-high and low-low agglomeration areas is relatively large, and the number of low-high and high-low agglomeration areas is relatively small, indicating that the development level of provincial digital logistics is dominated by similar agglomeration. In specific, coastal provinces always fall in the first quadrant, coastal areas rapid eco

nomic development, superior geographical location, the developed traffic and large population, for the development of logistics development provides a good environmental support, become the core area of China's digital logistics development, and the diffusion effect of inland areas, presents a high value agglomeration on the spatial distribution. Hainan, Tianjin, Jiangxi, Fujian and Hunan, showing significant spatial heterogeneity. Always fall into the third quadrant of provinces in Qinghai, Guizhou, Xinjiang, Chongqing, Ningxia, shanxi, Yunnan, Gansu, Sichuan, Guangxi, Heilongjiang, due to the market factors, economic conditions and factors such as infrastructure construction, the provinces and neighboring provinces of logistics development level at a low level, presents the low value agglomeration on spatial distribution. Guangdong province has been falling into the fourth quadrant, indicating that its logistics development level is high but its neighboring areas are low, so it should give full play to its own advantages to drive the development of neighboring provinces. It is worth noting that in 2021, Inner Mongolia Autonomous Region moved from the second quadrant to the third quadrant, indicating that its logistics development level has decreased; Sichuan Province moved from the third quadrant to the province and neighboring provinces, and the logistics industry is accelerating development.

**Table 4.** Digital logistics development level of spatial correlation change

| Cluster mode | 2011 | 2021 |
|---|---|---|
| HH | Anhui, Beijing, Henan, Hebei, Shanghai, Zhejiang, Shandong, Jiangsu | Anhui, Hubei, Henan, Hebei, Shanghai, Zhejiang, Shandong, Jiangsu |
| LH | Hainan, Jilin, Inner Mongolia, Tianjin, Jiangxi, Fujian, Shanxi, Hubei, Hunan | Hainan, Tianjin, Jiangxi, Fujian, Hunan |
| LL | Qinghai, Guizhou, Xinjiang, Chongqing, Ningxia, Shaanxi, Yunnan, Gansu, Sichuan, Guangxi, Heilongjiang | Qinghai, Guizhou, Xinjiang, Chongqing, Ningxia, Shanxi, Yunnan, Gansu, Guangxi, Heilongjiang, Inner Mongolia, Jilin, Shanxi |
| HL | Liaoning, Guangdong | Sichuan, Beijing, Guangdong |

### 4.3 Time Sequence Evolution Analysis

On the basis of the overall analysis of the development level of digital logistics in China, in order to further study the sequential evolution trend at any time, this paper draws the nuclear density estimation curve diagram of the logistics development level with the help of MATLAB software( Figure 2).Firstly, from the perspective of the position of the nuclear density estimation curve, the overall shift of the center from 2011 to 2021 to the right, indicating that the development of digital logistics is moving from low level to high level, but the right shift is small, indicating that the development speed is slow and needs to be further improved; secondly, from the perspective of the peak height of the nuclear density estimation curve, the continuous decline during the ten years and the change from "towering" to "flat type", indicating that the gap between the development level of China's logistics is expanding. Finally, from the perspective of the number of nuclear density estimation curve, 2011 curve the main peak on the right side and a smaller peak, jointly form "twin" characteristics, the provinces of logistics development level in a certain degree of polarization, in the subsequent years, "twin" gradually to "unimodal", the polarization phenomenon gradually disappear.

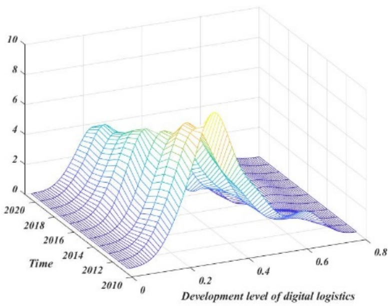


**Fig. 2.** Nuclear density estimation curve of the development level of digital logistics in China

## 5 CONCLUSIONS

Based on the carbon productivity of logistics industry, this paper proposes an index system of provincial digital logistics development level from three aspects of environmental regulation, digital logistics input and digital logistics output. The entropy right TOPSIS method was used to measure the development level of digital logistics in 30 provinces, autonomous regions and municipalities (except Hong Kong, Macao, Taiwan and Tibet) from 2011 to 2021, and the spatial distribution characteristics of provincial digital logistics development in China were analyzed through the Moran index and natural breakpoint method, and the following conclusions were drawn.

The overall development level of digital logistics development in China is on the rise, but the development between regions is extremely unbalanced. From the perspective of growth rate, a pattern of "eastern coastal areas lead the way, Sichuan and Chongqing areas have obvious development, and other regions catch up" has been formed.

Second, the results of spatial characteristics analysis show that the development of digital logistics in China has a tendency of global spatial correlation and local spatial agglomeration, mainly dominated by "low-high" agglomeration and "low-low" agglomeration, and excellent resources in space flow from low to high. The natural breakpoint method reveals the uneven spatial distribution of digital logistics development in China: the overall development of digital logistics presents a spatial distribution pattern of "high in the east, low in the west, and gradually deepening from coastal areas to inland areas".

(1) With the help of the strict environmental regulation system, accelerate the transformation of the new driving force of regional economic development, integrate the "double-carbon" goal and green development concept throughout the development of enterprises, encourage enterprises to accelerate the transformation of green and low-carbon industries, [7]and vigorously develop green and low-carbon industries. Build a new development system of logistics industry, improve the utilization rate of input resources, and realize the optimal allocation of resources. According to the resource factor endowment and location advantages, the region combines with the local advantageous industries to build a professional logistics agglomeration area. At the same time, improve the awareness of low carbon, use clean energy, so that the limited resources get full use, to achieve green transformation, the logistics industry from extensive to intensive development.

(2) According to the spatial difference of the distribution of resources, resources should be rationally distributed, and relevant policies should be issued to achieve the integrated development of logistics industry among regions. Government encourage efficient region drive inefficient areas, make inefficient areas get policy tilt, preferential policies in taxation, finance coastal carbon footprint, complete energy conservation and emissions reduction, inland build perfect ecological compensation mechanism, should strengthen cooperation between provinces, according to the geographical differences between establish regional responsibility sharing mechanism, adjust measures to local conditions to set up carbon emission reduction target and strategy, promote the logistics industry to cluster industry development.

## REFERENCES


1. Zeng Q, Zhang J. Space and temporal evolution and influencing factors analysis of logistics development level in the Yellow River Basin[J]. Journal of Henan Polytechnic University (Social Science Edition),2024,25(01):14-23. DOI:10.16698/j.hpu(social.sciences).1673-9779.2024.01.003.
2. Zhou J, Gao X, Pepe. Research on the influence of environmental regulation on China's green and low-carbon transformation and development under the "double-carbon" target[J/OL]. Journal of Jiangsu University (Social Science Edition),1-13[2024-03-27]. DOI:10.13317/j.cnki.jdskxb.2024.015.
3. Ma X, Nie Y. The mechanism and effect of digital logistics enabling sustainable development —— Based on the perspective of logistics carbon productivity[J/OL]. China’s circulation economy,1-12[2024-03-27]. http://202.199.233.17:8000/rwt/CNKI/http/NNYHGLUDN3WXTLUPMW4A/kcms/detail/11.3664.F.20240307.0742.002.html.

4. Li J, Liu L. Study on the space-time evolution of total factor energy efficiency in logistics industry[J]. Environmental science and technology,2019,42(11):222-231.
5. Li X, Cui L. Digital logistics, the coupling and influencing factors of regional economy and carbon environmental governance[J]. China's circulation economy，2022（2）：11-22.DOI: 10.13546/j.cnki.tjyjc.2023.01.005.
6. BUGARCIC F ,SKVAＲCIANY V,STANISIC N． Logistics performance index in international trade: case of central and eastern european and western balkans countries [J]. Verslas: teorija ir praktika, 2020 ， 21(2) : 452-459．https://doi.org/10.3846/btp.2020.12802
7. ZOU X，SOMENAHALLI S，SCＲAFTON D． Evaluation and analysis of urban logistics competitiveness and spatial evolution [J]． International journal of logistic 2020，23 (5) : 493-507．https://doi.org/10.1080/13675567.2019.1703916