Study on the Impact of Digital Finance on Carbon Emissions

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Abstract. This paper explores the relationship between digital finance and carbon emissions using a Two-way Fixed Effects Model based on provincial panel data from 2011-2019. The empirical findings show that there is a significant positive contribution of digital finance to carbon emissions, but there is an inverted U relationship between the two. The mechanism analysis reveals that digital finance has a more significant impact on carbon emissions in areas with less optimized industrial structure. Further, it is found that the effect of digital finance on carbon emissions is heterogeneous in three dimensions of digital finance and in different regions. Finally, based on the above analysis, the corresponding policy recommendations are put forward. The findings of this paper not only enrich the literature on digital finance and carbon emissions, but also provide a reference significance for the relevant departments in China to develop digital finance and control carbon emissions.

Keywords: Digital inclusive finance, Carbon emissions, Industrial structure upgrading.

1. Introduction

At present, China's economy has changed from high-speed development to a stage of high-quality development. As an important engine for high-quality economic development, digital economy plays an important role in China's sustained and sound economic development. Digital finance, as a core part of the digital economy, integrates traditional finance and modern technology. Relying on digital technologies such as the Internet, big data and cloud computing, digital finance has brought new changes to all aspects of the economy, production and life. However, in the process of booming economy, China's energy demand for industrialization is still growing, and carbon dioxide emissions in most cities are still on the rise year by year, so the issue of carbon emissions is still an important issue in the new economy. Therefore, based on this, what impact will digital finance exert on carbon emissions? Full analysis of the relationship, we can better understand the correlation between them, and provide favorable policy suggestions for specific situations.

Studies related to carbon emissions have focused on the measurement of carbon emission levels in different industries and regions[1][2] and the investigation of factors influencing carbon emissions. Cao Xiang et al. argued that the change of household registration system promoted the increase of carbon emission per capita[3] . Sun Jingbing and Qian Xue argued that science and technology innovation can significantly contribute to the efficiency of carbon dioxide emissions[4] . Xi Yanling and Niu Guimin argued that the relationship between economic growth and carbon emissions is uncertain, and the relationship between per capita national income and CO2 is "N" type[5] ; Liu et al. suggested that there is a significant positive correlation among technological innovation, industrial structure upgrading and carbon emission efficiency[6] ; Yi et al. suggested that the development of digital industry increases carbon emission intensity, but when the economy develops to a higher level, digital industry technology can reduce carbon emission intensity[7] .

Most of the studies on digital finance focus on the level measurement of digital finance[8] and its economic benefits, such as the analysis of the relationship between digital finance and technological innovation, urban-rural income gap, economic growth, poverty reduction effect, etc. Nie Xiuhua et al. found that digital finance significantly improves regional technological innovation by alleviating financing constraints and optimizing industrial structure[9]; Song Xiaoling found that the development of digital finance has a significant effect on narrowing the income gap between urban and rural residents[10]; Huang Qian and Xiong Deping found that digital finance development is generally beneficial to poverty alleviation, and the poor groups benefit more than the rich groups, improving income inequality[11] ; A small number of scholars have explored the impact of digital finance from the perspective of eco-efficiency, for example, Liang Qi et al. found that digital economy can promote economic ecologicalization and ecological economization by driving industrial structure upgrading[12] .

Through the above combing of carbon emissions and digital finance-related studies, it can be seen that there is a lack of relevant quantitative studies on the impact of digital finance on carbon emissions. Therefore, this paper empirically investigates the relationship between digital finance and carbon emissions using data from 30 provinces from 2011-2019. Firstly, this paper verifies the impact of digital finance on carbon emissions through a two-way fixed-effects model, and proves the difference of the impact in different areas through heterogeneity tests. Second, through the interaction term model, this paper further explores the possible impact mechanisms of digital finance on carbon emissions. Thus, the contribution of this paper mainly lies in: first, incorporate digital finance and carbon emissions into the same analytical framework, enriching the research on the ecological benefits of digital finance and the influencing factors of carbon emissions; second, systematically elaborate the impact of digital finance on carbon emissions, which provides meaningful policy insights for different regions to promote energy conservation and emission reduction through digital finance development.

2. Empirical design

2.1 Model Construction

In this paper, we construct a two-way fixed effects model in the region (province and city)-year dimension.

$$PCO_{ij} = \alpha_0 + \alpha_1 FI_{it} + \eta \cdot Control_{it} + \lambda_t + \gamma_i + \varepsilon_{it}$$

To reduce heteroscedasticity and data dispersion, the data of each variable is treated with logarithm.

$$\ln PCO_{ij} = \alpha_0 + \alpha_1 \ln FI_{it} + \eta \cdot \ln Control_{it} + \lambda_t + \gamma_i + \varepsilon_{it}$$

The subscripts i and t represent provinces and years, respectively, PCO is the explanatory variable, representing per capita CO2 emissions. FI is the core explanatory variable, representing the total level of digital finance development. Control represents the set of control variables, λt and γi represent year fixed effects and province fixed effects, respectively, and εit is a random disturbance term.

2.2 Variable description

2.2.1 Explanatory variables

per capita carbon dioxide emission (PCO).

2.2.2 Core explanatory variables

Digital Finance Development Index (FI) :the digital financial index system is constructed from a total index and three dimensions of digital financial coverage breadth, using depth and digitization.

2.2.3 Control variables

Table 1. Definition table of main variables

Variable Name			Variable Symbols	Metrics
Carbon emission level		CO2 emissions per	PCO	Total carbon emissions/GDP
Digital Finance Index		Total Index	FI	Total Digital Finance Development
	Sub-index	Breadth of coverage	Width	Breadth of digital financial
		Depth of use	Depth	Depth of use of digital finance
		Degree of digitization	Digital	Degree of digitization
Economic Development Level			pgdp	gdp/population of each province
Government intervention			Gov	Fiscal spending/GDP
Level of trade development			Trade	Total import and export trade/GDP
Population			Pop	Population by province
Urbanization rate			Ur	Percentage of urban population

In this paper, the following indicators are selected as control variables to be included in the model: a. level of economic development: per capita GDP (pgdp); b. government intervention: fiscal expenditure ratio (gov); c. population size (pop); d. import/export trade as a share of GDP (trade); e. urbanization rate (ur). Again, to reduce heteroskedasticity, data are taken as logarithms for all control variables.

2.2.4 Data

The Digital Finance Index is the Peking University Digital Financial Inclusion Index jointly compiled by Peking University Digital Finance Research Center and Ant Financial Services Group based on enterprise microscopic big data. Carbon emission data source ceads China Carbon Emission Database. Other data sources are from National Bureau of Statistics. And all data are for 30 provinces and cities from 2011-2019 (excluding Hong Kong, Macao, Taiwan and Tibet).

3. Results and Discussion

3.1 Baseline regression (total sample regression)

3.1.1 Total Digital Finance Development Index

In this paper, Two-way Fixed Effects Model is used for regression to control for differences between individuals in different provinces and cities that do not vary over time. Table 2 shows the baseline regression results of the impact of digital economy on carbon emissions. Column (1) contains only the digital finance development index and the index is significantly positive at the 5% level. In column (3),the coefficient of the total index is still significantly positive at the 10% level after adding control variables, indicating that the development of digital finance promotes the increase of carbon emissions, which may be the result the scale effect of digital finance. the scale effect facilitate some enterprises with traditional extensive growth model to increase their production, thus bringing about an increase in carbon emissions. However, with the mature development of digital economy, the structural effect of digital finance will propel the transformation and upgrading of industrial structure, realizing the effective allocation of financial resources, promoting the innovation and upgrading of enterprises, which will greatly reduce carbon dioxide emissions. To sum up, there is an inverted U relationship between digital finance and carbon emissions. The quadratic coefficient of the digital finance development index in column (2) is significantly negative at the 5% level, confirming this relationship.

From the regression results of adding control variables (3) (4), the coefficients of all five control variables are statistically significant. Among them, the coefficient of GDP per capita is significantly negative at the 1% level, indicating that the enhancement of economic level can reduce carbon emissions, which is probably because economic development will lead to technological innovation and the shift of the structure of economy. The proportion of government fiscal expenditure is significantly negative at the 10% level, indicating that with increased government intervention, carbon emissions can be reduced, probably due to the fact that with increased income, public awareness of environmental protection is higher and the fiscal expenditure structure of local governments is optimized, leading to the alleviation of environmental problems. The coefficients of population size, trade level, and urbanization rate are all significantly positive, illustrating that the expansion of population size,increasing in trade level and urbanization rate exacerbate carbon emissions. This is mainly because firstly, the expansion of population size will cause an increase in energy demand, and then lead to an increase in fossil energy consumption and carbon emissions; secondly, since most of the enterprises in China are still in the middle and lower reaches of the global industrial chain, the larger the scale of import and export means the stronger the manufacturing capacity of the middle and lower reaches. However,the middle and lower reaches of manufacturing mainly take over some energy-intensive and polluting parts transferred from developed countries. Therefore, the increase of import and export scale will lead to the increase of carbon emission. Thirdly, the accelerated urbanization process may be accompanied by the vigorous development of the manufacturing industry and more frequent transportation, which may deteriorate environmental problems.

Table 2. Baseline regression results for the total digital finance index

Variable Name	(1)	(2)	(3)	(4)
lnFI	0.136** (2.32)	0.983** (2.56)	0.121* (1.66)	1.003*** (2.71)
$(lnFI)^2$		-0.129** (-2.23)		-0.140** (-2.43)
lnpgdp			-0.823*** (-4.99)	-0.767*** (-4.65)
lngov			-0.224* (-1.96)	-0.234** (-2.06)
lntrade			0.095*** (2.93)	0.096*** (3.00)
lnpop			0.573* (1.81)	0.494* (1.57)
lnur			0.765*** (2.88)	0.918*** (3.40)
Observations	270	270	270	270
R-squared	0.047	0.067	0.182	0.203
Provincial area fixed effects	Control	Control	Control	Control
Year fixed effects	Control	Control	Control	Control

Note:***, **, * denote 1%, 5%, and 10% significance levels, respectively.

3.1.2 The Sub-Index of Digital Finance Development

This paper further explores the impact of digital finance development on carbon emissions in terms of three sub-dimensions of digital finance -- coverage breadth, using depth, and degree of digitization. The regression results are shown in Table 3.

Table 3. Baseline regression results of digital finance sub-index

Variable Name	Digital Finance Breadth (1)	Digital Finance Depth (2)	Degree of digitization (3)
lnWidth	0.045 (1.61)		
lndepth		0.095** (2.12)	
lndigtal			-0.115*** (-3.02)
lnpgdp	-0.839*** (-5.03)	-0.743*** (-4.53)	-0.719*** (-4.42)
lngov	-0.234** (-2.04)	-0.195* (-1.70)	-0.235** (-2.08)
lntrade	0.096*** (2.95)	0.100*** (3.08)	0.093*** (2.92)
lnpop	0.514* (1.68)	0.495* (1.66)	0.430 (1.49)
lnur	0.808*** (3.18)	0.843*** (3.59)	0.737*** (3.11)
Observations	270	270	270
R-squared	0.181	0.188	0.204
Provincial area fixed effects	Control	Control	Control
Year fixed effects	Control	Control	Control

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively.

As shown in column (1), the coefficient of the breadth of digital financial coverage does not show significant significance, indicating that the impact of the coverage breadth of digital financial on carbon emissions is not significant. Column (2) shows that the coefficient of the using depth of of digital finance is significantly positive at the 5% level, indicating that carbon emissions increase with the extension of the using depth of digital finance,which demonstrates that the coverage or use of new financial services is more concentrated in the secondary industry, and as the depth of use of digital finance in the secondary industry deepens, production continuously increases, leading to an increase in carbon dioxide emissions. Column (3) shows that the impact coefficient of digitization is significantly negative at the 1% level, indicating that as digitization becomes more widespread, more SMEs and individuals benefit from the affordability and convenience of digital finance, which lowers the threshold of entrepreneurship for micro and small enterprises and stimulates green innovation activities of enterprises, and also drives up the consumption level and promotes the industrial structure to " low energy consumption, low pollution" transformation of industrial structure, thus reducing carbon emissions.

3.2 Sub-regional regression

The impact of digital finance on carbon emissions in different regions may differ, and the results are shown in Table 4 through respective regressions on the central, eastern and western regions and the Yangtze River Economic Belt and non-Yangtze River Economic Belt.

Column (1) shows the effect of digital finance on carbon emissions in the eastern region, and the regression coefficient is significantly positive at the 10% level, indicating that digital finance and carbon emissions in the eastern region are positively correlated, probably because the effect of digital finance in the eastern region presents more of a scale effect; column (2) shows the effect of digital finance on carbon emissions in the central region, and the regression coefficient is significantly negative at the 5% level, indicating that digital finance in the central region has promoted emission reduction, which may because the structural effect and technology effect of digital finance in the central region are more obvious. In column (3) ,the coefficient of the effect in the western region does not show significance, indicating that the development of digital finance in the western region is not deep enough and has not yet caused a significant impact on carbon emissions.

Table 4. Sub-regional regression results

Variable Name	East	Middle	West	Yangtze River Economic Belt	Non-Yangtze River Economic Zone
	(1)	(2)	(3)	(4)	(5)
lnFI	0.228* (1.80)	-0.885** (-2.28)	0.170 (1.33)	0.251** (2.00)	0.007 (0.07)
lnpgdp	0.101 (0.52)	-2.019*** (-4.03)	-1.294*** (-2.76)	-0.334 (-0.83)	-0.992*** (-3.75)
lngov	-0.538*** (-5.13)	-0.836 (-1.62)	-0.306 (-0.91)	0.129 (0.73)	-0.379** (-2.53)
lntrade	0.215** (2.36)	-0.179 (-1.31)	0.157*** (3.29)	-0.003 (-0.05)	0.111*** (2.69)
lnpop	1.203** (2.39)	2.647* (1.71)	0.715 (1.09)	-0.642 (-0.97)	0.758* (1.87)
lnur	0.813*** (2.69)	1.469 (0.93)	1.591** (2.03)	0.274 (-0.75)	1.085*** (2.85)
Observations	99	72	270	99	171
R-squared	0.520	0.333	0.322	0.219	0.261
Provincial area fixed effects	Control	Control	Control	Control	Control
Year fixed effects	Control	Control	Control	Control	Control

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively.

Column (4) represents the impact of digital finance development on carbon emissions in the Yangtze River Economic Belt, and its coefficient is significantly positive at the 5% level, which may be the result of the distribution of secondary industries along the Yangtze River Economic Belt.The development of digital finance has promoted the development of traditional extensive industries and resource-based industries in the surrounding area, which causes an increase in carbon emissions.

3.3 Analysis of impact mechanisms

This paper uses three indicators to measure the optimization and upgrading level of China's industrial structure. One is the ratio of value added of tertiary industry to GDP (Structure1); the other is the ratio of value added of tertiary industry to secondary industry (Structure2); and the third is the ratio of increase of secondary industry to GDP (Structure3). Columns (1) (2) (3) of Table 5 report the corresponding regression results respectively. It can be found that the coefficient of the digital finance development index in column (1) is significantly positive, and in column(1)(2), the cross term of digital finance development index and industrial structure optimization index(Structure1 and Structure2) is significantly negative, which means digital finance has a greater and more significant impact on carbon emissions in areas with poor industrial structure optimization.

In column (3), the cross-product term of digital finance development index and industrial structure optimization index(Structure3) is significantly positive, that is, digital finance plays a more significant role in promoting carbon emissions in areas with a better proportion of secondary industry. It shows that in the regions with lagging industrial structure, the development of digital finance mainly provides power for the development of the secondary industry, and then promotes the increase of carbon emissions. In areas with better industrial structure optimization, digital finance provides services for more advanced industries and promotes the development of digital finance toward green services.

Table 5. Digital finance, transmission mechanisms and carbon emissions

Variable Name	Industrial structure optimization		
	Structure1	Structure2	Structure3
	(1)	(2)	(3)
lnFI	0.483*** (3.86)	0.103 (1.43)	-0.082 (-0.70)
lnFI×lnstru1	-0.103*** (-3.51)		
lnFI×lnstru2		-0.044*** (-3.09)	
lnFI×lnsi			0.052** (2.21)
lnpgdp	-1.044*** (-6.04)	-0.989*** (-5.80)	-0.906*** (-5.40)
lngov	-0.286** (-2.53)	-0.256** (-2.27)	-0.230** (-2.03)
lntrade	0.094*** (2.96)	0.077** (2.37)	0.074** (2.22)
lnpop	0.312 (0.98)	0.270 (0.83)	0.350 (1.06)
lnur	0.867*** (3.32)	0.712*** (2.72)	0.651** (2.43)
Observations	270	270	270
R-squared	0.224	0.215	0.199
Provincial area fixed effects	Control	Control	Control
Year fixed effects	Control	Control	Control

Note: ***, **, * denote 1%, 5%, and 10% significance levels, respectively.

3.4 Robustness tests

3.4.1 Replacing the explanatory variable

Replace per capita carbon emissions with carbon intensity. The empirical analysis results in Column (1) and (2) of Table 6 show that the coefficients of the digital financial development index are significantly positive, and there is still an inverted U relationship between the development of digital finance and carbon emissions, which is consistent with the previous baseline regression results.

3.4.2 Lagging the explanatory variables by one period

The explanatory variable lnFI and all Control variables are controlled with a lag of one period. The results are shown in columns (3) and (4), which are still consistent with the results of benchmark regression, confirming the robustness of benchmark regression results.

3.4.3 Instrumental Variables Method

In this paper, the one-period lagged value of digital finance is adopted as the instrumental variable. On the one hand, the digital financial development index is correlated with its lagged variables, and on the other hand, as the "pre-determined" value, it is not related to the disturbance term of the current period (that is, it is exogenous). The regression results of the instrumental variables are shown in columns(5)and (6), where the relationship between digital financial inclusion development and carbon emissions remains inverted U, passing the robustness test. Meanwhile, the p-values of Kleibergen-Paap rk LM statistics in column (5)and(6) are 0.000 and 0.000 respectively, strongly rejecting the original unrecognizable null hypothesis. The Cragg-Donald Wald F statistics are 17.818 and 25.702, respectively, larger than the empirical value of 10 for the relevant instrumental variables, indicating that there is no weak instrumental variable problem. In general, the instrumental variables selected in this paper are reasonable.

Table 6. Robustness test results

Variable Name	Displacement of explanatory variables		Explanatory variables lagged by one period		Tool Variables	
	(1)	(2)	(3)	(4)	(5)	(6)
lnFI	0.124*	0.989***	0.030	0.879**	0.043	4.005**
	(1.70)	(2.66)	(0.45)	(2.50)	(0.19)	(2.21)
$LnFI^2$		-0.137**		-0.136**		-0.498**
		(-2.38)		(-2.46)		(-2.19)
lnpgdp	-1.829***	-1.774***	-0.653***	-0.618***	-0.792***	-0.537**
	(-11.05)	(-10.72)	(-4.07)	(-3.88)	(-3.74)	(-2.22)
lngov	-0.225*	-0.234**	-1.114	-0.137	-0.212**	-0.169
	(-1.96)	(-2.06)	(1.03)	(-1.24)	(-2.09)	(-1.71)
lntrade	0.097***	0.098***	0.866***	0.085***	0.112***	0.121***
	(2.96)	(3.03)	(2.62)	(2.60)	(3.03)	(3.23)
lnpop	0.568**	0.491	0.478	0.322	0.829***	0.948***
	(1.78)	(1.55)	(1.42)	(0.95)	(3.18)	(3.53)
lnur	0.805***	0.956***	0.630**	0.848***	0.635**	0.597*
	(3.02)	(3.52)	(2.30)	(2.98)	(2.07)	(1.84)
R-squared	0.846	0.850	0.1458	0.171	0.986	0.986
Provincial area fixed effects	Control	Control	Control	Control	Control	Control
Year fixed effects	Control	Control	Control	Control	Control	Control
Cragg-Donald Wald F statistics					252.948	25.702
Kleibergen-Paap rk LM statistic (p-value)					17.818 (0.000)	32.061 (0.000)
Hansen J statistic					0.000	0.000

Note:***, **, * denote 1%, 5%, and 10% significance levels, respectively.

4. Conclusion and Suggestions

The empirical results show that digital finance has a catalytic effect on carbon emissions, but there is an inverted U relationship between the two. Most cities are currently in the left side of the inverted U curve,where carbon emissions increase with the development level of digital finance. However, when digital finance develops to a certain stage, digital finance will reduce carbon dioxide emissions. In addition, the heterogeneity analysis reveals that: the three dimensions of digital finance have different effects on carbon emissions and the effects of digital finance on carbon emissions also differ in different regions. The mechanism test finds that the impact of digital finance on carbon emissions is mainly realized through the industrial structure. Digital finance has a more significant impact on carbon emissions in regions with less optimized industrial structure (regions with a higher share of secondary industry), where financial resources flow more to the secondary industry, increasing production in the secondary industry and intensifying energy consumption.

Based on the above conclusions, this paper puts forward the following suggestions: first, vigorously develop digital finance, accelerate each region to reach the inflection point, and realize the green development of digital finance; second, according to the heterogeneous results, each region develops digital finance in accordance with local conditions: the central region continues to develop green industries and drive the low-carbon construction with the development of digital finance. The eastern region actively guides the flow of digital financial resources to the low-carbon environmental protection industries with low pollution and energy consumption to promote the continuous optimization and upgrading of industrial structure and speed up to the inflection point. The western region vigorously develops digital financial infrastructure and improves the acceptance and popularity of digital finance. Third, accelerate the construction of digital economy and promote the transformation and upgrading of industrial structure. Fourth, formulate relevant policies to encourage enterprises to carry out green technological innovation and promote the green transformation of industries.

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