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Original Research

The Influence and the Function of the Digitalization of Logistics on Carbon Emission in China

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Abstract

Digitization and greening, as two critical themes in the development of today's world, are also the main driving forces for high-quality and sustainable economic development. Based on the panel data of 30 provinces in China (except Tibet and Hong Kong, Macao, and Taiwan) from 2011-2019, this paper firstly measures the level of digital development of China's logistics industry by establishing a coupled and coordinated development model of China's logistics industry and digital industry, using two-way fixed effects model empirically China's logistics industry digital level on its carbon intensity, The mediating effect of logistics industry transformation and upgrading level on the impact of logistics digitalization level on its carbon emission intensity is further tested. The results show that: (1) the digitalization level of China's logistics industry shows an obvious "high in the east and low in the west"; (2) the influence of the digitalization level of the logistics industry on its carbon emission intensity is non-linear, with a significant inverse shape; (3) the transformation and upgrading level of the logistics industry has a positive mediating effect in the influence of the digitalization level of the logistics industry on its carbon emission intensity. The intermediary effect of positive regulation, in which the intermediary utility accounts for 66.7% of the total utility.

Keywords: digital economics, industry amalgamation, carbon emission, logistics

Introduction

Global climate change poses a severe challenge to human survival and development, the Party Central Committee, with Comrade Xi Jinping at its core, has made a major strategic decision to achieve a carbon peak in 2030 and carbon neutrality in 2060. As a complex service industry spanning transportation, warehousing, packaging, machinery and equipment, and information technology and covering multiple industries such as commerce, express delivery, and manufacturing, the logistics industry is responsible for developing the national economy and for leading the green low-carbon transformation. According to estimates, in 2019, China's logistics industry energy consumption and carbon emissions reached 440 million tons of standard coal and 860 million tons of carbon dioxide, accounting for 9.0% and 8.8% of the national energy consumption and carbon emissions, respectively. It is a critical area of carbon emission reduction. In the post-epidemic era, "digitization" and "greening" are essential tools for global economic recovery. The "double carbon" target cannot be achieved without the support of the digital

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economy. The “White Paper on China’s Digital Economy Development (2020)” released by the China Academy of Information and Communication Technology shows that the scale of China’s digital economy will reach 3.92 billion yuan in 2020, accounting for about 38.6% of GDP. Among them, the scale of industrial digitization reaches 31.7 trillion yuan, accounting for 31.25% of GDP. The digital economy is based on data elements, the use of data circulation can accelerate the digital transformation of primary, secondary, and tertiary industries, which is of great significance to promoting the adjustment and optimization of industrial and energy structures and is conducive to the formation of the “trinity” of production, circulation, and consumption of the sharing economy ecosystem, expanding the new space of the digital economy, and improving the efficiency of energy conservation and emission reduction. Digital economy penetration into the logistics industry can accelerate the process of freight organization intensification, represented by freight platforms, through the scale of resource aggregation. Intelligent algorithm-based transportation scheduling can effectively mobilize a large number of cross-regional vehicle and cargo resources, significantly reduce the vehicle idling rate, and powerfully reduce the vehicle’s ineffective and inefficient driving, with fewer emissions, providing more and better quality services.

In this context, to explore the digitalization level of the logistics industry, as well as to explore the carbon emission reduction path of digital logistics and improve the quality of low-carbon development of the logistics industry, this paper takes the digitalization and carbon emission of the logistics industry as the research object uses the panel data of 30 regions in China (except Tibet and Hong Kong, Macao and Taiwan) from 2010-2019, measures the digitalization level of logistics industry from the perspective of industrial integration, and uses the fixed-effect model and intermediation model to explore the mechanism of the effect of digitalization of logistics industry on carbon emission intensity. To provide new ideas for realizing the low-carbon development of the regional logistics industry.

Literature Review

The theory of the digital economy was first proposed by Don Tapscott and later promoted by the US Department of Commerce. The digital economy refers to the use of digitized knowledge and information as key factors of production, the modern information network as an important carrier, and the effective use of information and communication technology as an important driving force to improve efficiency and optimize the economic structure. The current academic research on the digital economy mainly focuses on the accounting of the digital economy and its economic effects. The digital economy measurement mainly includes the following five main methods: national economic accounting method [2-4], value-added measurement method [5-7], relevant index compilation method [8], and satellite account construction [9]. In terms of the effect of the digital economy, Frederico Cruz-Jesus (2017) analyzed the relationship between the digital economy and economic development in 110 countries and found that there is a non-linear correlation between the real economy and digital economy development, which is more obvious in poor countries [10]. Shahadat Hosan (2021) studied the relationship between digitalization and sustainable economic growth in 30 emerging countries, and the results showed that digitalization stimulated sustainable economic growth [11]. Han Lu et al. found that digital economy development has a positive driving effect on regional innovation by using panel data of prefecture-level cities in China, and the innovation environment (talent concentration and financial development) has a positive moderating effect [12]. Zhang Yan (2021) used Chinese provincial panel data to study and found that the digital economy has a spatial spillover effect, and its influence on technological efficiency is greater than that of technological progress [13]. He Weida (2022) tested the influence of the digital economy on green ecological efficiency in various regions of China based on the bidirectional fixed effect model, and the results showed that the digital economy was positively promoting green ecological efficiency [14]. Liu Weili (2022) found carbon emissions promoted by information and communication technology through research on countries along the belt and Road [15]. Yunfei Xie (2022) used inter-provincial panel data to empirically test and found that the digital economy significantly reduced the intensity of regional carbon emissions, and further tested the mechanism of the role of energy structure and technological progress in it [16]. Lujun Miao et al. (2022) found that the nonlinear impact of digital economy development on carbon emissions has spatial effects and acts on carbon emissions through innovation efficiency based on panel data of 278 prefecture-level cities in China empirically [17]. Yu Shan (2022) evaluated the level of regional digital economy development by constructing an index system and examined the impact of digital economy on carbon productivity using a stationary model, and found that digital economy development helps to improve carbon productivity and acts on carbon productivity through two transmission paths of regional technological innovation and optimization of industrial structure [18].

The research on carbon emission in the logistics industry can be divided into three aspects: calculation of carbon emission, driving factors of carbon emission, and how to achieve carbon emission reduction. There are mainly “top-down” and “bottom-up” methods for the calculation of carbon emissions. Sanjuan-Delmas (2015) used the “top-down” method to calculate the carbon emissions of Spain’s water transportation industry based on the carbon emission coefficient proposed by IPCC [19]. Selvakkumaran S (2015) estimated the carbon emissions of Thailand’s transportation sector through the “bottom-up” method. The main driving factors of carbon emission in the logistics industry include technological innovation, transportation structure, and industrial agglomeration [20]. Huang et al. (2018) proved that technological innovation can improve carbon emission efficiency and reduce carbon emission levels [21]. Some scholars also believe that technological innovation can expand the industrial scale and increase carbon emissions [22]. Transportation structure, as the main source of carbon emissions in the logistics industry, can be adjusted to achieve carbon emission reduction [23]. Ehrenfeld J. (2010) showed that industrial agglomeration would inhibit the growth of industrial carbon emissions [24], Wang Jian and Lin Shuangjiao (2021), based on the input-output table, tested the mechanism of logistics agglomeration on carbon transfer, and verified the mediating role of information operation and traffic pressure [25]. Most studies on carbon emission reduction strategies use system dynamics to conduct scenario simulations and build different research frameworks for carbon emissions [26].

There are many studies on the digital economy and carbon emissions in the academic circle. However, there is a lack of studies on how the digital economy can empower other industries and thus affect industrial carbon emission intensity. Therefore, this paper measures the digitalization level of the logistics industry from the perspective of industrial integration empirically studies the impact of the digitalization level of the logistics industry on its carbon emission intensity, and further explores the intermediary effect of transformation and upgrading of the logistics industry.

Measurement of Digital Development Level of Logistics Industry in China

Research Methods

The coupling coordination degree model is mainly used to analyze the level of coordinated development between things. The coupling degree is mainly used to measure the interaction between two or more systems, while the coordination degree mainly reflects the benign coupling degree in the coupling interaction relationship, which can reflect the good or bad coordination status. The coupling coordination degree model involves the calculation of three index values, namely, coupling degree C value, coordination index T value, and coupling coordination degree D value. Finally, the coupling coordination degree D value and coordination grade classification standard are combined to obtain the coupling coordination degree of each item. The formula is:

$$C = \sqrt{\frac{U_1 U_2}{\left(\frac{U_1 + U_2}{2}\right)^2}} = \frac{2\sqrt{U_1 U_2}}{U_1 + U_2} \tag{1}$$

$$T = \alpha_1 U_1 + \alpha_2 U_2 \tag{2}$$

$$D = \sqrt{C * T} \tag{3}$$

Evaluation Index System Design

Based on reading extensive literature, this paper combines the characteristics of the logistics industry and digital industry and constructs a comprehensive evaluation model of the digital development level of China's logistics industry from three aspects of infrastructure, output scale, and development potential. In the weight treatment, the NBI index is used to weigh each index. After determining the weight, the linear weighting method is used to calculate the comprehensive index of the logistics industry and digital industry. Finally, the coupling level of the two systems is calculated by using the coupling coordination degree model. The original data of all indicators came from China Statistical Yearbook, China Electronic Information Yearbook, China Information Yearbook, China Environmental Yearbook, and China Tertiary Industry Yearbook (2011-2019), and all data were dimensionless processed according to the range method.

The digitalization level of China's logistics industry shows the apparent characteristic of „high in the east and low in the west," as can be seen from Table 2, the top 5 provinces in the digitalization level of the logistics industry are from the eastern coastal region, among which Jiangsu and Guangdong's digitalization level of the logistics industry has reached the high-quality coordination level, while those at the bottom are from the western region, and belong to the severe disorder level. The imbalance in the digital development of the logistics industry mainly stems from the differences in resource endowment, location advantage, and industrial structure. Since the reform and opening up, the eastern region has been supported by national policies to build an economic circle, which has provided the economic foundation for the explosive growth of the digital economy. With the implementation of „Broadband China" and other series of work, the development level of China's information infrastructure has been rapidly improved. The length of fiber optic cable lines, Internet broadband access ports, cell phone base stations, and IPV6 addresses have been continuously increased. The digital infrastructure has been improved, and the supply capacity has been significantly enhanced. Secondly, digital talents are an important factor affecting the digital transformation process of China's logistics industry. In terms of talent distribution, Beijing, Tianjin, Yangtze River Delta, and Pearl River Delta are essential concentrations of digital talents; about 50% of digital talents are distributed in ICT primary industries such as the Internet, information, and communication, and traditional industries are mainly distributed in three major industries: manufacturing, finance, and consumer goods. 85% of digital talents

Table 1. Industrial evaluation index system.

Number	Evaluation index	Logistics industry	Digital industry
1	Infrastructure	Mileage line length	Cable density
2		The total length of the main route	Internet broadband access port density
3		Number of postal outlets	Mobile phone exchange capacity
4		Number of civilian trucks	Persons employed in urban units in information transmission, software, and information technology services
5		Length of the rural delivery line	Number of websites per 100 companies
6	The output size	Freight	Telecom traffic per capita
7		Post and telecommunications traffic	Software revenue scale
8		Express volume	E-commerce sales
9		The output value of the logistics industry	The proportion of e-commerce transaction activity
10	Development potential	Investment in fixed assets	Investment in fixed assets
11		Companies	Mobile phone penetration
12		Number of Internet users	Companies
13		Number of patent applications in the logistics industry	Number of patent applications for the electronic information industry

are distributed in the product development category. Less than 5% of talents in functions such as in-depth analysis, advanced manufacturing, and digital marketing are added together. The structural problem of digital talents is outstanding. Moreover, economically developed regions continue to absorb talents through talent introduction policy so that talents are further concentrated, expanding the difference in the digital level of the regional logistics industry; Finally, the regional industrial structure differences in the logistics industry digital level differences, the eastern region has gradually formed an advanced industrial structure mainly innovative industries, while the central and western regions are through the acceptance of foreign direct investment and the transfer of industries in the eastern region, still concentrated on the development of low-end manufacturing, and thus the lack of logistics demand, limiting the dynamics of the digital transformation of logistics enterprises.

Research Design

Model Design

To verify the impact of the digitalization level of the logistics industry on its carbon emission intensity, the following benchmark panel data model was constructed.

$$\ln CI_{it} = \alpha_0 + \alpha_1 DIG_{it} + \alpha_2 DIG_{it}^2 + \alpha_3 X_{it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{4}$$

In the formula, $\ln CI_{it}$ is the annual carbon emission intensity of the logistics industry in different regions, DIG is the digitalization level of the logistics industry, and DIG^2 is the quadratic term of the digitalization level of the logistics industry to capture the non-linear relationship between the digitalization level of the logistics industry and the carbon emission intensity. X is a group of related control variables, λ_{it} represents the time effect that does not change with individuals, μ_i represents the individual effect that does not vary over time, ε_{it} and refers to the random disturbance term.

To further verify the mechanism of the digitalization development of the logistics industry on its carbon emission intensity, this paper, referring to the method of Wen Zhonglin [27] et al., verifies that the digitalization level of the logistics industry affects the carbon emission intensity of logistics industry by promoting the transformation and upgrading of the logistics industry.

$$\ln CI_{it} = \alpha_0 + \alpha_1 DIG_{it} + \alpha_2 DIG_{it}^2 + \alpha_3 X_{it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{5}$$

$$\ln LI = \eta_0 + \eta_1 DIG_{it} + \eta_2 DIG_{it}^2 + \eta_3 X_{it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{6}$$

$$\ln CI_{it} = \beta_0 + \beta_1 DIG_{it} + \beta_2 DIG_{it}^2 + \beta_3 LI + \beta_4 X_{it} + \lambda_t + \mu_i + \varepsilon_{it} \tag{7}$$

The formula $\ln LI$ represents the transformation and upgrading level of the logistics industry. Other indicators have the same meanings as the preceding indicators.

Table 2. China Logistics Digital Development Level Index 2011-2019.

Province	2011	2013	2015	2017	2019	Mean	Rank
Guangdong	0.995	0.995	0.995	0.995	0.995	0.995	1
Jiangsu	0.862	0.874	0.863	0.828	0.803	0.846	2
Zhejiang	0.78	0.741	0.781	0.781	0.765	0.7696	3
Shandong	0.726	0.695	0.728	0.751	0.748	0.7296	4
Beijing	0.728	0.707	0.682	0.629	0.617	0.6726	5
Shanghai	0.708	0.641	0.653	0.618	0.582	0.6404	6
Sichuan	0.619	0.599	0.625	0.634	0.666	0.6286	7
Anhui	0.536	0.585	0.569	0.578	0.567	0.567	8
Hebei	0.555	0.564	0.516	0.578	0.603	0.5632	9
Fujian	0.583	0.553	0.559	0.555	0.534	0.5568	10
Henan	0.519	0.538	0.54	0.58	0.596	0.5546	11
Hubei	0.534	0.522	0.554	0.566	0.572	0.5496	12
Hunan	0.523	0.481	0.491	0.526	0.543	0.5128	13
Liaoning	0.556	0.542	0.538	0.455	0.417	0.5016	14
Shanxi	0.47	0.455	0.455	0.48	0.466	0.4652	15
Yunnan	0.399	0.396	0.416	0.453	0.476	0.428	16
Chongqing	0.404	0.403	0.411	0.427	0.434	0.4158	17
Jiangxi	0.385	0.398	0.387	0.403	0.419	0.3984	18
Guangxi	0.439	0.426	0.236	0.388	0.423	0.3824	19
Tianjin	0.43	0.403	0.389	0.352	0.321	0.379	20
Neimenggu	0.4	0.383	0.294	0.38	0.344	0.3602	21
Heilongjiang	0.347	0.328	0.306	0.354	0.306	0.3282	22
Shanxi	0.36	0.348	0.306	0.315	0.286	0.323	23
Guizhou	0.254	0.279	0.275	0.378	0.383	0.3138	24
Jilin	0.318	0.299	0.268	0.346	0.279	0.302	25
Xinjiang	0.325	0.33	0.224	0.192	0.192	0.2526	26
Gansu	0.258	0.242	0.226	0.259	0.249	0.2468	27
Hainan	0.247	0.205	0.234	0.212	0.177	0.215	28
Ningxia	0.189	0.124	0.119	0.142	0.106	0.136	29
Qinghai	0.1	0.104	0.124	0.174	0.135	0.1274	30

Note: Due to space limitations, the paper only shows the digitalization level of the logistics industry in odd-number years.

Table 3. Classification of digitalization level of the logistics industry in different regions of China.

Level of fusion	East	Middle	West
Good coordination (0.8-1)	Jiangsu / Guangdong	_	_
Intermediate coordinate (0.6-0.8)	Beijing / Hebei / Zhejiang / Shandong	_	Sichuan
Basic coordinate (0.4-0.6)	Shanghai / Fujian /Liaoning	Anhui / Jiangxi / Henan / Huanan / Hubei	Guangxi / Chongqing / Yunnan / Shanxi
Moderate disorders (0.2-0.4)	Tianjin / Jilin / Heilongjiang	Shanxi	NeiMengu / Guizhou / Gansu
Serious imbalance (0-0.2)	Hainan	_	Qinghai / Ningxia / Xinjiang

Data Sources and Variable Selection

Explained Variable: Carbon Emission Intensity of Logistics Industry

As one of the current mainstream carbon emission accounting methods, The IPCC carbon emission accounting method has the advantages of easy data acquisition and accurate measurement results. Therefore, this paper adopts this method to calculate the carbon emissions of the logistics industry. Then the carbon emission intensity of the logistics industry is represented by the ratio of carbon emission of the logistics industry to an output value of the logistics industry. Subject to data availability, transportation, warehousing, and postal services are used to represent the logistics industry in this paper.

$$CO_2 = \sum_{i=1}^{n} E_i \times CF_{\mathrm{i}} \times CC_i \times COF_i \times \frac{44}{12} \tag{8}$$

In the formula, i represents the type of energy consumed, E_i represents the consumption of type i energy, CF_i represents the caloric value of type i energy, CC_i represents the carbon content of type i energy, and COF_i represents the oxidation factor of type i energy.

Where $CF_{\mathrm{i}} \times CC_i \times COF_i \times \frac{44}{12}$ represents the CO_2 emission coefficient of type i energy.

Explanatory Variable: Level of Digitalization of the Logistics Industry

The data calculated by the coupling coordination method above are adopted.

Intermediate variable: transformation and upgrading of the logistics industry. This paper adopts the proportion of the added value of the logistics industry to GDP to represent the transformation and upgrading level of the logistics industry.

Table 5. VIF test of variables.

Variable	VIF	1/VIF
DIG	5.95	0.1680
LW	8.45	01183
AG	2.15	0.4659
UR	3.04	0.3289
GDP	7.96	0.1257
LC	3.15	0.3289
MD	5.88	0.1702

Control variables: (1) Development level of logistics industry (LW), which is represented by the added value of logistics industry, converted to 2011 as the base period and took its natural logarithm. (2) Logistics agglomeration (AG), using the location quotient index of the logistics industry to represent the degree of logistics agglomeration. (3) Urbanization level (UR): It is measured by the ratio of the urban population at the end of the year to the regional total population. (4) Economic development level (GDP): represented by gross regional product, converted to 2011 as the base period and taking its natural logarithm. (5) Labor productivity (LC): represented by the ratio of the added value of the logistics industry to the number of employees. (6) Marketization level (MD): characterized by the Fan Gang [28] marketization index.

Data Sources and Description

Considering the data availability and consistency of statistical caliber. This paper selects panel data of 30 Chinese provinces (except Tibet, Hong Kong, Macao, and Taiwan) from 2011 to 2019 for empirical analysis. Data from "China statistical yearbook", "China's electronic information yearbook information China yearbook" the China environment yearbook

Table 4. Descriptive analysis of variables.

Variable types	Variable symbol	Mean	Std. Err	Min	Max
Explained variable	CI	1.47	0.55	0.66	4.71
Explanatory variable	DIG	0.47	0.20	0.1	0.99
Control variable	LW	6.61	0.81	4.37	8.03
	AG	1.22	0.123	0.35	0.89
	UR	0.5837	0.1230	0.3504	0.8958
	GDP	9.59	1	6.42	11.41
	LC	84.69	204.17	7.45	1540.22
	MD	6.73	1.8	2.33	11.40
Intermediate variable	IL	0.1	0.03	0.034	0.24

"Yearbook of China's third industry, related indicators in 2011 as a base for the deflator, and arranged to get through to eliminate the influence of heteroscedastic regression results, in this paper, the ratio and the logarithm processing without standardized variables. The descriptive statistical results of each variable and the multicollinearity test results are shown in Table 4 and Table 5. It can be seen from Table 5 that the maximum VIF value between variables is 8.45, less than 10, indicating that there is no multicollinearity between variables of the test model.

Empirical Results and Discussion

Regression Analysis of the Impact of Logistics Digitalization Level on Carbon Emission Intensity

Table 6 reports the results of the baseline regression of the impact of the level of digitalization of the logistics industry on carbon emissions. From the regression results (1), it can be seen that the digitalization of the logistics industry has a significant positive effect on its carbon emission intensity, but the quadratic term of the digitalization level of the logistics industry shows a significant inhibitory effect on the carbon emission intensity of the logistics industry; from the regression results (2). After adding control variables again, the effect of the digitalization level of the logistics industry on carbon emission intensity is still significant. This is because China's e-commerce is in a period of rapid development since 2011, and the demand for logistics is growing rapidly, the "quality effect" brought by the digitalization level at this time is not enough to offset the "expansion effect". The high input and cost caused by the digitization of the logistics industry have increased the level of carbon emission in the process, and while forcing enterprises to carry out research and development of green technology, it has further formed the superimposed influence of energy consumption input, thus making the carbon emission intensity of the logistics industry increasing. With the growth of the digitalization level of the logistics industry, digital technology and equipment penetrate all aspects of logistics activities, which improves the energy utilization effect of the logistics industry, and the capital, human, and technology investment consumed in the early stage gradually starts to produce a positive net effect, and the "quality effect" of digitalization level of the logistics industry is greater than At this time, the "quality effect" of the digitalization level of the logistics industry is greater than the "expansion effect", so the carbon emission intensity of logistics industry is suppressed. In addition, because of the differences in the level of economic development,

Table 6. Impact of digitalization level of logistics industry on carbon emission intensity.

	lnCI			
	(1)	(2)	(3)	(4)
Dig	6.6248*** (3.48)	9.2289*** (5.37)	3.1168*** (2.45)	7.0402*** (2.43)
Dig^2	-7.1901*** (-3.4)	-9.9626*** (-4.78)	-2.6567*** (-2.54)	-6.4129 (-1.55)
lnLW		3.881*** (5.77)	-2.4147*** (-4.40)	4.7951*** (5.68)
AG		-3.2512*** (-6.1)	1.5535*** (3.86)	-4.2469*** (-6.13)
lnUR		1.1565 (1.31)	0.4096 (0.86)	7.4969*** (4.35)
lnGDP		-5.2672*** (-8.33)	1.1227*** (2.66)	-7.9196*** (-9.0)
LC		-.0.0013*** (-3.65)	-0.0032*** (-2.64)	-0.0011** (-2.90)
MD		0.0084 (0.14)	0.0814*** (-4.44)	0.0139 (0.15)
Constant	0.3397 (0.9)	29.1252*** (7.8)	3.8341* (1.82)	53.2922*** (8.63)
City fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
N	270	270	99	171

Note:" *, ** and *** "in the table respectively represent significant test statistics at the level of 10%, 5%, and 1%.
The t value is reported in brackets

resource endowment, and industrial structure among regions, this paper draws on Chen Shuangying [29] (2022) to classify economically developed regions and less developed regions according to the economic development level index of each provincial region in China, where economically developed regions mainly include eight regions: Beijing, Tianjin, Guangdong, Zhejiang, Jiangsu, Shandong, Shanghai, and Fujian, and the rest are less developed regions. Columns (3) and (4) show the impact of the digitalization level of the logistics industry on carbon emission intensity in developed and less developed regions, respectively. The results show that the digitalization of the logistics industry has a non-linear effect on the carbon emission intensity of both developed and less developed regions, and the promotion effect for economically developed regions in the early stage is smaller than that for less developed regions, and it has a significant carbon emission reduction effect in the later stage. The reason for this is that the eastern region has gathered a large number of innovative talents and innovative capital, and its digital infrastructure and digital industry development advantages are obvious, which can better play the role in carbon emission reduction of the digital economy. The less developed regions, on the other hand, are still in the stage of vigorously developing the digitalization of the logistics industry, which consumes various resources and generates carbon emissions in the development process, offsetting the carbon emission reduction effect brought by the digital development of the logistics industry.

Robustness Test

Replace the Explained Variable

To verify the reliability of the conclusion, the contingency phenomenon caused by variable selection should be avoided. In this paper, the total carbon emissions of the logistics industry were selected to replace the carbon emission intensity index, and the original control variables were maintained for the robustness test. The estimated results are shown in Table 7. It can be seen from the table that although there are partial differences in parameter estimates after the replacement of explained variables, the positive and negative signs between parameter estimates do not change, indicating that the above conclusions are relatively reliable.

Shortened Sample Periods

Since the digital economy enters a booming period from 2015, this paper adjusts the sample period to 2015-2019 to examine the impact of the digital development of China's logistics industry on carbon emission intensity. From the second column of Table 7, it can be seen that the promotion effect of the digitalization level of the logistics industry on carbon emission intensity from 2015 onward is significantly reduced, which is because the promotion effect on the intensity of carbon emission of the logistics industry has decreased as the penetration degree of the digital economy to logistics industry deepens, optimizing the logistics industry process and significantly improving the operational efficiency of each link.

Endogeneity Test

To circumvent the endogeneity problem that there is a two-way causality between the digitalization level of the logistics industry and carbon emission intensity, therefore, this paper draws on Qunhui Huang [30] (2019), and Tao Zhao [31] (2020), etc., where the cross product term of the number of fixed telephones per 100 people in 1984 in each region and the national IT service revenue in the previous year is used as an instrumental variable. The main reasons are 1. traditional communication facilities generate only a trace amount of CO_2 as the frequency of use decreases, satisfying the exclusivity of the selected instrumental variable. 2. the number of fixed phones in 1984 represents the underlying conditions for the development of the digital economy in each region. Empirical tests using 2sls, as shown in Table 7 (3), show that both the primary and secondary terms of the level of digitalization of the logistics industry are significant at the 1% level and in the same direction as the baseline regression, confirming the robustness of the aforementioned results. In the regression using instrumental variables, the value of Wald F for identifying weak instrumental variables is 16.68, which is greater than the empirical value of 10 proposed by STAIGER for the relevant instrumental variables, indicating that there is no problem with weak instrumental variables. Meanwhile, the Kleibergen-Paap rk LM statistic is 12.763, which corresponds to a p-value of 0, indicating that there is no problem of under-identification. It can be seen that the selection of instrumental variables in this paper is reasonable.

Further, explore the path analysis of the impact of the digitalization level of the logistics industry on carbon emission intensity.

The extensive penetration of digital technology in the logistics industry has significantly improved the efficiency of the organization and operation of the logistics industry, upgraded the traditional logistics industry, and promoted the transformation of the traditional logistics industry to intelligence. Digital technology further improves the types and structures of production factors, enhances the efficiency of production factor allocation, makes the production methods and supply chains of the traditional logistics industry optimized, helps the transformation and upgrading of the logistics industry, and gradually improves the efficiency of resource and energy utilization, reduces the energy consumption of logistics industry, and thus reduces the carbon emission of the logistics industry. The test results of digital transformation of the logistics

Table 7. Robustness test of variable model analysis results.

Variable	Replace the explained variable (1)	Shortened time window (2)	2sls (3)
Dig	2.168*** (3.21)	6.5039** (2.29)	15.5881*** (3.40)
Dig^2	-2.871*** (-3.53)	-7.7466** (-2.25)	-16.8774*** (-3.26)
Constant	7.1036*** (4.88)	40.1366*** (4.24)	31.6474*** (4.3)
City fixed effects	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
N	270	150	270
Wald F			16.68
LM			12.763 (0.00)

Note: *, **, and *** in the table respectively represent significant test statistics at the level of 10%, 5%, and 1%. The t value is reported in brackets

Table 8. Mediating effect test.

Variable	LnIL	LnCE
	(3)	(4)
Dig	-0.6047*** (-6.76)	3.1308** (1.94)
Dig^2	0.6212*** (5.76)	-3.6376** (-1.91)
IL		-10.1824*** (-9.25)
lnLW	0.4282*** (12.31)	8.2411*** (11.11)
AG	0.4155*** (15.06)	0.98 (1.52)
UR	0.1272*** (2.78)	2.4522*** (1.99)
lnGDP	-0.4483*** (-13.71)	-9.8324*** (-8.54)
LC	0.00002 (1.04)	-0.001*** (-3.5)
MD	-0.0032 (1.04)	0.0406 (0.81)
Constant	-1.9132*** (-9.9)	9.6441*** (2.53)
Individual effect	Yes	Yes
Time effect	Yes	Yes
N	270	270

Note: *, **, and *** in the table respectively represent significant test statistics at the level of 10%, 5%, and 1%. The t value is reported in brackets

industry affecting carbon emission intensity through the intermediary effect of transformation and upgrading of the logistics industry are listed in Table 8. Table 8 illustrates the transformation and upgrading of logistics digitalization level through to the logistics industry exists nonlinear influence, this is because the digital logistics industry development initial period, digital level is also unable to cope with the rapid development of the logistics industry itself, the industrial transformation and upgrading of the positive influence. However, as the country develops the digital economy and strengthens the osmosis of the digital economy to the real economy, digital development permeates the logistics industry and promotes its transformation and upgrading. In the test of the mediation effect of logistics industry transformation and upgrading, the coefficient of model (4) shows a downward trend compared with model (2), indicating that the transformation and upgrading of the logistics industry plays a partial intermediary role in influencing the path of carbon emission intensity of logistics industry by the digitalization level of the logistics industry, and the intermediary utility accounts for 66.7% of the total effect.

Conclusions and Recommendations

To achieve the “double carbon” goal under the digital economy development pattern, based on the panel data of 30 Provinces in China from 2011 to 2019, this paper constructed a coupling coordination model of China’s logistics industry and digital industry to measure the digitalization level of China’s logistics industry. It empirically tested the impact mechanism of China’s logistics digitalization level on carbon emission intensity. The main conclusions are as follows: (1) The digitalization level of China’s logistics industry shows a prominent characteristic of “high in the east and low in the west,” among which Jiangsu and Zhejiang have the highest digitalization level in the logistics industry, reaching the level of quality coordination. In contrast, Qinghai, Ningxia, and Xinjiang have the lowest digitalization level in the logistics industry. (2) the digitalization level of China’s logistics industry has a nonlinear impact on carbon emission intensity, which is manifested as promoting carbon emission intensity in the early stage and significantly reducing carbon emission intensity in the later stage, presenting a significant inverted a-shape. (3) The influence mechanism analysis shows that the transformation and upgrading level of the logistics industry has a positive moderating mediating effect on the impact of the digitalization level of the logistics industry on its carbon emission intensity, and the mediating utility accounts for 66.7% of the total utility.

Based on the above conclusions, this paper makes the following recommendations: (1) Strengthen digital infrastructure construction. Accelerate the construction of new infrastructures such as 5G, artificial intelligence, and big data center, promote the coordinated and integrated development of traditional industries and new infrastructure, and strive to build a modern infrastructure system that is intensive, efficient, economical, and intelligent, green, safe and reliable. Accelerate the degree of penetration of digital technology into the traditional logistics industry, strengthen the empowering effect of digital technology in all aspects of the logistics industry, realize the quality and efficiency of the logistics industry, further improve the efficiency of energy utilization, reduce energy consumption, thereby reducing carbon emissions in the logistics industry, and help achieve the goal of "double carbon." (2) We need to create differentiated advantages based on the local resource endowment, industrial structure, and development plan in the overall pattern of the national digital economy. The empirical results show that the digitalization level of the logistics industry has not been able to play a good carbon emission reduction effect in less developed regions, so the country should increase the support for the digital economy in less developed regions, strengthen technology cooperation and sharing between regions, and build a regional coordinated development of carbon emission reduction pattern. (3) We should pay attention to both government-led and enterprise-led development, accelerate the construction of an integrated digital government, improve digital governance and government services, and strengthen the training of digital talents to eliminate the "digital divide" that exists between regions and drive the overall development of digital logistics. (4) Promote the digital transformation of small and medium-sized logistics enterprises. Small and medium-sized logistics enterprises account for more than 80% of China's logistics business, but the level of digitalization is not optimistic. Therefore, when small and medium-sized logistics enterprises carry out digital transformation, on the one hand, they should focus on core business, choose a reasonable logistics operation mode, make full use of third-party logistics platform services, improve the enterprise data collection, analysis, and application capabilities, integrate e-commerce, Internet of Things and other resources, accelerate the level of terminal automation, and make logistics business digital, visualized and standardized operation. On the other hand, we should use platform technology to empower the digital development of logistics, drive the transformation and upgrading of the logistics industry, give full play to the intensive integration advantages of the network freight platform, and accelerate the integration of logistics enterprises with the platform.

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Conflict of Interest

The authors declare no conflict of interest.

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