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RESEARCH ON THE IMPACT OF DIGITAL INCLUSIVE FINANCE ON CARBON EMISSION INTENSITY — AN EMPIRICAL TEST BASED ON CHINESE DATA

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Abstract

Using the provincial panel data from 2011 to 2021, the paper constructs carbon emission intensity indicators according to ten energy sources, and uses the fixed effect model and mediation effect model to empirically test the impact of digital inclusive financial development on carbon emission intensity and its impact path. The results show that the development of digital financial inclusion has a significant negative effect on carbon emission intensity. The optimization and adjustment of industrial structure can effectively reduce carbon emission intensity; further heterogeneity test shows that digital financial inclusion has the most significant effect on carbon emission suppression at the 60% quantile point; digital financial inclusion has the greatest effect on carbon emissions in the central and eastern regions The negative impact of emissions is the most significant, and the impact coefficient in the central region is greater than that in the eastern region, while the negative effect in the western region is not significant; the coverage, depth of use, and degree of digitalization of the secondary indicators of digital financial inclusion have an average effect on carbon emission intensity. It has a significant negative impact, specifically manifested in the strongest depth of use, followed by the breadth of coverage, and the weakest degree of digitization.

Key words: digital inclusive finance, carbon emission intensity, intermediary effect, technological innovation, industrial structure optimization and adjustment

Introduction

With the rapid development of industrialization and urbanization, the

issue of carbon emissions has become the focus of attention of all countries. In response to the challenge of global climate change, the international community has taken actions and formulated a series of policies and agreements, including the United Nations Framework Convention on Climate Change (UNFCCC), its Kyoto Protocol, and the Paris Agreement. These international agreements aim to promote countries to jointly reduce carbon emissions and achieve sustainable development goals through global cooperation. In recent years, with the rapid economic development of developing countries, their carbon emissions have also shown a trend of rapid growth. However, while pursuing economic development and improving living standards, they are also facing huge energy demand and carbon emission pressure. Therefore, developing countries play an important role in reducing carbon emissions and addressing climate change. As the largest developing country, China proposed the "3060" goal in 2020, that is, to achieve carbon peaking in 2030 and carbon neutrality in 2060. It fully reflects China's confidence and determination to implement carbon governance. How to reduce carbon emissions has become an important issue at present.

However, existing studies mostly focus on technological innovation (Junbing Huang et al. , 2020; Su et al. , 2023), economic growth (Lukman et al. , 2019; Hewage et al. , 2022), environmental regulation (Khan et al. . 2019; Qingmin Yuan et al. 2020) on carbon emission intensity. Few literatures directly study the relationship between digital financial inclusion and carbon intensity. Based on the advantages of big data and Internet technology, digital financial inclusion has improved financial access (Geda et al. , 2006), broadened the scope of financial services (Helms, 2006), and made up for the financial exclusion and information asymmetry of traditional financial services. (Stiglitz et al. , 1981) and other deficiencies. Regarding the measurement and measurement of digital financial inclusion, the existing literature measurement methods include banking service coverage (Beck, 2005), UNDP index construction method (Sarma, 2008), comprehensively measure digital financial inclusion from five aspects: penetration, availability, transaction convenience, transaction costs and usability (Gupte, 2012). At present, the mainstream classification includes the following three types: AFI inclusive financial index system, World Bank inclusive financial index system, GPF Iinclusive financial index system. Based on the digital financial inclusion index system constructed by international scholars and after comprehensive consideration of various factors, this paper selects the digital financial inclusion index released by the Digital Finance Research Center of Peking University for empirical evidence.

The Digital Finance Research Center of Peking University began to evaluate China's digital financial inclusion in 2017, forming the China Digital Financial Inclusion Index, which provides data support for relevant research (SGuo, F et al, 2020). According to data released by the Digital Finance Research Center of Peking University, the average value of

the digital financial inclusion index of 30 provinces in China from 2011 to 2021 increased from 40. 797 to 373. 7383, with an average annual growth of 24. 79%. On the one hand, the vigorous development of digital inclusive finance can directly build an online financial payment and trading platform, and effectively reduce the carbon emissions generated during business processing; On the other hand, the development of digital inclusive finance helps small and medium-sized enterprises to obtain loans, ease financing constraints, and promote enterprises to channel funds into technology research and development and industrial structure upgrading and adjustment to achieve carbon emission reduction. However, there are few researches on the carbon emission of digital financial inclusion.

To sum up, in the context of peaking and carbon-neutral development, and with the trend of vigorous development of digital inclusive finance, this paper uses the panel data of 30 provinces in China (excluding Hong Kong, Macao, Taiwan and Tibet) from 2011 to 2021 to conduct an empirical test on the relationship between digital inclusive finance and carbon emission intensity. Firstly, based on the results of Hausmann test, a bi-directional fixed effect model was constructed to empirically verify the impact of digital financial inclusion on carbon emissions. Secondly, this paper explores two possible mechanisms by which digital financial inclusion affects carbon emissions: promoting technological innovation and upgrading industrial structure. On this basis, in order to verify the robustness of the benchmark model, this paper uses three methods: changing the explained variables, excluding the four municipalities directly under the Central Government and Hainan Province, and shrinking the tail. Thirdly, the heterogeneity of scale, region and type was analyzed. Based on the above analysis and regression results, the research conclusions of this paper are drawn and corresponding suggestions are given. The research on these issues has enriched the research perspective of carbon emission intensity, provided a new development idea for China to achieve carbon emission reduction, and is of great significance for China to formulate carbon emission reduction policies, strategies and policy paths.

The marginal contributions of this paper are as follows: (1) Most current research focuses on the impact of traditional finance on carbon emissions. At the same time, most of the research on digital inclusive finance focuses on economic growth, poverty alleviation, income gap, entrepreneurial effects, etc. For digital There are few studies on the green effect of inclusive finance, so this paper enriches the research on the green effect of digital inclusive finance by studying the impact of digital inclusive finance on carbon emission intensity; (2) There is no unified carbon emission index For the first time, this paper uses ten kinds of energy to construct carbon emission indicators, which enriches the measurement standard of carbon emission and provides empirical evidence for related research on carbon emission reduction and green and low-carbon development; Regression analysis with different regional samples will help the

government implement refined policies and help China's carbon emission reduction cause.

Theoretical Analysis and Research Hypothesis

As a new form of inclusive finance, digital inclusive finance has gradually developed relying on digital technologies such as big data, blockchain, and cloud computing. It can effectively overcome the shortcomings of traditional financial transactions such as high transaction costs, narrow reach, and insufficient financial resources. Provide convenient financial support for SMEs and low-income groups (Ahmad, Mahmood, et al. , 2021). It can significantly expand the scope of financial services and improve the efficiency of financial services, improve and perfect the financial service network, effectively change the phenomenon of resource misallocation, produce a huge green economic effect, and provide a new idea for realizing carbon emission reduction (Saint-Paul, 1992).

The direct impact of digital financial inclusion on carbon emissions

The direct effect of digital inclusive finance on carbon emissions is reflected in: on the one hand, for individuals, digital inclusive finance is based on digital platforms and mobile terminals, and through the combination of scenarios, data and financial innovation products, it makes up for the gaps in traditional financial services. Insufficient, it reduces the cost of information search and risk identification, and promotes the onlineization of offline business (Demertzis, 2018). The way of handling business online will greatly reduce the original transaction costs and resource consumption, thereby reducing carbon emissions (Li et al. , 2020). Digital inclusive finance is conducive to broadening the channels for the public to participate in environmental protection, increasing the transparency of environmental protection public welfare activities, and helping the public to participate in environmental protection through digital financial platforms to reduce carbon emissions (Lei, Tianyi, et al. , 2023). Digital financial inclusion provides strong support for green technology reserves and product promotion, and its social attributes will further promote the public to practice green life (Ding, Xuemeng, et al. , 2022), thereby reducing personal carbon emissions. On the other hand, for enterprises, digital financial inclusion builds an online transaction platform for suppliers and buyers of financial products through digital means, and uses digital technology to create a diversified. The financial products broaden the financing channels, speed up the flow of funds in space and time, provide more financing facilities for companies (Huang Bo, 2021), effectively alleviate the problem of information asymmetry, promote enterprise technology research and development, and increase resources. Use efficiency, so as to achieve the effect of carbon emission reduction (Cao, Shaoopeng, et al. , 2021). Based on this, this paper proposes Hypothesis 1:

H1: The higher the degree of development of digital financial inclusion, the more it helps to reduce carbon emission intensity.

The indirect impact of digital financial inclusion on carbon emissions

The Impact of Digital Inclusive Finance on Carbon Emissions from the Perspective of Technological Innovation.

The technological innovation effect of digital financial inclusion is an important means to achieve China's carbon emission reduction. Traditional finance has the defect of long-term insufficient supply, which leads to high research and development costs for enterprises to carry out technological innovation, thereby inhibiting enterprises from carrying out technological innovation. Digital financial inclusion can promote technological innovation and thus affect carbon emissions. First of all, digital financial inclusion can change traditional social interaction methods (Kabakova & Plaksenkov, 2018) and meet the needs of market players for financial services (Klapper , 2012), reduce the cost and threshold of credit for financial institutions, increase the success rate of SME loans (Heiskanen, 2017), increase the channels and volume of financing for them (Yang et al. , 2022), can provide green technology R&D and use provide more financial support (Love, I. , 2003), so digital financial inclusion promotes technological innovation of enterprises (Zhu & Zheng, 2021). Second, technological innovation can effectively reduce total carbon emissions and improve economic effects. On the one hand, technological innovations such as clean production technology and pollution control technology can significantly increase the demand for energy-intensive durable goods, and the use of these durable goods can effectively reduce carbon emissions (Frankel & Romer, 1999). Research and development of low-carbon technologies and products The application of can significantly limit fossil fuel energy consumption and reduce carbon emissions (Lin et al. , 2017; Wan et al. , 2021). On the other hand, although non-green innovations in scientific and technological innovation activities will not directly affect the total carbon emissions, they will promote the improvement of the overall technological level of the society, thereby providing a steady stream of impetus for the growth of regional GDP (Wang et al. , 2022). Therefore, digital financial inclusion can significantly promote technological innovation, and technological innovation can reduce total carbon emissions and increase regional GDP, thereby reducing carbon emission intensity. Based on this, this paper proposes Hypothesis 2a:

H2a: Digital financial inclusion reduces carbon emission intensity by improving the level of technological innovation.

The Impact of Digital Inclusive Finance on Carbon Emissions from the Perspective of Industrial Structure Upgrading and Adjustment.

The development of digital inclusive finance is an important path to promote the optimization and upgrading of industrial structure, and the optimization and adjustment of industrial structure can significantly curb carbon emissions. First of all, the development of digital financial inclusion can promote the optimization of industrial structure through policy guidance, resource allocation and other means (Sasidharan et al. , 2015).

Digital financial inclusion can efficiently match capital supply and industrial development needs (Bruhn & Love , 2014), improve the efficiency of capital allocation (Fisman et al. , 2003), with the enhancement of factor resource allocation capabilities, resources will be inclined to high-end elements such as technology and human capital, thereby promoting the optimization and adjustment of industrial structure (Bruhn & Love, 2014). The optimization and adjustment of industrial structure can effectively reduce carbon emissions. First of all, most of China's high-energy-consuming industries are concentrated in the secondary industry, and its total emission ranks first among the three major industries. The upgrading of industrial structure can reduce the dependence of economic development on energy, so the optimization and adjustment of industrial structure will reduce carbon emissions put strong (Chen & Li, 2018). Secondly, the upgrading of the industrial structure can promote the flow of labor force, capital and other elements within and between industries, realize the efficient allocation and use of resources, improve the production efficiency of enterprises, accelerate the green development of enterprises, and optimize the balance between stock and increment. Improving service quality on a basic basis can improve carbon emissions and effectively control pollution emissions from a macro perspective (Wang, Xiong, et al, 2022). Finally, the evolution direction of the industrial structure plays a decisive role in the change trend of energy consumption. The upgrading of the industrial structure can effectively accelerate the emergence of the inflection point of the inverted "U" change of the Environmental Kuznets Curve, that is, accelerate the reduction of carbon emissions (Huang et al. , 2022; Grossman & Krueger, 1991). Therefore, digital inclusive finance promotes the optimization and adjustment of industrial structure through resource allocation and policy guidance, thereby reducing energy consumption and carbon emission intensity. Based on this, this paper puts forward Hypothesis 2b:

H2b: Digital financial inclusion can reduce carbon emission intensity by promoting the optimization and adjustment of industrial structure.

Research Design

Model setting

Baseline regression model.

Based on the above theoretical analysis, in order to explore the internal relationship between digital financial inclusion and carbon emission intensity, this paper empirically tests the impact of digital financial inclusion on carbon emission intensity through the fixed effect model of Hausman test results:

$$CEi,t=\alpha 0+\alpha 1FINi,t+\alpha 2Controli,t+\mu i+\nu t+\varepsilon i,t \quad (1)$$

Among them, $CE_{i,t}$ is the carbon emission intensity; $FIN_{i,t}$is the development level of digital financial inclusion; $Control_{i,t}$ is the control variable. In order to better examine the time effect and regional effect, this paper adopts a two-way fixed effect model, where $\mu_i$represents the province fixed effect, ν_t repre-

sents the time fixed effect, and $\varepsilon_{i,t}$ are random disturbance items.

Mediation model.

In order to further test whether digital inclusive finance can promote regional technological innovation and industrial structure adjustment to achieve the effect of carbon emission reduction, this paper adopts the stepwise regression method (Wen et al. , 2014) for relevant empirical analysis, and constructs the mediation effect model as follows:

$$INN_{i,t} = \beta_0 + \beta_1 \mathrm{FIN}_{i,t} + \beta_2 \mathrm{Control}_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (2)$$

$$CE_{i,t} = \theta_0 + \theta_1 FIN_{i,t} + \theta_2 INN_{i,t} + \theta_3 Control_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (3)$$

$$UPGRADE_{i,t} = \delta_0 + \delta_1 \mathrm{FIN}_{i,t} + \delta_2 \mathrm{Control}_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (4)$$

$$CE_{i,t} = \omega_0 + \omega_1 FIN_{i,t} + \omega_2 UPGRADE_{i,t} + \omega_3 Control_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (5)$$

Among them, the intermediary variables are technological innovation $INN_{i,t}$ and industrial structure adjustment $UPGRADE_{i,t}$ respectively.

Variable Selection and Data Sources

Explained variable.

This paper uses carbon emission intensity as the explained variable. Carbon emission intensity (CE) is represented by the ratio of provincial carbon emissions to regional GDP (Zhang et al. , 2018). The smaller the value, the better it reflects the positive development trend of my country's low-carbon economy. Since there is no authoritative organization to measure the total amount of carbon emissions at the provincial level in China, this paper uses raw coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, liquefied natural gas, natural gas and electricity to calculate the total energy consumption of 10 kinds of energy, using the IPCC method Carbon emissions (IPCC, 2006) The carbon emission coefficients of various energy sources are shown in Table 1. The specific calculation methods are as follows:

$$C_{it} = \sum_{i=1}^{10} C_i K_i N_i \quad (6)$$

C_{it} is the total carbon emission of province i in year t; C_i represents the consumption of the i energy, K_i represents the energy conversion coefficient of the i energy, and N_i represents the CO2 conversion coefficient of the i energy. Since the consumption of various energy sources is based on physical objects in the initial statistics, this paper converts them into standard statistics when measuring carbon emissions. According to the "China Energy Statistical Yearbook", China's final energy consumption can be divided into raw coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, liquefied natural gas, natural gas and electricity. The conversion coef-

ficients and carbon emission coefficients of the 10 energy sources are shown in Table 1. The measurement units of the conversion coefficients are t standard coal/10, 000 m³ for natural gas, t standard coal/10, 000 Kwh for electricity, and kg standard coal for other energy sources. /kg, while the unit of carbon emission coefficient is t carbon/t standard coal.

C_{it}

$$CE_{i,t} = C_{i,t}/GDP_{i,t} \quad (7)$$

Carbon emission intensity $CE_{i,t}$, expressed as the ratio of the total carbon emission of each province to GDP. $C_{i,t}$ is the total carbon emission of province i in year t, and $GDP_{i,t}$ is the gross regional product of province i in year t.

Table 1. Energy conversion coefficient and carbon dioxide conversion coefficient

Energy	Energy Conversion Coefficient	Carbon dioxide conversion factor
Coal consumption	0. 7143	1. 9003
Coke consumption	0. 9714	2. 8604
Crude oil consumption	1. 4286	3. 0202
Gasoline consumption	1. 4714	2. 9251
Kerosene consumption	1. 4714	3. 0179
Diesel consumption	1. 4571	3. 0959
Fuel consumption	1. 4286	3. 175
LNG consumption	1. 7143	3. 1013
Natural gas consumption	13. 3	21. 622
Electricity consumption	1. 229	0. 785

Core explanatory variable.

The development level of digital financial inclusion (FIN) This paper selects the representation of "Peking University Digital Financial Inclusion Index" (SGuo, F. , et al, 2020). This paper uses logarithmic processing on the digital financial inclusion index to eliminate The purpose of the dimensional difference between indicators.

Mediator variable.

The level of technological innovation (INN) and the upgrading and adjustment of industrial structure (UPGRADE). This paper selects the number of authorized patent applications per 10, 000 people to represent the level of technological innovation, and performs natural logarithm processing on the original data. The sum of the added value of the three industries is used to measure the upgrading and adjustment of the regional industrial structure. The specific calculation method is shown in formula (8), so as to realize the empirical analysis of the intermediary effect of digital inclusive finance on the carbon emission intensity through the upgrading and adjustment of the industrial structure.

$$UPGRADE_{i,t} = \sum_{i=1}^{3} X_{i,t} *_{i} \quad (8)$$

Among them, $X_{i,t}$represents the proportion of the added value of the i industry in the t province to the GDP, which can reflect the tertiary output The overall changes in industry upgrading and adjustment.

Control variable.

In order to alleviate the endogeneity and reverse causality problems caused by the omitted variables, the control variables selected in this paper are energy consumption structure (CON), economic development level (GDP), foreign direct investment (FDI), degree of opening to the outside world (OPEN) and The degree of environmental protection (PRO), and the proportion of the total amount of coal and coke to the total energy consumption, the logarithm of the regional GDP, the proportion of the actual foreign investment in each province to the regional GDP, the total import and export volume of the regional production The proportion of the total value and the proportion of environmental protection expenditure in the GDP of the region are used as proxy variables for the above variables.

Data Sources**.**

In this paper, samples from Hong Kong, Macao, Taiwan and Tibet Autonomous Region, where a large number of data are missing, were eliminated, and finally data from 30 provinces covering a time span from 2011 to 2021 were obtained. Among them, the total carbon emission data of each province comes from the China Energy Statistical Yearbook; The data of the Digital Financial Inclusion Development Index and its three sub-dimensions are from the Peking University Digital Financial Inclusion Index. Other data are from China Economic Network and China Statistical Yearbook. The following data and related tests are implemented using Stata17.

Table 2. Variable names and calculation methods

Categories	Name	Computing method
variable being explained	Carbon emission intensity (CE)	Total carbon emissions of each province (million tons) as a percentage of GDP
Core explanatory variable	The development level of digital financial inclusion (FIN)	Digital Financial Inclusion Index, logarithm
mediating variable	Level of Technological Innovation (INN)	Number of grants per 10,000 patent applications, logarithm
	Upgrading the Industrial	The sum of the

	structure (UPGRADE)	added value of the three industries in the proportion of GDP
control variable	Energy consumption structure (CON)	(coal + coke consumption) accounted for Proportion of energy consumption
	Economic development level (GDP)	GDP, take the logarithm
	Foreign direct investment (FDI)	Ratio of actual utilized foreign investment to GDP
	Environmental protection (PRO)	Expenditure on environmental protection as a proportion of GDP
Mechanism variable	Digital financial inclusion coverage (WID)	Digital Financial Inclusion coverage index, logarithm
	Digital financial inclusion uses deep (DEP)	Digital financial inclusion uses a depth index, taking logarithms
	Digitization degree of digital inclusive finance (DIG)	Digital Financial Inclusion Digital degree index, logarithm

Descriptive statistics.

The descriptive statistical results are shown in Table 3 below. The average value of carbon emission intensity is 2. 428, the maximum value is 9. 016, and the minimum value is 0. 253. The difference between the maximum value and the minimum value is large, indicating that there are large differences in carbon emission intensity in different regions; The average value of the financial inclusion index is 5. 283, and there is a certain gap between the maximum value of 6. 129 and the minimum value of 2. 909, indicating that the development level of digital financial inclusion in various provinces is uneven and unbalanced; the maximum value of technological innovation is 4. 863 and There is still a large difference between the minimum value of 0. 253.

Table 3. Descriptive statistics results (N=330)

VARI-ABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
CE	330	2. 428	1. 926	0. 253	9. 016
FIN	330	5. 283	0. 669	2. 909	6. 129
WID	330	5. 149	0. 817	0. 673	6. 072
DEP	330	5. 266	0. 652	1. 911	6. 236
DIG	330	5. 556	0. 681	2. 026	6. 136
CON	330	0. 934	0. 467	0. 0146	2. 520
GDP	330	9. 832	0. 897	7. 223	11. 83
FDI	330	0. 668	3. 104	0. 0478	47. 82
PRO	330	0. 801	0. 547	0. 212	4. 344
OPEN	330	0. 273	0. 286	0. 00739	1. 498
INN	330	2. 569	1. 010	0. 253	4. 863
UPGRADE	330	2. 395	0. 125	2. 133	2. 838

Empirical Results and Analysis

Benchmark regression results

According to the results of the Hausman test, the fixed effect model is selected to verify the carbon emission reduction effect of digital inclusive finance. The coefficient of digital financial inclusion in column (1) of Table 4 is -0. 55, indicating that the improvement of the level of digital financial inclusion is consistent with expectations and significantly suppresses carbon emissions. In order to further reduce the endogenous problems caused by omitted variables and factors related to independent variables, after adding control variables in column (2), the impact coefficient of digital financial inclusion on carbon emission intensity is -0. 374 and at the 1% confidence level significantly. Regardless of whether control variables are added, digital financial inclusion has a significant negative impact on carbon emission intensity, and hypothesis H1 is verified. From the control variables, it can be seen that the energy consumption structure (CON) has a positive impact on carbon emission intensity, that is, the more energy consumption, the greater the carbon emission intensity. A 1% increase in the level of economic development (GDP) will lead to a reduction in carbon emission intensity of about 0. 476%. The level of economic development is associated with environmental protection technology and high-efficiency technology. The higher the level of economic development, the more likely it is to introduce low-carbon and efficient production technologies. Therefore, it is beneficial to reduce carbon emission intensity; the impact coefficient of foreign investment (FDI) on carbon emission intensity is significantly negative, and foreign direct investment will change the country's industrial structure. The scale of investment in the industry makes the industrial structure gradually change to "three two one", which contributes to the reduction of

carbon emissions; the coefficient of environmental protection (PRO) is significantly negative, Every 1% increase in environmental protection will result in a 0. 148% reduction in carbon emission intensity. The higher the degree of opening to the outside world (OPEN), the more conducive it is to introduce foreign advanced low-carbon technologies and equipment, thereby helping to reduce the total amount of carbon emissions, thereby reducing carbon emission intensity.

Table 4. Benchmark regression results.

VARIABLES	（1） CE	（2） CE
FIN	-0. 550***	-0. 374***
	(-11. 15)	(-4. 88)
CON		0. 665**
		(2. 57)
GDP		-0. 476**
		(-2. 40)
FDI		-0. 018***
		(-6. 32)
PRO		-0. 148***
		(-2. 83)
OPEN		-0. 694**
		(-2. 59)
Constant	5. 335***	8. 782***
	(20. 46)	(5. 39)
Code FE	YES	YES
Year FE	YES	YES
R-squared	0. 533	0. 594
F test	0	0
r2_a	0. 532	0. 586

Robust t-statistics in parentheses *** p<0. 01, ** p<0. 05, * p<0. 1

Intermediary Mechanism Analysis

Theoretical analysis shows that digital financial inclusion can have a certain impact on China's carbon emission intensity by improving the technological innovation level of each province and promoting the adjustment of industrial structure. Therefore, this paper builds a mediation effect model to test. The specific regression results are shown in Table 5.

Analysis on the Transmission Mechanism of Technological Innovation Level.

Digital inclusive finance can effectively alleviate the financing constraints of small and medium-sized enterprises, provide financial support for

Table 5. Mediating effect regression results

VARIABLE	Technological innovation level effect			Effect of upgrading and adjusting industrial structure		
	(1) CE	(2) INN	(3) CE	(4) CE	(5) UPGRADE	(6) CE
FIN	-0. 374***	0. 432***	-0. 293***	-0. 374***	0. 035***	-0. 327***
	(-4. 88)	(5. 50)	(-3. 25)	(-4. 88)	(4. 74)	(-5. 78)
INN/UPGRADE			-0. 189*			-1. 375**
			(-1. 76)			(-2. 01)
control variable	YES	YES	YES	YES	YES	YES
Provincial control	YES	YES	YES	YES	YES	YES
Year control	YES	YES	YES	YES	YES	YES
_cons	-0. 374***	-5. 487**	7. 746***	-0. 374***	1. 597***	10. 978***
	(-4. 88)	(-2. 36)	(5. 90)	(-4. 88)	(9. 21)	(7. 02)
adj. R2	0. 594	0. 787	0. 602	0. 594	0. 727	0. 599
indirect effect	Partial mediation effect The intermediate effect accounted for 21. 83%			Partial mediation effect The intermediate effect accounted for 12. 86%		

Robust t-statistics in parentheses *** p<0. 01, ** p<0. 05, * p<0. 1

technological progress and innovative research and development of enterprises, and effectively improve the level of technological innovation, thereby affecting the total carbon emissions and carbon emission intensity. Therefore, in order to further test the impact path of digital financial inclusion on carbon emission intensity, the mediation effect model is used to test whether technological progress is a mediating variable. According to the judgment standard of mediating variables, the level of technological innovation shows a partial mediating effect, and the size of the mediating effect is 21. 83%. Column (2) shows that the influence coefficient of digital financial inclusion development on technological progress is 0. 432, which is significant at the 1% confidence level, indicating that the vigorous development of digital financial inclusion has a positive effect on the technological innovation level of each province. In column (3), two indicators of technological innovation and digital inclusive finance index are added. The regression results show that technological progress has a negative impact on the carbon emission intensity of each province, that is, technological progress is conducive to reducing carbon emission intensity and

achieving the effect of carbon emission reduction. It shows that digital inclusive finance provides more financing channels for innovative entities such as enterprises and scientific research institutions, thus effectively promoting technology research and development in the fields of energy conservation, emission reduction and green environmental protection, and improving the technological innovation capacity of provinces, thus contributing to the further reduction of carbon emission intensity. Suppose H2a is verified.

Analysis on the Transmission Mechanism of Industrial Structure Upgrading and Adjustment.

Columns (4), (5) and (6) in Table 5 are the regression results of using the three-step method to test the adjustment of industrial structure as an intermediary variable. According to the judgment standard of intermediary effect, in the process of the effect of digital inclusive finance on carbon emission intensity, the upgrading and adjustment of industrial structure has a certain intermediary effect, and its effect size is 12. 86%. The regression results in column (5) show that digital financial inclusion significantly promotes the optimization and adjustment of industrial structure. After controlling the intermediary variable of industrial structure upgrading, digital financial inclusion has a significant negative impact on carbon emission intensity. The element allocation effect of digital inclusive finance can realize the optimal allocation of resources among different industries, thereby promoting the optimization and adjustment of industrial structure, and gradually shifting the industrial structure from "one, two, three" industries to "three, two, one" industrial structures. To sum up, the development of digital inclusive finance can effectively promote the rational allocation of resources, provide financial support for the development of various industries, promote the rapid development of high-tech industries to promote the optimization and adjustment of industrial structure, and make high-pollution and high-energy-consuming enterprises gradually Transform to a green and environment-friendly enterprise, so as to effectively reduce carbon emissions. Therefore, hypothesis H2b is verified.

Robustness check

The empirical research results show that the development of digital financial inclusion can help reduce carbon emission intensity. In order to verify the reliability of the results, the article conducts a robustness test by changing the explained variables, changing the sample size, and shrinking the tail. The specific results are shown in Table 6.

Change the explained variable.

This paper further conducts a robustness test by changing the calculation method of the explained variable carbon emission intensity. This paper uses the carbon emission data of China's provinces collated by the China Carbon Accounting Database (CEADs) to calculate the carbon emission intensity. Due to the lack of data for 2020 and 2021, this paper uses linear interpolation to supplement it. The regression results are shown in columns (1) and (2) of Table 6. Regardless of whether the control variable

Table 6. Regression results of robustness test

VARIABLES	Change the explained variable		Excluding four municipalities and Hainan province		Tailing treatment	
	(1) CE2	(2) CE2	(3) CE	(4) CE	(5) CE	(6) CE
FIN	-0. 458***	-0. 342***	-0. 550***	-0. 313***	-0. 547***	-0. 352***
	(-9. 65)	(-5. 69)	(-9. 88)	(-3. 58)	(-10. 70)	(-4. 80)
CON		0. 599		0. 698**		0. 678**
		(1. 01)		(2. 43)		(2. 55)
GDP		-0. 349*		-0. 683***		-0. 407**
		(-2. 02)		(-2. 85)		(-2. 08)
FDI		-0. 011***		-0. 016***		-0. 316**
		(-5. 07)		(-4. 96)		(-2. 11)
PRO		-0. 092**		-0. 168***		-0. 134**
		(-2. 11)		(-3. 11)		(-2. 43)
OPEN		-0. 874***		-0. 922**		-0. 688**
		(-4. 17)		(-2. 31)		(-2. 06)
Constant	4. 231***	6. 815***	5. 563***	10. 614***	5. 316***	8. 083***
	(16. 89)	(3. 39)	(19. 03)	(5. 58)	(19. 67)	(5. 20)
Code	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES
R-squared	0. 477	0. 528	0. 507	0. 578	0. 531	0. 603
F test	1. 46e-10	0	6. 27e-10	0	0	0
r2_a	0. 475	0. 519	0. 505	0. 568	0. 530	0. 596
F	93. 19	518. 9	97. 54	940. 8	114. 5	31. 56

Robust t-statistics in parentheses *** p<0. 01, ** p<0. 05, * p<0.

digital financial inclusion is added or not, it has a significant inhibitory effect on the carbon emission intensity of each province. After adding the control variables, every 1% increase in the digital financial inclusion index will lead to a 0. 342% reduction in carbon emission intensity, achieving the effect of carbon emission reduction. The symbols of the influence coefficients of other control variables are consistent with the benchmark regression results, which shows that the research conclusions of this paper are robust and reliable.

Excluding the four major municipalities and Hainan Province.

Considering that the municipality directly under the Central Government is a provincial administrative region, the administrative level of the districts and counties under its jurisdiction is equal to that of other provinces and cities, and that Hainan is a special economic zone, which is obviously different from other provinces. Therefore, this paper excludes

the data of Beijing, Tianjin, Shanghai, Chongqing, and Hainan province. The results after changing the sample size are shown in columns (3) (4) of Table 6. No matter whether the control variable digital financial inclusion is added or not, the impact coefficient on carbon emission intensity is negative, which is consistent with the baseline regression, indicating that the original model The regression results are robust and reliable.

Indentation.

In order to avoid the impact of data outliers on the analysis of empirical results, this paper uses Stata17 software to shrink the tail of all variables, so as to achieve the purpose of eliminating the interference of outliers. Regression results Table 6 column (5) (6) shows that no matter whether control variables are added or not, the regression results of the shrinking model are basically consistent with the regression results of the original model, and the development of digital financial inclusion significantly negatively affects carbon emission intensity, and in It is significant at the confidence level of %, indicating that the regression results of the original model are robust and reliable.

Heterogeneity test

Scale heterogeneity.

Table 7. Panel instrumental variable quantile regression model results

VARIABLES	(1) q20	(2) q40	(3) q60	(4) q80
FIN	-0. 402***	-0. 593***	-0. 685***	-0. 537***
	(0. 0969)	(0. 151)	(0. 150)	(0. 111)
CON	1. 439***	2. 273***	2. 696***	2. 579***
	(0. 337)	(0. 364)	(0. 262)	(0. 371)
GDP	0. 00785	0. 195	0. 160	0. 0485
	(0. 0817)	(0. 121)	(0. 122)	(0. 150)
PRO	0. 00127	-0. 0146	-0. 0224	-0. 0488
	(0. 228)	(0. 281)	(0. 311)	(0. 323)
FDI	0. 0154	0. 939**	1. 211***	1. 044***
	(0. 172)	(0. 387)	(0. 190)	(0. 292)
OPEN	-0. 0227	0. 303	0. 197	-0. 844**
	(0. 117)	(0. 232)	(0. 251)	(0. 368)
Constant	2. 102**	0. 230	1. 139	2. 820*
	(0. 892)	(1. 487)	(1. 234)	(1. 700)

Robust t-statistics in parentheses *** p<0. 01, ** p<0. 05, * p<0. 1

Since the estimation method of the panel instrumental variable quantile model is not easily affected by extreme values and can reflect the regression results more comprehensively, this paper uses quantile regression for robustness testing. The specific results are shown in Table 7. At the 20% quantile point, the regression coefficient between digital financial inclusion and carbon emission

intensity is -0. 402, indicating that at the 20% quantile point, digital financial inclusion promotes the reduction of carbon emission intensity. At the 40% quantile point, the correlation coefficient between digital financial inclusion and carbon emission intensity is -0. 593, which is significant at the 1% confidence level. At the 60% quantile point, the negative impact coefficient of digital financial inclusion on carbon emission intensity reaches the maximum -0. 685, which is significant at the 1% confidence level. At the 80% quantile point, digital financial inclusion Although the absolute value of the impact coefficient on carbon emission intensity is lower than that at the 60th percentile point, the development of digital financial inclusion still has a negative impact on carbon emission intensity. Although there are differences in the impact of digital financial inclusion index on carbon emission intensity at different quantiles, they all have a negative impact, and they are all significant at the 1% confidence level. It shows that digital financial inclusion can significantly reduce carbon emission intensity, and at the 60% quantile point, the impact coefficient of digital financial inclusion on carbon emission reduction is the most obvious.

Regional heterogeneity.

Due to the differences in geographical location, terrain, resources and environment among provinces, the development degree of digital inclusive finance in each province is inconsistent. Therefore, the promotion or inhibition effect of digital inclusive finance on carbon emission intensity and whether the effect is significant may vary depending on the region. In order to further investigate the regional differences of digital inclusive finance on carbon emission intensity, this paper divides the selected 30 provinces into three parts: central, eastern and western. The regression results are shown in Table 8. No matter whether control variables are added or not, digital financial inclusion has a negative impact on carbon emission intensity in the central, eastern and western regions. When the regression results are not significant after the control variables are added to the western region, the other models are statistically significant. Table 8 (1) (2) shows the regression results of the eastern region. After adding control variables, the influence coefficient of digital inclusive finance on carbon emission intensity is -0. 369 and becomes significant at 1% confidence level, indicating that the development of digital inclusive finance in the eastern region has significantly promoted carbon emission reduction. Secondly, Table 8 (3) (4) shows the regression results of the central region. After adding control variables, every 1% increase in the digital inclusive finance index will lead to a 0. 19% reduction in carbon emission intensity, indicating that the vigorous development of digital inclusive finance in the central region also has a inhibitory effect on carbon emission intensity. Table 8 (5) (6) shows the regression results of the western region. The addition of control variables results in a negative but insignificant influence coefficient of digital financial inclusion on carbon emission intensity. The possible reasons are as follows: On the one hand, due to the

Table 8. Regression results of East and West

VARIABLES	Eastern Region		Middle Region		Western Region	
	(1) CE	(2) CE	(3) CE	(4) CE	(5) CE	(6) CE
FIN	-0. 513***	-0. 369***	-0. 224*	-0. 187***	-0. 577***	-0. 247
	(-10. 55)	(-6. 05)	(-2. 15)	(-4. 37)	(-5. 13)	(-1. 41)
CON		0. 939		0. 300***		0. 833
		(1. 37)		(3. 48)		(0. 89)
GDP		-0. 352***		-0. 822***		-0. 890
		(-3. 31)		(-3. 86)		(-1. 45)
FDI		-0. 028		-0. 401		-0. 014
		(-0. 54)		(-1. 57)		(-1. 43)
PRO		-0. 158		0. 037		-0. 191**
		(-1. 56)		(0. 29)		(-2. 89)
OPEN		-0. 692*		2. 263***		-0. 164
		(-1. 99)		(4. 65)		(-0. 08)
Constant	4. 413***	6. 941***	54. 077*	46. 931***	6. 108***	12. 725**
	(16. 82)	(5. 78)	(2. 27)	(5. 06)	(10. 47)	(2. 79)
Observations	132	132	110	110	88	88
Number of code	12	12	10	10	8	8
R-squared	0. 800	0. 862	0. 323	0. 588	0. 412	0. 477
F test	4. 32e-07	3. 63e-06	0. 0635	3. 77e-05	0. 000901	0
r2_a	0. 798	0. 855	0. 316	0. 564	0. 406	0. 439
F	111. 3	29. 53	4. 635	25. 32	26. 28	3904

Robust t-statistics in parentheses *** p<0. 01, ** p<0. 05, * p<0.

shortage of human resources, imperfect network structure and weak infrastructure construction in the western region, the development of digital inclusive finance is in its infancy, so the increase in resource consumption brought by the early development of digital inclusive finance offsetting the dividends brought by digital inclusive finance; On the other hand, it may be due to the serious mismatch of production factors in the production process of various industries and the low development level of digital inclusive finance, which cannot effectively promote the adjustment of industrial structure and technological progress, and limits the effective allocation of resources, so that the impact of digital inclusive finance on carbon emission intensity is not significant in the western region.

Type heterogeneity.

Table 9. Regression results of sub-dimensions of digital financial inclusion

VARIABLES	Breadth of digital financial inclusion coverage		Depth of use of digital financial inclusion		Degree of digitalization of digital financial inclusion	
	(1) CE	(2) CE	(3) CE	(4) CE	(5) CE	(6) CE
WID	-0. 451***	-0. 278***				
	(-11. 31)	(-4. 60)				
DEP			-0. 570***	-0. 378***		
			(-11. 33)	(-4. 88)		
DIG					-0. 454***	-0. 208***
					(-8. 04)	(-3. 26)
CON		0. 645**		0. 773***		0. 632**
		(2. 34)		(3. 26)		(2. 40)
GDP		-0. 561***		-0. 502**		-0. 887***
		(-2. 89)		(-2. 41)		(-4. 27)
FDI		-0. 017***		-0. 018***		-0. 019***
		(-5. 81)		(-6. 52)		(-5. 27)
PRO		-0. 146***		-0. 165***		-0. 180***
		(-2. 87)		(-3. 46)		(-2. 89)
OPEN		-0. 521*		-0. 753***		-1. 006***
		(-1. 82)		(-2. 93)		(-3. 31)
Constant	4. 750***	9. 047***	5. 430***	8. 980***	4. 953***	12. 144***
	(23. 14)	(5. 38)	(20. 50)	(5. 19)	(15. 78)	(6. 69)
Observations	330	330	330	330	330	330
Number of code	30	30	30	30	30	30
R-squared	0. 525	0. 591	0. 513	0. 586	0. 391	0. 555
F test	0	0	0	0	7. 17e-09	0
r2_a	0. 523	0. 583	0. 511	0. 578	0. 389	0. 547
F	127. 9	889. 7	128. 4	1259	64. 70	344. 6

Robust t-statistics in parentheses *** p<0. 01, ** p<0. 05, * p<0.

According to the Peking University Digital Financial Inclusion Sub-Index, three indicators of coverage breadth (WID), depth of use (DEP) and digitization degree (DIG) were further used to verify the impact of digital financial inclusion on carbon emission intensity. The specific results are shown in Table 9. Regardless of whether control variables are added or not, digital financial inclusion has an inhibitory effect on carbon emission intensity. It can be seen from column (2) that the expansion of the coverage breadth of digital inclusive finance can reach areas and

fields that are difficult to reach by traditional finance, providing convenience for enterprises in various provinces to research and develop new products and use new technologies, thus promoting enterprises to research and develop low-carbon and efficient new products and technologies, and further reduce energy consumption to achieve carbon emission reduction. It can be seen from column (4) that the depth of use of digital inclusive finance has a significant negative impact on carbon emission intensity. In the process of extending the depth of use of digital inclusive finance, diversified financing and financing methods are provided for enterprises, and financial support and guarantee are provided for enterprises to carry out low-carbon production, thus contributing to carbon emission reduction. Column (6) The enhancement of digitalization makes the payment method more convenient, reduces the cost of financial services, activates the efficient flow of capital factors among provinces, and encourages enterprises to adopt low-carbon technologies, thus effectively realizing carbon emission reduction. However, as can be seen from Table 9, there are differences in the impact coefficients of various dimensions of digital inclusive finance. The depth of use has the greatest effect on carbon emission reduction, while the degree of digitalization is relatively low. This indicates that China's digital infrastructure is still relatively weak, the hardware equipment and facilities of digital inclusive finance are not perfect, and the digitalization level needs long-term investment and continuous improvement.

Conclusion and Suggestions

In recent years, digital financial inclusion and low-carbon economy have become hot issues of global concern. In this paper, the panel data of 30 provinces in China from 2011 to 2021 are selected and the bidirectional fixed effect model is constructed based on the results of Hausmann test to empirically test the impact of digital financial inclusion on carbon emission intensity and its influencing mechanism. The results of this paper are as follows: (1) The benchmark regression results show that the higher the index of digital financial inclusion, the lower the carbon emission intensity. (2) The results of the intermediary effect model show that the development of digital inclusive finance helps to promote the improvement of regional innovation level, which in turn leads to the reduction of carbon emission intensity, and the development of digital inclusive finance helps to rationally allocate resources to promote the upgrading and adjustment of industrial structure, which in turn reduces carbon emission intensity. (3) Heterogeneity test results show that digital inclusive finance has the largest negative effect on carbon emission intensity at 60% of the sub-sites; The negative impact of digital inclusive finance on carbon emission intensity in different regions is significant at the confidence level of 1%, and the influence coefficient is larger in the eastern region. The coverage breadth, depth of use and degree of digitization of the secondary indicators of digital inclusive finance have a significant inhibitory effect on carbon emission intensity, which is manifested as the strongest use depth,

the second coverage breadth, and the weakest digitalization degree.

Therefore, this paper puts forward the following suggestions: (1) Implement the differentiated development strategy of digital inclusive finance. Digital financial inclusion should be vigorously developed to promote carbon reduction. Due to different geographical locations, terrain and resource endowments, digital financial inclusion has different impacts on carbon emission intensity in the Middle East and western regions of China. Therefore, for regions with weak financial foundation and imperfect institutional environment, it is necessary to accelerate the construction of financial infrastructure and improve the construction of digital financial inclusion system. For digital financial inclusion developed areas should increase technology research and development, reduce the cost of financial services, improve the level of financial services and service efficiency to promote carbon emission reduction. In addition, the development level and promotion degree of regional digital inclusive finance should be fully considered, and the policy requirements for the integration of digital inclusive finance and carbon emission reduction should be formulated according to local conditions, and timely adjusted according to the implementation effect. 2) Vigorously promoting industrial restructuring. To promote the coordinated development effect of "one, two and three" industries, the government should promote the rational layout of industrial structure, promote the effective transfer of resource factors, low-end and high-energy-consuming industries should change their development mode to high-end and low-carbon industries, promote the coordinated, healthy and orderly development of various industries, and increase the proportion and level of service industries with low carbon emissions. Make full use of the advantages of digital inclusive finance to open the technical window in the process of industrial structure upgrading to help carbon emission reduction, encourage the research and development and application of low-carbon technologies, and help China's carbon emission reduction cause. Secondly, the Middle East and western region should rationally arrange the industrial structure, promote the effective allocation of resources and improve their utilization efficiency. 3) Promoting technological innovation. Local governments should actively expand the investment of financial funds in technology research and development, and actively promote the incentive policy of technological innovation. Formulate policies for the introduction of low-carbon innovative talents, give full play to the big data network and cloud computing platform of digital inclusive finance, accurately identify the status of loan enterprises, provide loan support and convenience for high-tech industries, and rely on the research and development of low-carbon technologies and low-carbon products to achieve carbon emission reduction. Adhere to the guidance of low-carbon development, actively carry out technological innovation and reform, strengthen the technological transformation of key industries and heavy polluting enterprises, and promote technological transformation as an im-

portant starting point to promote the development of low-carbon economy.

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