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Research on the Impact of Digital Trade on Urban Carbon Emissions in China under the "Dual Carbon" Target

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Abstract

After the "dual carbon" goal was put forward, low-carbon development has gradually become the focus of attention from all walks of life, and digital technology plays an important role in the process of helping carbon emission reduction. Digital trade, as an active field in international economy and trade, is of great significance to the economic growth of all countries and to deal with the problem of carbon emission reduction. This paper analyzes the transmission path of digital trade on urban carbon emission reduction in China from the theory of scale effect, structure effect and technological progress effect, and based on the panel data of 280 cities in China from 2011 to 2019, uses two-way fixed effect model to conduct regression analysis on the carbon emission reduction effect of digital trade. The study finds that China's digital trade development reduces urban carbon emission intensity, and the conclusion is still valid after the robustness test. Heterogeneity analyses show that the carbon emission reduction effect of digital trade varies in different regions in the East, West and Centre, as well as in regions with different degrees of carbon emissions. In terms of the transmission path, digital trade reduces regional carbon emission intensity by promoting scale effects, technological progress and industrial structure upgrading. Therefore, on the road of actively realizing the goal of "dual carbon", China should vigorously promote the development of international trade mode mainly represented by digital trade. At the same time, we fully recognize the heterogeneity of the impact of digital trade on carbon emissions, and adopt differentiated policies according to the different utility levels of digital trade on carbon emissions in different regions. This will narrow the "digital divide" between cities and help achieve China's "dual carbon" goal.

Keywords: digital trade, carbon emissions, two-way fixed effects, "dual carbon" targets, cities

1. Introduction

With the rapid advancement of the global economy and exponential population growth, environmental issues have gradually come to the forefront. Among these concerns, global warming has garnered widespread attention across various sectors. Consequently, major countries and regions are accelerating their efforts towards achieving carbon neutrality. Against the backdrop of pursuing both "dual carbon" objectives and high-quality economic development, it is of immense practical significance to explore strategies for promoting carbon emission reduction. Simultaneously, emerging technologies such as big data, artificial intelligence (AI), cloud computing, and 5G are rapidly evolving within economic and social domains. In 2022, China witnessed a remarkable surge in digitally deliverable services with an import-export value reaching USD 372.71 billion—an impressive year-on-year increase of 3.4%, setting a new record in terms of scale. Digital technology can provide networked platforms along with intelligent technical means to facilitate green economic and social development by enabling industrial transformation and upgrading while optimizing structural aspects through enhancing government supervision modernization levels as well as improving social service quality (Digital Carbon Neutrality Research Report, 2021). Moreover, digital technology promotes the adoption of environmentally friendly production methods and lifestyles while facilitating an overall reduction in societal energy consumption levels. The second session of the 14th National People's Congress emphasized the full implementation of the negative list for cross-border service trade, as well as the introduction of policies to foster innovative development in service trade and digital trade. We will expedite the integrated development of domestic and foreign trade, with digital trade playing a pivotal role in advancing green ecological civilization construction and facilitating low-carbon development through reduced transaction costs, avoid misallocation of resources, and optimized structures.

So, can digital trade reduce carbon emissions in China's cities? Through which path does digital trade contribute to carbon emission reduction? The exploration of the above questions is of great significance. On the one hand, it can improve the theory of the relationship between trade and carbon emissions at the theoretical level (Wang Yafei, & Liujing, 2023). On the other hand, it can help to provide rich policy implications for the exploration of China's path to "peak carbon and carbon neutrality" as well as for the high-quality development of the economy at the practical level.

This paper analyzes the impact mechanism of digital trade on carbon emissions. Using the panel data of 280 prefecture-level cities in China from 2011 to 2019, the two-way fixed effect model is used to test the impact of digital trade on urban carbon emissions(Cheng Xiaoqiang, Yao Dingjun, Qian Yuanyuan, Wang Bin, & Zhang Dingjun, 2023). At the same time, the heterogeneity test is conducted based on different regions in eastern, middle and western China and regions with different degrees of carbon emissions. The possible contributions and innovations of this paper are as follows. Second, we examine the regional heterogeneity of the carbon emission reduction effect of digital trade and the heterogeneity of carbon emission degree. Thirdly, it proposes policy recommendations for China's regions to develop digital trade to promote carbon emission reduction, which provides new ideas for China to explore carbon emission reduction and achieve carbon neutrality at an early date (Han Jing, Jiang Ruyue, & Sun Yawen, 2021).

2. Literature Review

The concept of digital trade was first proposed by Webert (2010) in his article on international trade rules in the era of digital economy. Generally speaking, digital trade refers to the commercial activities of transmitting valuable products or services through electronic means such as the Internet. China first proposed the concept of "digital trade" to summarize the global digital trade as a business model based on the Internet, using digital exchange technology as the means, providing digital electronic information needed for the interaction between the supply and demand sides, and realizing the trade target of digital information(Xiongli, Lihui, & Liuling, 2011). The Digital Trade Measurement Manual (Second Edition) released in 2023 further makes it clear that trade enabled by digital intermediary platforms is an integral part of digital ordering trade, and digital trade only includes digital ordering trade and digital delivery trade. Digital platform empowerment is included in digital ordering trade, which is no longer a category of digital trade alongside the former two. With the continuous development of information technology, the concept of digital trade is still being improved, and there is no broad consensus at present(Hong Ji, Xiong Biqing, & Zhou Fengxiu, 2023).

However, the academic circle is still actively exploring the characteristics and role of digital trade. Digital trade is a modern information network as a carrier, through the effective use of information and communication technology to achieve the efficient exchange of traditional physical goods, digital products and services, digital knowledge and information, and then promote the transformation of the consumer Internet to the industrial Internet and ultimately realize the manufacturing industry intelligent new trade activities, is the expansion and extension of the traditional trade in the era of digital economy (Ma Shuzhong, Fangchao, & Liang Yinfeng, 2018). Cheng Shixiong and Lu Yuyue (2024) supports that digital trade has become a new engine for the growth of international trade, and has gradually become an important starting point for the country to optimize the allocation of resources, adjust the foreign trade structure, and build a new double-cycle development pattern. Ye Linli and Xue Xiangji (2024) supports that through empirical research that digital trade can promote the high-quality development of China's manufacturing industry through technological innovation effect, factor allocation effect and industrial integration effect.

Carbon peak and carbon neutrality are the responsibility of a major country to build a community with a shared future for mankind. As the largest emitter of carbon, China plays a pivotal role in global climate governance(Wang Xingan, & Zhong Min, 2023). China has been under great pressure to promote economic and social development and reduce carbon emission intensity for a long time. Among them, the research on foreign trade, digital trade and carbon emissions has the following views. Fu Jingyan and Zhang Chunjun (2014) argued that trade reduced the carbon emissions of the entire manufacturing industry and low-carbon manufacturing industry, but increased the carbon emissions of high-carbon manufacturing industry. Some scholars, by using the bibliometric software CiteSpace to analyse the literature related to carbon neutrality under the theme of international trade, concluded that import and export trade has gradually become the driving force of economic development in emerging economies, and that the global carbon governance should be shifted to emerging economies and regional integration (Yu Jianjun, Xiao Ruolan, & Ma Renfeng, 2022). Research by Chen Jingrui (2024) supports that through empirical research that technological innovation and export trade have significant carbon emission reduction effects nationwide. Studies on digital trade and carbon emissions have also emerged in recent years. Based on the empirical study of 50 countries, showed that the development of digital service trade has a positive impact on carbon emission reduction through scale effect, structure effect and technology effect, and the level of Internet development can affect the relationship between the development of digital service trade and carbon emission by adjusting the above three effects (Han Jing, Jiang Ruyue, & Sun Yawen, 2021). By using China's provincial panel data concluded that digital trade has an obvious carbon emission reduction effect, and the effect is stronger in the north than in the south(Wang Yafei, Liu Jing, Zhao Zihan, Ren Jin, & Chen Xinrui, 2023).

According to the existing literature, there are not many studies directly on the relationship between digital trade and carbon emissions. However, the panel data in the empirical study mainly focus on the selection of other countries or the selection of China's provincial-level data. Compared with the existing literature, the contribution of this paper is as follows: based on the vision of "dual carbon" goal under the new development concept, some cities in China are selected as the research objects to explore the impact of digital trade on the carbon emissions of Chinese cities, hoping to put forward constructive suggestions for China's carbon emission reduction.

3. Theoretical Analysis

3.1 Analysis of Economies of Scale

For the traditional trade structure, trade openness ultimately helps to reduce environmental pollution (Zhang Zhixin, Huan Hairong, & Linli, 2021). The trade object of digital trade breaks through the traditional trade mode. On the other hand, the connotation of digital trade includes the digitization of trade mode and trade object. The digitization of trade methods has replaced more and more traditional trade. Digital trade breaks through the constraints of time and space, and gets rid of the limitations of traditional logistics and transportation modes, thus saving energy consumption caused by time and space constraints in production and transportation. Moreover, the continuous expansion of the scale of digital trade provides good technical support for the birth of digital consumption products in trade, expands the scope of trade, and promotes the growth of the scale of service trade. The expansion of the economic scale caused by the increase of such trade volume will not lead to the increase of carbon emissions, and may even play a role in reducing carbon emissions to a certain extent. To sum up, the scale effect of digital trade does not necessarily inhibit carbon emissions, and specific conclusions need to be further proved.

Based on the above analysis, hypothesis H_1 is proposed: digital trade inhibits carbon emission intensity through scale effect.Based on the above analysis.

3.2 Analysis of Industrial Structure Upgrading

The vigorous development of digital trade has played a positive role in promoting the adjustment and upgrading of industrial structure, especially in promoting the development of industrial structure to the direction of optimization, and provides a strong support for promoting the development of service trade. This effect is mainly reflected in two aspects. On the one hand, the application of digital technology has injected new vitality into the reasonable adjustment of industrial structure. With the continuous improvement of digital infrastructure, the digital resources of enterprises have been effectively enhanced. With the support of digital platforms and network coordination, factor exchange and resource allocation among industries can be more reasonable and efficient. The rise of digital trade reduces the intermediate links of trade, improves the capital allocation efficiency of enterprises, thus reducing the investment and financing pressure of enterprises in the process of low-carbon transformation, and creating favorable conditions for the low-carbon transformation of energy structure. On the other hand, digital means have played an important role in promoting the optimization of industrial structure. The optimization of the industrial structure is mainly reflected in the increasing proportion of the secondary and tertiary industries in the overall economy, as well as the transformation of the existing industrial structure from labor-intensive to capital and technology-intensive industries. In this process, enterprises with high energy consumption and high pollution gradually transform to the service industry, realizing the leap from low level to high level of industrial structure. As an important form of the trad-ability of digital economy, digital trade not only accelerates the digital transformation of industrial structure, but also increases the proportion of high-tech industries in the overall economy, and gradually eliminates industries with high energy consumption and low output value, thus reducing carbon emission intensity and laying a solid foundation for high-quality economic development.

Based on the above analysis, hypothesis H_2 is proposed: digital trade suppresses carbon emission intensity through industrial structure upgrading.

3.3 Analysis of Technological Advances

The rise of digital trade has broken down trade barriers, paved the way for smooth global trade, and promoted the degree of openness of countries to the outside world. This process not only directly and indirectly promotes the innovation activities of enterprises, but also improves the level of production technology and creates favorable conditions for reducing carbon emissions. On the one hand, the enhancement of innovation efficiency has become a strong driving force for the development of green environmental protection technology. By adopting measures such as environmentally friendly materials, recycling technology and pollution control equipment, the enterprise significantly improved the utilization efficiency of fossil energy and strengthened the monitoring of carbon emissions, thus effectively restraining the growth of carbon emissions. On the other hand, the enhanced efficiency of innovation also promotes the diffusion of green technologies in the market. With the continuous expansion of the green technology market, high-tech industries have been able to flourish. In this process, enterprises with high energy consumption and high pollution are gradually eliminated, and the industrial structure is optimized and upgraded, thus further reducing carbon emissions. This series of positive effects together constitute the positive contribution of digital trade to global trade and environmental protection.

Based on the above analysis, hypothesis H_3 is proposed: digital trade suppresses carbon emission intensity through technological progress.

4. Design of Empirical Studies

4.1 Empirical Model

This paper uses the STIRPAT model to model the impact around the level of digital trade development on carbon emissions in China's cities.The STIRPAT model is a development of the IPAT model, which is mainly used to analyze the impact of human activities on the environment, and is generally formulated as follows.

$$I = P \times A \times T \tag{1}$$

In equation (1), the letter I denotes environmental impact, P denotes population size, A denotes wealth per capita, and T denotes the level of technology. However, this expression is partially flawed because population size, wealth per capita, and technology level have similar levels of impact on the environment, which does not correspond to the reality of the situation. In order to compensate for this defect, this paper adopts the STIRPAT model proposed by Dietz and Rosa, which can well eliminate the defect in (1) (Deng Xiaohua,& Jia Jun, 2023).The STIRPAT model expression is generally:

$$I = aP^{b}A^{c}T^{d}e \tag{2}$$

In equation (2) , α are the estimated parameters, e is the random error term, and b, c, and d are the indices of each variable. In order to eliminate the effect of heteroscedasticity to a certain extent, the natural logarithm is taken on each side of equation (2) to obtain equation (3):

$$\ln I = \ln a + b\ln P + c\ln A + d\ln T + \ln e \tag{3}$$

On the basis of STIRPAT model, this paper refers to related studies to construct the required empirical model. Since the research purpose of this paper is to explore the impact of the development level of digital trade on carbon emissions(Wang Yafei et., 2023), Environmental Impact I is positioned as Carbon Emission Intensity (CEI); the development level of digital trade is taken as the core explanatory variable and counted in the T category of the STIRPAT model, which also includes the level of foreign openness (FDI), the comprehensive utilization rate of general industrial solid wastes (PCC), the structure of industry (Industry), Total Factor Productivity (TFP), Energy Consumption (EC); Category P of the STIRPAT model includes Urbanization Rate (Urban); Category A of the STIRPAT model includes Logarithmic Per Capita Income of Urban Residents (Income). The final empirical model obtained is as follows:

$$ECI_{\mathrm{it}} = \partial + \beta TRADE_{\mathrm{it}} + \lambda \sum X_{jit} + \omega_j + \sigma_t + \varepsilon_{it} \tag{4}$$

Where, in equation (4), *i* denotes cities, *t* denotes time and ∂ is a constant term, CEI_{it} is the intensity of carbon emissions in different years in each city, $TRADE_{\mathrm{it}}$ is the level of digital trade development in different years in each city, the regression coefficient β denotes the intensity of the impact of the level of digital trade development on carbon emissions in each region, X_{jit} denotes other control variables, ω_{i} denotes an individual fixed effect, δ_{t} denotes a time-fixed effect, and $\varepsilon_{\mathrm{it}}$ denotes a random perturbation term.

4.2 Selected Variables

4.2.1 Explanatory Variable

Carbon dioxide emissions (CO_2). In measuring the measurement of carbon emissions, the carbon emission coefficient method is used, and the energy consumption data of raw coal, coke, crude oil and other energy consumption of industries in each prefecture-level city are selected for calculation. The specific calculations are as follows:

$$CE_{it} = \sum (E_{jit} \times NCV_j \times CC_j \times COF_j \times \frac{44}{12}) \tag{5}$$

Where CE_{jit} denotes the total industrial carbon emissions of region i in year t, E_{ijt} denotes the consumption of energy source j in region i in year t, NVC_j denotes the average low-level heat production of energy source j, CC_j denotes the carbon content per unit calorific value, and COF_j denotes the carbon oxidation rate, where 44 and 22 represent the molecular masses of CO_2 and C, respectively. Finally, the CO_2 emissions from different energy sources are summed up to obtain the total CO_2 emissions of the region in a given year. Based on the above calculation method, this paper obtained the carbon emission data of 280 prefecture-level cities in China from 2011 to 2019. The data for each indicator is from the National Greenhouse Gas Emission Inventory Guidelines.

4.2.2 Core Explanatory Variables

Development level of digital trade. This paper starts from the definition of digital trade in a broad sense, draws lessons from the research of relevant institutions and scholars on digital economy and digital trade, and combines the availability of current prefecture-level city data. This paper selects the Internet basic environment, logistics and transportation environment, digital trade ability, digital technology level and trade potential to construct the digital trade development index measurement system. The five first-level indicators are further subdivided into 14 second-level indicators, and the detailed composition is shown in Table 1. Considering the availability and integrity of data, this paper excludes some cities with insignificant development of digital trade, and finally takes 280 prefecture-level cities in China as the research object and selects their data from 2011 to 2019 for calculation. The data of each index mainly come from China City Statistical Yearbook and local Statistical Yearbooks, as well as Wind database.

Table 1. System of indicators of the level of development of digital trade

Level 1 indicators	Level 2 indicators	Variable symbol	Indicator properties
Internet infrastructure	Number of Internet broadband access subscribers	X_1	positive indicator
	Number of cell phone subscribers	X_2	positive indicator
Logistics and transportation environment	Road freight	X_3	positive indicator
	Practitioners in logistics-related activities	X_4	positive indicator
Digital trade capacity	Number of enterprises with e-commerce activities	X_5	positive indicator
	Total telecommunication services	X_6	positive indicator
	Revenue from main business of information technology	X_7	positive indicator
	Revenue from software operations	X_8	positive indicator
Level of digital technology	Number of information transmission computer services and software	X_9	positive indicator
	Number of patents granted for inventions	X_{10}	positive indicator
	R&D Expenditures of Industrial Enterprises Above Scale	X_{11}	positive indicator
Trade potential	Gross regional product per capita	X_{12}	positive indicator
	Total retail sales of consumer goods	X_{13}	positive indicator
	Trade openness	X_{14}	positive indicator

4.2.3 Control Variable

Residents' affluence level. From the STIRPAT model, it can be seen that the affluence of a region has a very significant impact on the environment, and this paper adopts the per capita income of urban residents to measure the affluence level of residents in prefecture-level cities. In this paper, the per capita income of urban residents in each prefecture-level city is logarithmically processed.

Urbanization rate. The urbanization rate reflects the extent to which a region is transforming into a modern urban society, and to a certain extent reflects the level of economic development of the region. As the urbanization rate increases, the demand and utilization of energy will also change to different degrees. In this paper, the urbanization rate is expressed as the ratio of the urban population to the total population of each region. It is normalized to reduce the error.

Industrial structure. The influence of industrial structure on the environment is stage-specific. The paper dividing the added value of the tertiary industry by the added value of the secondary industry, and using this ratio to indicate the industrial structure of each region (Gan Chunhui, Zheng Guyue, & Yu Dianfan, 2011).

Level of openness to the outside world (FDI). The increase in foreign investment has an impact on the environment mainly through the establishment of MNCS in various regions. This paper uses the proportion of total utilized foreign capital in GDP to represent the level of opening-up of each region.

Energy Consumption. Coal consumption in the energy consumption structure of coal occupies a dominant position is also the most important source of carbon emissions, in view of the availability of data at the prefecture level, this paper adopts the per capita electricity consumption of the prefecture level to measure the energy consumption of the region, and take the logarithmic treatment.

Pollution control capacity. A region's ability to manage pollutants has a direct impact on the region's overall environment, and in view of the availability of data from prefecture-level cities, this paper chooses the comprehensive utilization rate of general industrial solid waste to represent the region's ability to manage pollution.

The data were mainly obtained from the China Urban Statistical Yearbook, local statistical yearbooks, as well as the Wande and Cathay databases, and some missing values were filled in using linear interpolation and approximate annual averaging methods.

Table 2. Control variables and their specific meanings

control variable	notation	concrete meaning
Level of affluence of the population	Income	Logarithmic per capita income of urban residents in each prefecture-level city
urbanization rate	Urban	Share of urban population in total regional population
Industrial structure	Industry	Ratio of value added of the tertiary sector to that of the secondary sector
Level of opening up	FDI	Ratio of total FDI to GDP
Energy consumption	EC	Electricity consumption per capita in prefecture-level cities is taken in logarithms
Pollution control capacity	PCC	Comprehensive utilization rate of general industrial solid waste

Table 3. Descriptive statistics

variant	sample observation	average value	standard deviation	Minimum value	maximum values
CEI	2516	0.307	0.434	0.026	3.289
TRADE	2516	0.098	0.088	0.042	1.082
Income	2516	10.866	0.313	8.509	12.062
Urban	2516	0.407	0.243	0.075	1.819
Industry	2516	0.977	0.541	0.114	5.168
FDI	2516	27.484	29.290	0	270.951
EC	2516	14.046	0.899	11.110	16.568
PCC	2516	79.401	23.091	-1.430	110.900

5. Results

5.1 Analysis of Baseline Regression Results

In the empirical test, the multicollinearity test is first conducted on each variable, and the VIF is no more than 10 after the test, so it can be shown that there is no multicollinearity among each variable. Considering that there may be omitted variables that do not change with time, this paper adopts the two-way fixed effect model and conducts benchmark regression on digital trade and carbon emission intensity according to the setting of Formula (4). It can be seen from the table that no matter whether control variables are added or not, the coefficient of the development level of digital trade is negative at the level of 1%, indicating that the development of digital trade has a significant inhibitory effect on carbon emissions.

In terms of control variables, the industrial structure is significantly positive at the level of 5%, indicating that the secondary industry still accounts for a large proportion in most cities, so the demand for energy is large and the carbon emissions are large. The level of opening to the outside world is significantly positive at the level of 1%, indicating that the level of opening to the outside world of a city will have a significant promoting effect on carbon emission intensity. May be due to the introduction of a large number of pollution-intensive enterprises, resulting in the increase of carbon emissions; Energy consumption is significant at the level of 1%, indicating that the increase in energy consumption will lead to an increase in carbon emissions, which is consistent with reality (Mu Lujun, Chen Jing, Fan Tianzheng, & Lv Yanqin, 2022).

Table 4. Empirical Results

variant	CEI (Model 1)	CEI (Model 2)	CEI (Model 3)	CEI (Model 4)
Trade	-1.089***	-1.080***	-1.090***	-1.075***
	(-2.78)	(-2.65)	(-2.79)	(-2.75)
Income		-0.048	-0.079	-0.091
		(-0.51)	(-0.86)	(-1.14)
Urban		-0.129	-0.147	-0.147
		(-0.99)	(-0.96)	(-1.02)
Industry			0.075**	0.078**
			(2.23)	(2.30)
FDI			0.001***	0.001***
			(3.50)	(3.45)
CE				0.181***
				(3.34)
PCC				-0.000
				(-0.51)
Constant	0.287***	0.841	1.086	-1.028
	(7.78)	(1.00)	(1.30)	(-0.98)
N	2516	2516	2516	2516
R-squared	0.391	0.391	0.397	0.400
individual fixed effect	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes

Note: Standard errors in parentheses, "***" "**" "*" represent significant at the 1%, 5%, and 10% levels, respectively. Same as below.

5.2 Robustness Tests

5.2.1 Substitution of Variables

In order to eliminate the robustness impact of different measurement methods of carbon emissions on the test results, it is also considered that there are huge differences in the population and economic development level in different urban areas. In this paper, per capita carbon dioxide emissions are used to replace carbon emission intensity, and the logarithm of it is taken for robustness test. This paper refers to the measurement method of the digital economy index at the prefecture-level replaces the core explanatory variables (Zhao Tao, Zhang Zhi, & Liang Shangkun, 2010). The coefficient of the empirical results after replacing the variables is still negative, indicating that the benchmark regression results are robust.

5.2.2 Lagged Variable

Considering the impact of the development level of digital trade on carbon emission intensity, there may be a lag to a certain extent. Therefore, in order to avoid that the development level of digital trade is affected by its previous value, this paper lags the development of digital trade, the core explanatory variable, by one period. The regression results are shown in Model 3 of Table 5, and the coefficient of the lag period of digital trade development is negative and significant at the level of 1%, further confirming the general significance of the regression results in this paper.

Table 5. Robustness check

variant	Substitution of explanatory variables (model 1)	Replacement of core explanatory variables （model 2）	Core explanatory variables lagged one period （model 3）
TRADE	-2.145***		
	(-4.71)		
ECONOMY		-2.31**	
		(-1.98)	
TRADE_LAG			-1.172**
			(-2.47)
Constant	-12.649***	-0.892	-1.631
	(-10.32)	(-0.85)	(-1.33)
Control	Yes	Yes	Yes
N	2505	2510	2254
R-squared	0.654	0.389	0.403
individual fixed effect	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes

5.3 Heterogeneity Analysis

5.3.1 Region-Based Heterogeneity Analysis

Considering that there may be heterogeneity in the impact of digital trade development level on carbon emissions in different regions. Based on the division of regions by the National Bureau of Statistics, the cities are divided into the eastern region, the central region and the western region for grouping tests (Hong Ji, Xiong Biqing, & Zhou Fengxiu, 2023). The regression results are shown in Table 6. The coefficient of digital trade development level in the eastern region is significant at the significance level of 1%, the coefficient of digital trade development level in the central region is still insignificant at the significance level of 10%, and the coefficient of digital trade development level in the western region is significant at the significance level of 5%. This shows that compared with the central region, the carbon emission reduction effect of the development level of digital trade has a stronger influence on the eastern and western regions, especially the eastern region. This may be due to the fact that compared with the central and western regions, the eastern region contains a large number of digital infrastructure and gathers a large number of high-tech talents, which is more able to play the role of digital empowerment at the trade level by virtue of its resource endowment advantages, so the carbon emission reduction effect is obvious.

Table 6. Heterogeneity regression results based on region

variant	Eastern region CEI (model 1)	Central Region CEI (model 2)	western region CEI (model 3)
TRADE	-1.144***	-1.562	-1.026*
	(-3.29)	(-0.93)	(-1.72)
Constant	-5.821***	3.780	-0.661
	(-3.48)	(1.56)	(-0.49)
Control	Yes	Yes	Yes
N	908	873	735
R-squared	0.487	0.450	0.435
individual fixed effect	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes

5.3.2 Heterogeneity Analysis by Level of Carbon Emissions

In order to verify whether the development level of digital trade in regions with different carbon emission intensity has an impact on carbon emission intensity, five quantiles of 10%, 25%, 50%, 75% and 90% are selected for regression corresponding to cities with different carbon emission levels. The results are shown in Table 7, when the quantile is 10%, the impact of digital trade development on carbon emission intensity is not significant. However, as the quantile increases, the effect changes from promotion to inhibition, and the significance gradually increases. This shows that in regions with low carbon emission intensity, the carbon emission reduction effect of digital trade is not obvious, and it may even promote carbon emission intensity. This may be due to the low carbon emission intensity in these areas, which has not attracted the attention of local governments and enterprises. However, in the regions with high carbon emission intensity, digital trade has a significant inhibitory effect on it, which is consistent with the previous sub-regional regression results.

Table 7. Heterogeneity regression results based on the extent of carbon emissions

variant	q=10% CEI (model 1)	q=25% CEI (model 2)	q=50% CEI (model 3)	q=75% CEI (model 4)	q=90% CEI (model 5)
TRADE	-0.179	0.254**	-0.263***	-0.488***	-0.602***
	(-1.13)	(2.09)	(-4.11)	(-7.99)	(-7.03)
Constant	0.092	0.124	-0.465***	-0.705***	-0.634**
	(0.73)	(1.06)	(-3.79)	(-4.15)	(-2.52)
Control	Yes	Yes	Yes	Yes	Yes
N	252	629	1254	1887	2265
R-squared	0.117	0.096	0.422	0.527	0.524
individual fixed effect	Yes	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes	Yes

5.4 Mechanism Analysis

The above research results show that digital trade can significantly reduce regional carbon emission intensity. Next, the impact of digital trade development on mechanism variables is analyzed one by one, and the results are shown in Table 8.

For the mechanism test of economies of scale, referring to the practice of Wang Yafei and Liujing (2023), the

GDP of each city is selected to measure the output scale (SC). The results of Model I show that digital trade can significantly promote the scale of urban output. The results of Model 2 show that the output scale of a city has an inhibitory effect on carbon emissions, and the result is at the significance level of 1%. Therefore, digital trade can inhibit urban carbon emissions through economies of scale, that is, Hypothesis 1 is established.

In the structural optimization mechanism test, the capital-labor ratio (KL) is represented by the ratio of fixed capital stock to the annual average number of employees to represent the industrial structure upgrading. The results of Model 3 and Model 4 show that digital trade significantly promotes the upgrading of urban industrial structure, while the upgrading of industrial structure inhibits urban carbon emission intensity, that is, Hypothesis 2 is established.

In the test of technological innovation mechanism, the number of patents granted is used as the mechanism variable for regression, and the results are shown in Model 5. The coefficient of digital trade in the table is positive at the 1 per cent significance level, indicating that the development of digital trade can significantly promote patent invention. The relationship between patented inventions and carbon emission intensity is shown in Model 6, indicating that the increase in the number of patents granted will inhibit carbon emission intensity, that is, Hypothesis 3 is established.

Table 8. Mechanistic analysis test results

variant	SC (model 1)	CEI (model 2)	KL (model 3)	CEI (model 4)	TECH (model 5)	CEI (model 6)
TRADE	115.461***		4.134***		12.956***	
	(42.80)		(7.89)		(29.72)	
SC		-0.012***				
		(-5.39)				
KL				-0.044***		
				(-2.80)		
TECH						-0.037**
						(-2.33)
Constant	29.530***	-0.709	1.057	-0.895	4.001***	-0.537
	(3.96)	(-0.68)	(0.76)	(-0.85)	(3.39)	(-0.51)
Control	Yes	Yes	Yes	Yes	Yes	Yes
N	2516	2516	2515	2510	2507	2507
R-squared	0.598	0.406	0.370	0.401	0.376	0.399
individual fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes

6. Research Findings and Policy Advice

6.1 Findings

Based on the panel data of 280 prefecture-level cities in China from 2011 to 2019, this paper conducts empirical test through two-way fixed effect model to study the impact of digital trade development on urban carbon emissions. The following conclusions are drawn: first, the development of digital trade can significantly inhibit carbon emissions, and this conclusion is still valid after replacing the explained variable, the core explanatory variable and the one-period lagged variable. Second, there are significant differences in the impact of digital trade development on carbon emissions in different regions of eastern, central and western China and regions with different carbon emission intensity. Third, the development of digital trade reduces regional carbon (Hong Ji, Xiong Biqing, & Zhou Fengxiu, 2023) emission intensity by promoting scale effect, technological progress and industrial structure upgrading.

6.2 Policy Advice

First, grasp the development of digital trade to (Hong Ji, Xiong Biqing, & Zhou Fengxiu, 2023) boost low-carbon and green economy. The research in this paper finds that the improvement of the development level of digital trade has a significant effect on curbing carbon emissions (Wang Yafei et., 2023). The development of social economy should adhere to the concept of green and low-carbon, and the development of digital trade can not only play the economic effect of driving trade growth and promoting economic development, but also promote carbon emission reduction effect, thus bringing environmental optimization. Therefore, digital trade should be vigorously developed to promote the digital transformation of the real economy. We will promote the digital transformation and upgrading of traditional industries with high energy consumption and high pollution, and transform the industrial structure from high-carbon and low-end to low-carbon and high-end. Strengthen the innovation and application of green and low-carbon science and technology, cultivate new green and low-carbon drivers, and make full use of the carbon emission reduction utility of digital trade to achieve China's "dual carbon" goal (Shi Honglian, Wang Yuliang, & Kong Xixian, 2022).

Second, prioritize and actively promote the development of digital infrastructure. Digital infrastructure is the fundamental pillar of digital trade. A large amount of literature shows that regions with more developed digital infrastructure tend to have higher levels of digital trade development and better carbon emission reduction effects. Therefore, digital trade should be vigorously developed to promote the digital transformation of the real economy. In particular, it should promote the transformation and upgrading of high-energy-consuming and high-polluting traditional industries in the direction of digitization, and promote the transformation of the industrial structure from high-carbon low-end to low-carbon high-end (Wang Yafei et., 2023). Relevant preferential policies should be set up to apply digital trade to more small and medium-sized enterprises, giving full play to its carbon emission reduction effect and helping China to achieve its "dual-carbon" goal.

Third, a scientific and reasonable coordination mechanism for regional digital trade development should be constructed. China should fully understand the differentiated impact of digital trade on carbon emissions, rationally allocate support resources, formulate differentiated digital trade development policies for each city, and ensure the effectiveness and pertinence of policies. For digital products and services with high carbon emissions, a corresponding carbon tax system should be implemented to encourage market players to give priority to low-carbon and environmentally friendly products and services. For cities with developed economy and high degree of digitization, they can pay more attention to the innovative development of digital trade and promote the deep integration of digital economy and real economy. For cities with relatively backward economy and low degree of digitization, more attention should be paid to the construction and popularization of digital infrastructure to provide strong support for the development of digital trade. Only by rationally allocating support resources, avoiding the "one size fits all" approach, and establishing a scientific and effective policy evaluation mechanism, can we ensure the healthy and rapid development of digital trade and inject new impetus into the sustainable development of China.

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Authors contributions

Wang Xinyue were responsible for study design and revising. Li Ruiqi was responsible for data collection and Prof. Ma Haiying revised it. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

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The Publication Ethics Committee of the Canadian Center of Science and Education.

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