# The Impact of Digital Finance Development on CO₂ Emissions in China

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## Abstract

The problem of environmental pollution caused by massive $CO_2$ emissions is becoming increasingly serious. As an environment-friendly financial service, digital finance is conducive to the development of a low-carbon economy. Based on the panel data of 287 cities in China from 2011 to 2019, this paper uses a two-way fixed-effect model and an intermediary model to study the impact of digital finance on carbon emissions. The empirical analysis results show that: in the whole of China, digital finance has an obvious effect on reducing carbon dioxide emission intensity; the impact of digital finance on carbon emission intensity has regional heterogeneity, and the development of digital finance in eastern China can play a significant role in reducing carbon dioxide emissions. The impact of digital finance on carbon emission intensity is dimensionally heterogeneous, and the development of the usage depth of digital finance and the digitization level can reduce carbon emission intensity; technological progress plays a partial intermediary role in the process of digital finance affecting carbon emissions. Digital finance can drive low-carbon development by promoting the optimization and upgrading of technology. Based on the above conclusions, this paper puts forward corresponding suggestions for the development of China's green and low-carbon economy.

## Keywords

$CO_2$ Emission Intensity, Digital Finance, Mediating Effect

## 1. Introduction

China is the largest $CO_2$ emitter in the world, with 11.9 billion tons of carbon dioxide emissions in 2021, more than one-third of global $CO_2$ emissions (data from the International Energy Agency). In order to control excessive $CO_2$ emissions, improve environmental quality and promote sustainable economic devel-

opment, China has proposed the carbon peaking and carbon neutrality goals, that is, to achieve carbon peaking by 2030 and carbon neutrality by 2060. The development of a low-carbon economy requires financial support. With the rapid development of the Internet, the popularity of smartphones and the rise of digital technology, China's financial development is moving towards digitalization. The development of digital finance can lower the threshold of financial services, ease the financing constraints of enterprises, and have an important impact on the expansion of production scale and technological progress, thereby affecting $CO_2$ emissions and the ecological environment. Therefore, this paper will study whether digital finance can affect $CO_2$ emissions and how to affect $CO_2$ emissions, hoping to provide some ideas for the development of green economy in China.

## 2. Literature Review and Research Hypotheses

Schueffel (2016) summarized previous research results and defined digital finance as an emerging financial industry that applies information technology to improve financial activities. Gomber, Koch, and Siering (2017) believe that digital finance usually refers to the financial business realized by using digital technology. Huang Yiping and Huang Zhuo (2018) believe that digital finance refers to the use of the Internet, big data and other emerging technological innovation services by traditional financial companies and Internet companies in the process of providing financing, credit, payment and other services, in order to extend financial coverage, reduce transaction costs, and improve the efficiency of financial services. The launch of Yu Ebao in 2013 ushered in a new era of rapid development of digital finance in China. Digital finance is a new trend in China's financial development in the new era, and it is the focus of China's economic development. In the context of China's development of green economy and the carbon peaking and carbon neutrality goals, the impact of digital finance on the environment has gradually become a research hotspot. Based on the panel data of Chinese cities, Hui Xianbo (2021) found that the development of digital inclusive finance has a significant role in promoting green total factor productivity in Chinese cities. Liang Qi and others (2021) pointed out that the digital economy can promote the improvement of urban ecological efficiency by promoting the upgrading of industrial structure. Xu Weixiang and others (2022) found that the development of digital economy has obvious spatial heterogeneity, and the development of digital economy in eastern China has a negative effect on carbon emissions.

The role of finance lies in the optimal allocation of resources. Financial development can promote the flow of resources to green development industries with more reasonable allocation and more efficient utilization. Deng Rongrong and Zhang Aoxiang (2022) believe that digital finance, as a further development of traditional finance, is itself a resource-saving and environment-friendly financial service. Digital finance can use the information in the digital platform to guide the flow of financial resources to energy-saving and environmental-friendly enterprises. At the same time, it can promote carbon financial prod-

ucts to the public. Fan Xin and others (2021) believe that digital finance can solve the problem of information asymmetry more accurately and quickly with the help of modern information technologies such as big data, cloud computing, and artificial intelligence, effectively allocate financial resources and improve green total factor productivity. Xu Zhao and others (2021) believe that digital finance has lowered the threshold of financial services, and individuals and enterprises can easily enjoy digital financial services if they meet the conditions. Digital finance breaks the time and space limitations of obtaining financial services. The popularity of online transactions and payments saves transaction time and certain resource consumption, which is conducive to the public to develop green consumption awareness. At the same time, the coverage of digital finance involves all aspects of life, and online platforms have also launched a variety of easy-to-operate green public welfare activities to enhance the enthusiasm of the public to participate in environmental protection activities.

Based on the above analysis, this paper proposes Hypothesis 1: Digital finance has a carbon emission reduction effect.

The IPAT model proposed by Ehrlich and Holdren (1971) shows that the level of technology is one of the important factors affecting the environment. Chen Yang et al. (2019) believe that technological progress is the core means to promote China's carbon emission reduction. In recent years, China's technological innovation has the characteristics of environmental friendliness. Research by Liu Dianlan and Zhou Jieqi (2015) shows that technological advances can curb carbon emissions, and this effect will gradually increase over time. Technological innovation requires financial support. Xie Xuanli and others (2018) believe that with the help of digital technology, digital finance can broaden loan channels, reduce loan costs, improve the allocation efficiency of financial resources, and alleviate the financing problems of some enterprises. After obtaining credit, enterprises will increase investment in research and development and promote technological innovation. Tang Song et al. (2020) believe that the development of digital finance can effectively correct the resource misallocation problem existing in traditional finance and promote technological innovation of enterprises. Enterprises use new technologies in the production process to improve resource utilization efficiency and total factor productivity, and gradually eliminate high-pollution and high-energy-consuming production models, thereby reducing $CO_2$ emissions.

Based on the above analysis, this paper proposes Hypothesis 2: Digital finance can affect $CO_2$ emissions by promoting technological progress.

## 3. Model Setting and Variable Selection

### 3.1. Model Setting

In order to study the impact of digital finance development on $CO_2$ emissions at the urban level in China, this paper draws on the model construction method of Zhao Jun et al. (2020) on the impact of financial development on carbon emis-

sions, and establishes the following benchmark regression model.

$$
\begin{aligned}
\ln CI_{it} = {}&\alpha_0 + \alpha_1 index_{it} + \alpha_2 \ln pgdp_{it} + \alpha_3 \left( \ln pgdp_{it} \right)^2 \\
&+ \sum \alpha_j control_{it} + u_i + v_t + \varepsilon_{it1}
\end{aligned}
\tag{1}
$$

In Equation (1), CI represents $CO_2$ emission intensity; index represents digital financial index; pgdp represents per capita GDP, and the quadratic term is added to test whether the Environmental Kuznets Curve (EKC) proposed by Grossman and Krueger (1992) holds in China, that is, whether there is an inverted "U" relationship between economic growth and $CO_2$ emission intensity. Control represents other control variables, including the level of urbanization (urban), foreign direct investment (fdi), government intervention (gov), and human capital (hc); $i$ and $t$ represent city effect and year effect respectively, $u_i$ is the individual effect, $v_t$ is the time effect, and $\varepsilon_{it}$ is the random error term.

At the same time, this paper draws on the research results of Wen Zhonglin and Ye Baojuan (2014), and uses the stepwise regression method to construct an intermediary effect model on the basis of Equation (1) to explore whether digital finance can have an impact on carbon emission intensity through technological progress. The mediation effect model consists of Equations (2) to (4).

$$
\ln CI_{it} = \beta_0 + \beta_1 index_{it} + \sum \beta_j control_{it} + u_i + v_t + \varepsilon_{it2}
\tag{2}
$$

$$
tech_{it} = \gamma_0 + \gamma_1 index_{it} + \sum \gamma_j control_{it} + u_i + v_t + \varepsilon_{it3}
\tag{3}
$$

$$
\ln CI_{it} = \varphi_0 + \varphi_1 index_{it} + \varphi_2 tech_{it} + \sum \varphi_j control_{it} + u_i + v_t + \varepsilon_{it4}
\tag{4}
$$

In the above equations, tech represents technological progress as a mediating variable. The description of the mediation effect is as follows. First, the overall impact of digital finance on $CO_2$ emission intensity is tested by the size and significance of $\beta_1$, $\beta_1$ represents the total effect of digital finance on $CO_2$ emission intensity. On the premise that $\beta_1$ is significant, observe the significance of $\gamma_1$ and $\varphi_2$, and test the impact of digital finance on technological progress and the impact of technological progress on $CO_2$ emission intensity in turn. The product of the two coefficients $\gamma_1\varphi_2$ represents the mediation effect, and the proportion of the mediation effect in the total effect is $\gamma_1\varphi_2/\beta_1$; $\varphi_1$ represents the direct effect of digital finance on $CO_2$ emission intensity after considering the mediation effect of technological progress. If $\varphi_1$ is significant, it means that technological progress plays a partial mediating role, and if it is not significant, it plays a complete mediating role.

### 3.2. Variable Description

1) Explained variable

This paper selects the natural logarithm of $CO_2$ emission intensity (CI) as the explained variable. $CO_2$ emission intensity is the ratio of total $CO_2$ emission to GDP. The lower the $CO_2$ emission intensity, the lower the $CO_2$ emission per unit of GDP and the higher the energy efficiency. This paper draws on the research method of Ren Xiaosong et al. (2020) to estimate the $CO_2$ emissions at the city

level. The calculation method is as Equation (5).

$$CO_2 = C_1 + C_2 + C_3 = kE_1 + vE_2 + \varphi(\eta E_3) \tag{5}$$

In the above Equation (5), $CO_2$ represents the total amount of $CO_2$ emissions; $C_1$, $C_2$, and $C_3$ respectively represent the $CO_2$ emissions caused by natural gas, liquefied petroleum gas and electricity consumption in the whole society; $E_1$, $E_2$ and $E_3$ represent the natural gas consumption, LPG consumption and electricity consumption of the whole society in turn; $k$ is the $CO_2$ conversion coefficient of natural gas, $v$ is the $CO_2$ conversion coefficient of LPG, $\varphi$ is the greenhouse gas emission coefficient of the coal power fuel chain, and $\eta$ is the proportion of coal power in the total power generation.

2) Core explanatory variables

Digital Finance (index). This paper uses the comprehensive index of inclusive finance compiled by the Digital Finance Research Center of Peking University to measure the development level of digital finance in each city. This data comes from the research results of Guo Feng et al. (2020). At the same time, three different dimensions of digital finance are considered, namely, digital finance coverage breadth index (breadth), usage depth index (depth), and digitization level (digit).

3) Other variables

Mediating variable: technological progress (tech). The ratio of science and technology expenditure to the general budget expenditure of local finance is used to express the technological progress at the city level.

Control variables: economic growth level (lnpgdp), expressed by the natural logarithm of per capita GDP; urbanization level (urban), expressed by the proportion of urban construction land to urban area; foreign direct investment (fdi), expressed by the ratio of the actual amount of foreign capital used to GDP; government intervention (gov) is expressed by the proportion of the general budgetary expenditure of the local government to GDP; human capital (hc) is expressed by the proportion of the number of undergraduates and junior colleges in the total population.

### 3.3. Data Sources and Descriptive Statistics

This paper uses the panel data of 287 cities in China from 2011 to 2019 as the research sample. Most of the city-level data comes from the "China Urban Statistical Yearbook", and the proportion of coal power comes from the "China Electricity Yearbook". Individual missing values were filled by consulting the statistical yearbooks of relevant cities and linear interpolation. The data in all the following tables are sorted and calculated from the original data in the Statistical Yearbook, and are derived by stata16 software according to the corresponding model formula.

Table 1 is the descriptive statistics of the main variables. It can be seen from Table 1 that the carbon emission intensity of different cities in China is different, which means that the efficiency of energy utilization in different regions is different; the development degree of digital finance in different cities is also quite different.

Table 1. Descriptive statistics of the main variables.

| Variable Name | Variable Symbol | Observations | Mean | Sd. | Min. | Max. |
|---|---|---|---|---|---|---|
| $CO_2$ emission intensity | lnCI | 2583 | 6.24 | 0.87 | 3.62 | 10.07 |
| digital finance | index | 2583 | 165.40 | 65.45 | 17.02 | 321.60 |
| coverage_breadth | breadth | 2583 | 155.60 | 63.52 | 1.86 | 310.90 |
| usage_depth | depth | 2583 | 163.10 | 67.99 | 4.29 | 332.00 |
| digitization_level | digit | 2583 | 201.70 | 81.91 | 2.70 | 581.20 |
| technical progress | tech | 2583 | 1.63 | 1.66 | 0.06 | 20.68 |
| per capita GDP | lnpgdp | 2583 | 10.71 | 0.59 | 8.77 | 15.68 |
| urbanization level | urban | 2583 | 9.18 | 22.62 | 0.14 | 834.00 |
| foreign direct investment | fdi | 2583 | 1.94 | 2.75 | 0.00 | 77.48 |
| government intervention | gov | 2583 | 25.07 | 27.14 | 4.39 | 604.10 |
| human capital | hc | 2583 | 1.88 | 2.44 | 0.00 | 13.11 |

## 4. Empirical Results and Analysis

### 4.1. Benchmark Regression Results

The Hausman test was performed on the benchmark regression model, and the test result rejected the null hypothesis, so the fixed-effects model was selected. In addition, due to the different development levels of each city, there are obvious individual differences, and variables such as carbon emission intensity will also change with time, so this paper chooses a two-way fixed effect model to control the individual effect and the time effect.

Table 2 shows the results of the regression of the above Equation (1) using the two-way fixed effect model. The regression (1) does not add control variables, and digital finance reduces the carbon emission intensity at a significant level of 1%. Regression (2) adds per capita GDP and its quadratic term to verify whether the Environment Kuznets Curve (EKC) holds in China. From the results, it can be seen that the coefficients of the primary and quadratic terms of per capita GDP satisfy the condition of the inverted "U" shape, but they are not significant, indicating that the environmental curve is not significantly established in China. Regression (3) adds other control variables, digital finance has a negative impact on $CO_2$ emission intensity at a 5% significance level, indicating that digital finance has a significant carbon reduction effect, which verifies the above hypothesis 1. Among the control variables, the level of urbanization can significantly reduce $CO_2$ emission intensity, probably because urbanization will lead to population concentration and energy agglomeration, and more scientific production technology will be used in cities, which can reduce energy consumption and improve energy utilization. At the same time, the consumption habits of the urban population are more inclined to green environmental protection, so the improvement of the urbanization level will help reduce the carbon emission intensity. The coefficient of foreign investment is not significant but positive, which

will promote China's carbon emissions as a whole. Foreign investment will carry out industrial transfer, and transfer high-polluting and high-energy-consuming enterprises to China, causing damage to China's ecological environment to a certain extent. Government intervention has significantly boosted carbon emission intensity. The possible reason is that government spending is mostly used for infrastructure construction, which will promote the development of labor-intensive industries, thereby causing pollution to the environment, indicating that excessive government intervention is not conducive to China's carbon emission reduction. The coefficient of human capital is not significantly negative, indicating that the concentration of talents can promote the development of local green environmental protection undertakings.

Table 2. Benchmark regression results.

| | (1) | (2) | (3) |
|---|---|---|---|
| | lnCI | lnCI | lnCI |
| index | −0.008*** | −0.007** | −0.006** |
| | (0.0028) | (0.0029) | (0.0027) |
| lnpgdp | | 2.276 | 1.460 |
| | | (1.4744) | (0.9474) |
| lnpgdp2 | | −0.103 | −0.065 |
| | | (0.0685) | (0.0433) |
| urban | | | −0.001** |
| | | | (0.0003) |
| fdi | | | 0.012 |
| | | | (0.0089) |
| gov | | | 0.011*** |
| | | | (0.0024) |
| hc | | | −0.006 |
| | | | (0.0421) |
| _cons | 6.433*** | −6.058 | −1.938 |
| | (0.1484) | (7.9832) | (5.2068) |
| city effect | Yes | Yes | Yes |
| time effect | Yes | Yes | Yes |
| $R^2$ | 0.573 | 0.579 | 0.673 |
| F | 89.437 | 78.102 | 149.136 |
| N | 2583 | 2583 | 2583 |

a. * * *, **, * respectively indicate that the correlation coefficient is significant at the level of 1%, 5% and 10%; the standard deviation is in brackets, and the table below is the same.

## 4.2. Robustness Test

1) Instrumental variable estimation

The regression in this paper may have some endogeneity problems. First, there are many factors that affect the intensity of $CO_2$ emissions. Although the above model controls the relevant variables as much as possible, there is still the problem of missing variables. Secondly, areas with lower $CO_2$ emission intensity may be more conducive to the development of digital finance, which leads to the problem of two-way causality. Therefore, this paper adopts the method of instrumental variable estimation to alleviate the endogeneity problem, and selects the number of mobile phone users at the end of the year as the instrumental variable. The rapid development of digital finance is inseparable from the popularization of mobile phones. At present, people can enjoy most of the digital financial services through mobile phones, which well meets the conditions of relevance. As an infrastructure construction, mobile communication is promoted by the state, which satisfies the exogenous condition. Regression (1) in Table 3 is the estimation result of the first stage. It can be seen that there is a very significant positive correlation between the number of mobile phone users and the digital financial index. At the same time, the F statistic of the first stage is 15.47, which is greater than the critical value of 10. It can be considered that there is no weak instrumental variable. The regression results show that the instrumental variable selected in this paper are effective because it rejects the null hypothesis of insufficient identification of instrumental variables and weak identification. Regression (2) in Table 3 is the estimation result of the second stage. There is a

**Table 3.** Robustness test.

|  | (1) | (2) | (3) |
|---|---|---|---|
|  | index | lnCI | lnCI |
| index |  | −0.033** | −0.005** |
|  |  | (0.0135) | (0.0027) |
| phone | 0.011*** |  |  |
|  | (0.0027) |  |  |
| control variables | Yes | Yes | Yes |
| _cons | Yes | Yes | Yes |
| city effect | Yes | Yes | Yes |
| time effect | Yes | Yes | Yes |
| Kleibergen-Paap rk LM | 13.051 |  |  |
| Cragg-Donald Wald F | 67.001 |  |  |
| Kleibergen-Paap rk Wald F | 15.469 |  |  |
| $R^2$ | 0.994 | 0.635 | 0.679 |
| N | 2583 | 2583 | 2547 |

significant negative correlation between digital finance and $CO_2$ emission intensity. And the absolute value of the coefficient is larger than that of the benchmark regression result, indicating that the estimation result of the instrumental variables is robust, which further proves that the carbon emission reduction effect of digital finance is significantly tenable.

2) Delete the sample of municipalities directly under the Central Government

The development of cities in China is uneven, and the impact of digital finance on $CO_2$ emission intensity may be inconsistent. The four municipalities directly under the Central Government, namely Beijing, Shanghai, Tianjin and Chongqing, occupy an important position in the country's political economy and culture, and will have an economic radiation effect on the surrounding cities. Therefore, this paper deletes the samples of these four municipalities, and the regression results are shown in regression (3) in Table 3. Digital finance still significantly reduces the $CO_2$ emission intensity, which confirms the robustness of the above empirical results.

### 4.3. Heterogeneity Analysis

1) Regional heterogeneity

Unbalanced development among regions in China. The development of the eastern region is at the forefront of China and is in a leading position in economic transformation and upgrading. The development of the central and western regions is relatively slow and mostly relies on energy-consuming industries. Therefore, $CO_2$ emissions in different regions will be different. At the same time, the popularity of smartphones and the Internet is high in the east and low in the west, and the development level of digital finance varies from region to region. There may be differences in the impact of digital finance on carbon emissions in different regions.

This paper divides the sample data into three parts according to the region. The regressions (1)-(3) in Table 4 represent the effect of digital finance development on $CO_2$ emission intensity in the eastern, central and western regions. The results show that the impact of digital Finance on $CO_2$ emission intensity has regional heterogeneity. The improvement of the level of digital finance in eastern China can significantly reduce the intensity of $CO_2$ emissions at the level of 10%. The digital finance in central China can promote $CO_2$ emissions but not significantly, and the digital finance in western China has an insignificant emission reduction effect. The possible reason is that the development level of digital finance in eastern China is at the forefront of the country, and the development of digital finance can promote technological progress and industrial upgrading in the eastern region to reduce the intensity of $CO_2$ emissions. The economic development of central China is still inseparable from the secondary industry. The development of digital finance is conducive to the enterprises in the central region to further expand their production scale and promote carbon emissions. In western China, the regression coefficient of digital finance is not significant. It

Table 4. Regional heterogeneity analysis.

| | (1) | (2) | (4) |
|---|---|---|---|
| | Eastern China | Central China | Western China |
| index | −0.007* | 0.002 | −0.003 |
| | (0.0039) | (0.0036) | (0.0051) |
| lnpgdp | 0.787 | 10.474*** | −0.747 |
| | (1.5756) | (2.3227) | (1.109) |
| lnpgdp2 | −0.032 | −0.494*** | 0.023 |
| | (0.0685) | (0.1104) | (0.0454) |
| urban | −0.001*** | −0.003 | −0.001 |
| | (0.0002) | (0.004) | (0.007) |
| fdi | 0.009 | 0.010 | 0.075* |
| | (0.0138) | (0.0087) | (0.0423) |
| gov | 0.027*** | 0.008*** | 0.012*** |
| | (0.0021) | (0.0028) | (0.0030) |
| hc | 0.094* | 0.041 | −0.110* |
| | (0.0531) | (0.0786) | (0.0592) |
| _cons | 1.213 | −49.724*** | 11.193* |
| | (9.0426) | (12.2602) | (6.6196) |
| city effect | Yes | Yes | Yes |
| time effect | Yes | Yes | Yes |
| $R^2$ | 0.705 | 0.761 | 0.653 |
| F | 62.595 | 67.073 | 69.995 |
| N | 900 | 900 | 783 |

may be that the development of the western region is relatively slow, and the insufficient development environment and conditions limit the carbon emission reduction effect of digital finance. In terms of control variables, the inverted "U"-shaped environmental Kuznets curve is significantly established in central China; the level of urbanization in eastern China can significantly restrain the expansion of carbon emission intensity; foreign direct investment significantly damages the environment in western China, increasing the intensity of carbon emissions in the western region; government intervention significantly increases $CO_2$ emission intensity nationwide; human capital promotes the increase in $CO_2$ emission intensity in eastern China, and can significantly reduce $CO_2$ emission intensity in the western region.

2) Dimensional heterogeneity of digital finance

Digital finance specifically affects $CO_2$ emissions through three dimensions: coverage breadth, usage depth and digitization level. The greater the coverage of digital finance, the greater the popularization of financial services. The usage

depth of digital finance refers to the actual use of payment, credit, insurance, investment and other digital financial services by the public. The digitization level of digital finance includes mobility, affordability, credit and facilitation. The development of these three dimensions will have an impact on the use of financial services, which will affect $CO_2$ emissions. Due to the different degrees of development of these three dimensions, the impact on carbon emissions may be different.

Table 5 examines the heterogeneous impact of different dimensions of digital finance on $CO_2$ emission intensity. Regression (1) shows that the coverage of digital finance will increase $CO_2$ emissions, and regression (2) and (3) show that the usage depth and digitalization of digital finance can inhibit $CO_2$ emissions at the significance level of 1% and 10% respectively. The development of digital finance in different dimensions has obvious differences in the impact on $CO_2$ emission intensity. Improving the usage depth and digitization of digital finance is more conducive to reducing the intensity of $CO_2$ emissions and achieving high-quality economic development in China.

## 4.4. Analysis of Mediation Effect

In order to verify the mediating role of technological progress between digital finance and $CO_2$ emission intensity, the mediation Equations (2)-(4) are regressed, and the results are shown in Table 6. Regression (2) shows that there is a significant positive correlation between digital finance and urban technological progress, and digital finance significantly promotes technological progress at the

Table 5. Dimensional heterogeneity analysis of digital finance.

|  | (1) | (2) | (3) |
|---|---|---|---|
|  | lnCI | lnCI | lnCI |
| breadth | 0.001 |  |  |
|  | (0.0027) |  |  |
| depth |  | −0.005*** |  |
|  |  | (0.0016) |  |
| digit |  |  | −0.001* |
|  |  |  | (0.0006) |
| _cons | −2.013 | −1.145 | −1.737 |
|  | (5.7154) | (5.2132) | (5.4508) |
| control variables | Yes | Yes | Yes |
| city effect | Yes | Yes | Yes |
| time effect | Yes | Yes | Yes |
| $R^2$ | 0.671 | 0.673 | 0.672 |
| F | 138.861 | 154.705 | 142.319 |
| N | 2583 | 2583 | 2583 |

**Table 6.** Intermediary effect test.

| | (1) | (2) | (3) |
|---|---|---|---|
| | lnCI | tech | lnCI |
| index | −0.006** | 0.026*** | −0.005* |
| | (0.0027) | (0.0051) | (0.0026) |
| tech | | | −0.038*** |
| | | | (0.0141) |
| _cons | −1.938 | −4.392 | −2.104 |
| | (5.2068) | (6.9300) | (5.0374) |
| control variables | Yes | Yes | Yes |
| city effect | Yes | Yes | Yes |
| time effect | Yes | Yes | Yes |
| $R^2$ | 0.673 | 0.079 | 0.675 |
| F | 149.136 | 8.069 | 145.244 |
| N | 2583 | 2583 | 2583 |

1% level. The result of regression (3) means that the improvement of technological level can promote carbon emission reduction. In the case of controlling the mediating effect of technological progress, the direct effect of digital finance on $CO_2$ emissions is still significantly inhibited, which indicates that technological progress has played a partial mediating role, accounting for 16.47% of the total effect. The above analysis shows that digital finance can inhibit $CO_2$ emissions by promoting the improvement of technological level at the city level and improving the level of energy utilization, which verifies hypothesis 2.

## 4.5. Summary of Empirical Results

Based on panel data of 287 cities in China from 2011 to 2019, this paper uses a two-way fixed-effects model to study the relationship between digital finance and $CO_2$ emission intensity. The research results show that the development of digital finance can significantly reduce China's $CO_2$ emission intensity, and the conclusion is still valid after deleting the sample of municipalities and using the number of mobile phone users at the end of the year as an instrumental variable to estimate. The impact of digital finance on $CO_2$ emission intensity has regional heterogeneity and dimensional heterogeneity. Digital finance in the eastern region will significantly inhibit the growth of $CO_2$ emission intensity. The improvement of the usage depth and digitization levell of digital finance is conducive to energy conservation and emission reduction. Technological progress plays a partial intermediary role in the process of reducing $CO_2$ emission intensity by digital finance. Digital finance can reduce $CO_2$ emission intensity by promoting the improvement of technological level.

## 5. Recommendations

According to the research in this paper, this paper puts forward some suggestions for China to take a green and low-carbon economic path of sustainable development and achieve the dual-carbon goal: 1) Vigorously develop a digital finance, accelerate the construction of digital financial system, improve the development environment of digital finance, and clarify the corresponding regulatory requirements. 2) While improving the popularity of digital finance, it is necessary to pay more attention to the development of the usage depth and digitalization level of digital finance, improve the actual use and convenience of digital finance, and the development of credit, so that digital finance can play a greater role in reducing emissions effect. 3) Promote the coordinated development of digital finance in different regions, and implement the differentiated development strategy according to local conditions, so as to give full play to the emission reduction benefits of digital finance in all regions and promote the development of green economy. 4) Promote the innovative development of digital finance, develop new digital financial services, enable digital finance to better support the development of individuals and enterprises, and give full play to the intermediary role of technological progress. Encourage technological innovation at the city level, apply environmental protection technologies, and achieve high-quality economic development. 5) Increase the training of relevant talents, focus on solving the current situation of uneven distribution of human resources in regions, and import more high-level talents into central and western China to inject vitality into economic development.

## Fund Project

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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