Digital finance and greener emissions: An empirical analysis of cities in China

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Research Article

Keywords: Digital finance, Industrial pollution emissions, Green funds, Digital Inclusion, Awareness, Urban China

Posted Date: February 28th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1360059/v1

Abstract

We match the city-level finance digitization data from the Peking University digital financial inclusion index with the industrial pollution emissions information to study the relationship between digital finance and industrial pollution emissions. After alleviating endogenous problems with our instrument variable, we found that the development of digital finance significantly mitigates industrial pollution emissions, and the coverage and depth of digital finance also have a significant impact on industrial pollution emissions mitigation. We explain the mechanism through green personal finance and individual awareness. First, green finance programs provided on Alipay encourage greener emissions. Second, digital finance directly affects individuals' environmental awareness and daily behaviors. Our empirical results show an average of 17.3% decrease in the industrial pollution emissions caused by digital finance.

1. Introduction

Climate risk poses risks to the financial system, and understanding how digital finance programs can mitigate climate risk help the economy, especially for the emerging markets. Since the 1980s, China has entered an era of economic boom but with high environmental costs. Substantial pollution comes from industrial emissions. On the one hand, digital finance may increase pollution emissions. Investment can stimulate production, and as a result, active production generates more industrial pollution emissions. Investment may be more open towards green projects, but green projects may be more costly than brown projects. Also, digital finance service suppliers can be heavy energy users themselves. For example, the total power consumption of the world's data centers reached at least 203 terawatt-hours by 2010, which is about 1.1% of the global total power consumption in that year[1]. On the other hand, digital finance can increase green projects, and financed green projects can reduce local industrial pollution emissions. It is essential to study this topic because mitigating climate risks and reducing industrial pollution can help to build a sustainable economy in the long run.

This paper aims to investigate whether digital finance mitigates carbon emissions and what is the mechanism causing greener emissions. The new generation of digital technologies allows individuals to access investment projects instantly through their cell phone applications. There are three ways that digital finance can contribute to reducing pollution emissions. Firstly, digital finance provides greater financial inclusion (Ozili 2021), so more investors can invest in green projects, and these projects then can have more funds to reduce industrial pollution emissions. In the case of China, individual investors have the chance to invest in green funds using Alipay, a payment platform with no minimum lump sum investment. Secondly, digital finance reduces industrial pollution emissions through individual awareness. Individuals who invest in green funds have the financial incentive to go green. These green financing can also promote awareness towards green daily actions. Thirdly, digital finance promotes corporate green innovation and green economic efficiency (Hong et al. 2021; Li et al. 2021; Liu et al. 2022; Wang et al. 2022). In this paper, we mainly examine the first two mechanisms.

Although there has been a great deal of research on the relationship between traditional finance and pollution reduction, there is still a lack of systematic research on the impact of digital finance on carbon reduction (Bruton et al. 2015). Most of the research related to digital finance in the environmental field is primarily based on the micro-mechanism research of listed corporations or single-platform enterprises (Liu et al. 2022; Duarte et al. 2012; Allison et al. 2015). The literature has different attitudes about whether digital finance is effective in reducing carbon emissions and environmental improvement. For example, microeconomics studies have questioned whether crowdfunding can promote carbon emission reduction (Harrison 2013; Mollick 2014). Most of the research focuses on peer-to-peer lending and crowdfunding platform. However, because digital finance is a relatively new topic with limited data, there lacks empirical research exploring its impact on the green environment. More recently, Ozili's study (2021) only proves the linkage between digital finance and green finance in a conceptual model. The Digital Finance Research Center research group at Peking University compiled a set of Digital Inclusive Finance indexes, which made up for this deficiency (Guo et al. 2020) and allows us to study the relationship between digital finance and industrial emission mitigation. Based on this set of digital inclusive finance index and city-level pollution emission data, we analyze the relationship between China's urban digital-finance inclusion and carbon emission from 2011 to 2019.

The rest of this paper is organized as follows. Section 2 is the literature review. Section 3 describes data and model. Section 4 presents the empirical results. Section 5 shows our conclusions and policy implications.

[1] Masanet, Eric, et al. "Recalibrating Global Data Center Energy-Use Estimates." *Science Magazine*, 28 Feb. 2020, https://datacenters.lbl.gov/sites/default/files/Masanet_et_al_Science_2020.full_.pdf. Accessed 14 Feb. 2022.

2. Literature Review

2.1 Finance and carbon mitigation

The existing literature is rich on the factors affecting carbon emissions, and some of the driving factors identified are economic growth, technological innovation, urbanization, industrial structure, and financial development. However, few discussions on how digital finance development mitigates Chinese urban carbon emissions in academia. Some scholars believe that financial products can reduce carbon emissions by promoting technological innovation and enhancing environmental awareness (Shahbaz et al. 2013). Tamazian et al. (2009) and Jalil (2011) found that financial development had an inhibitory effect on carbon emissions in various countries. Other scholars believe that financial products will accelerate economic growth, increase energy consumption, and increase carbon emissions, and there is an inverted u-shaped relationship between the two (Salahuddin et al. 2015; Dogan and Seker 2016; Charfeddine and Khediri 2016). One possible reason for the discrepancy is the dimensions used to measure financial development.

With the improvement of green finance, academic research on green finance has gradually deepened. In the early stage, scholars paid more attention to green finance's connotations, functions, and paths. Green finance development can help bank risk control and transform the Chinese economy (Li and Hu 2014). It is also believed that the legal environment builds a foundation for green finance and green credits (Duan and Niu 2011). With the development of green finance, many scholars began to pay attention to measuring the development level of green finance (Aizawa and Yang 2010; Li and Hu 2014). They study the impact of green finance policies on enterprise investment, energy conservation, and emission reduction. Liu et al. (2017) constructed a theoretical CGE model and found that green credit policies are effective in restraining investment in energy-intensive industries. Xiu et al. (2015) also found in theory that green credit regulatory measures are conducive to energy conservation and emission reduction under the constraints of industrial growth, with a nonlinear dynamic panel model. Wan et al. (2022) used a dynamic spatial econometric model and proved that digital finance reduces pollution emissions through innovation, structural change, and capital allocation. Our research contributes to this stream of literature by further investigating how digital finance affects industrial carbon emissions with empirical evidence.

Lacking digital finance data in the early years, existing empirical studies on emission mitigation mainly theoretically explain green credits policy effects. Other more recent research on digital credit primarily focuses on its impact on innovation activities (Arqué-Castells 2012; Grilli and Murtinu 2014), and innovation is an essential driver of carbon emission reduction (Albino et al. 2014; Li et al. 2017). Therefore, there is little empirical literature on whether digital finance directly causes greener emissions.

2.2 The mechanism of digital finance

The Chinese financial system is still under development, which negatively influences the nation's sustainable economic growth (Huang and Wang 2011). The shortage of traditional financial supply has dramatically restricted pollution reduction activities (Aghion et al. 2007). However, digital finance, a new economic model, is different from conventional finance and has flourished in China in recent years. Digital finance has reduced financial transaction costs, expanded service scope, and increased finance capacity. Electronic payment platforms, such as Alipay, greatly expanded finance services by making financial services more accessible to individual investors, providing selling platforms to funds, and promoting small-scale-friendly personal finance. Alipay further increases individuals' environmental awareness through green finance (Appendix) and green credits such as Sesame Credits (Zhi Ma Xin Yong in Chinese) and Ant Forests (Ma Yi Sen Lin in Chinese).

First, digital finance inclusion increases green personal finance, and green finance reduces industrial emissions. Digital payment platforms can provide user-friendly personal finance opportunities through finger clicking on personal smartphones, which traditional banking cannot. Alipay is the leading private finance platform with the most individual investors[2] in China, and according to the China Securities Journal's news, Alipay reached over 248.2 billion RMB in 2010. The more digital finance service is delivered to cities, the more green finance projects are funded. As a result, green finance mitigates industrial pollution emissions. Some of the mitigation effects come from green innovation (Falcone and Sica 2019; Li et al. 2021; Liu et al. 2022). For instance, Falcone and Sica (2019) find empirically that green finance helps sustainable innovation for specific industries in Italy. Some of the mitigation effects come from financial incentives to enterprises. To be financially invested, firms have the motivation to engage in economic activities for resource-saving and efficient use. Thus, digital finance mitigates polluted industrial emissions through green personal finance.

Second, the spread of digital finance increases awareness of the environment and thus leads to less industrial pollution emission. The Sesame Credits in Alipay phone applications provides high-credit-score users benefits including cash-back, online and offline shopping with discounts, pay-later for online shopping and shipping charges, deposit-free for checking-in hotels, and rentals, and free insurance extension and lease extension. Sesame Credits can also be used as financial support for apply visas from Thailand, South Korea, Canada, Latvia, and Argentina. To enjoy all the Sesame benefits, users have to increase their credit scores above 750 points, while the original credit score starts at 653 points. The Sesame credit score consists of five dimensions: personal relationship, honor records, financial assets, personal identity, and behavioral records. Honor and behavioral records are the two most important factors defining a person's credit score. These rewards increase individuals' environmental awareness, and individual users are motivated to boost their credit scores by accumulating environmental-friendly behaviors (Appendix). Therefore, digital finance provides essential support for developing a green economy.

To sum up, we believe that the spread of digital finance in urban China can reduce pollution emissions. The mechanisms are that digital finance inclusion reduces industrial emissions through green projects and that digital finance promotes individual awareness. We will test these mechanisms empirically below.

[2] IiMedia Research on internet users where to invest: https://www.iimedia.cn/c460/77872.html

3. Data And Model

The data are from the following resources:

1. The Digital Financial Inclusive Index from the Research Center for Digital Finance at Peking University.

2. The industrial pollutant emission data come from the 2011–2019 China City Statistical Yearbook.
3. The city-level internet penetration rate comes from China Internet Network Information Center, which we use as an instrumental variable for digital financial development.
4. The sewage and harmless treatment rates of domestic garbage come from the China Urban and Rural Construction Statistical Yearbook, which we use as proxies for individual awareness.
5. The macro-level data come from the Chinese Statistical Yearbook includes variables, such as per capita GDP, fixed asset investment level (annual average balance of net fixed assets / GDP), foreign direct investment (utilization of foreign capital / GDP), and fiscal expenditure scale (general public budget expenditure / GDP).

3.1 Data of independent variable

Digital financial inclusion index. In terms of overall development, the city-level average of the Chinese Digital Financial Inclusion Development Index increased from 51.71 in 2011 to 245.17 in 2019. During the sample period, China's digital finance has experienced rapid growth. We select two specific indicators to explore digital finance's impact on carbon emission mitigation: *Coverage_breadth* and *Usage_depth*. The coverage breadth is compiled based on the number of Alipay accounts in the region. The average city-level coverage of the sample has increased from 50.24 in 2011 to 235.59 in 2019, showing that the coverage of digital finance has become more extensive. The second dependent variable is usage depth, which measures the frequency of internet financial services use in the region. The city-level average usage depth increased from 55.52 (in 2011) to 240.52 (in 2019). See Table 1 for more specific indicators.

Table 1 Digital Finance Inclusive Index Detailed Indicators.

First dimension	Secondary dimension	Descriptions
Coverage breadth	Account coverage	Number of Alipay accounts per 10,000 people
		Percentage of Alipay card users
		The average number of bank cards connected with each Alipay account
Usage depth	Payment service	Number of payments per person
		Amount of payments per person
		Percentage of active users with high-frequency (50 or more times per year), (high-frequency user divided by total active who use at 1 time per year)
	Monetary fund	The average number of payments using Yu E Bao (debit accounts in Alipay)
		The average account amounts using Yu E Bao
	Credit/Loan Service-for personal customers	The number of users with internet consumer loans (in every ten thousand Alipay adult users)
		The average number of loans per user
		The average amount of loans per user
	Credit/Loan Service-for small business owners	The number of internet small-business loan users (in every ten thousand Alipay adult users)
		The average number of loans per small business owner
		The average amount of loans per small business owner
	Insurance	Number of insured users per 10,000 Alipay users
		The average number of insurance per user
		The average amount of insurance per user
	Investment business	Number of people participating in internet investments and asset management per 10,000 Alipay users
		Number of investments per capita
		Per capita investment amount
	Credit business	Number of people using credit to consume services (including financing, housekeeping services, entertainments, etc.) per 10,000 Alipay users
		Number of credit reports per person

Internet penetration. According to the annual Statistical Report on Internet Development from China Internet Network Information Center, the urban internet penetration rates match with 31 provinces (municipalities and autonomous regions) located in mainland China. The national internet penetration rate in 2019 was 31.2%. Comparing 2019's rate with 2011, we found an increase of 14.7 percent.

3.2 Data of dependent variables

Industrial pollutant emissions. The data comes from the 2011–2019 China Urban Statistical Yearbook, including industrial sulfur dioxide emissions (Ins1), industrial nitrogen oxides emissions (Ins2), industrial smoke dust emissions (Ins3), and other types of emissions. We focus on urban carbon emission mitigation. In addition, we use the air quality indicator released by China Air Quality Online Testing and Analysis Platform, including delicate particulate matter (PM2.5).

Individual awareness proxies. We obtained the data from the Statistical Yearbook of China's Urban and Rural Construction. Measuring personal awareness is not straightforward. Neither province nor city level data on environment awareness are available. Despite the aforementioned drawbacks, the centralized treatment rate of sewage treatment plants (lns8) and the harmless treatment rate of domestic garbage (Ins9) are good proxies for individual awareness for several reasons. The Statistical Yearbook of China's Urban and Rural Construction figures are one the most common indicators used in Chinese environmental research. Moreover, individual awareness is positively correlated with the centralized treatment rate of sewage treatment plants and the harmless treatment rate of domestic garbage. The centralized treatment rate of sewage treatment plants (lns8) and the harmless treatment rate of domestic garbage (Ins9) range from 2011 to 2019, which increased from 77.6% and 85% in 2011 to 94% and 98.5% in 2019, respectively.

3.3 Data of control variables

Control variables include per capita GDP, investment level of fixed assets (average net fixed assets / GDP), foreign direct investment (utilization level of foreign capital / GDP), fiscal expenditure scale (general public-budget expenditure / GDP), etc. The data comes from China Urban Statistics Yearbook. We use these variables to control the influence of local economic development, public investment, and financial support on industrial pollution emissions.

3.4 Model specification

We first analyze how the inclusion of digital finance impacts industrial pollutant emission. We use the logarithm of industrial sulfur dioxide emissions, industrial nitrogen oxides emissions, and industrial dust emissions as the dependent variables. And the regression model is shown in the formula (1):

$$Pollution_{it} = \beta_0 + \alpha_i + \beta_1 index_{i(t-1)} + \beta_2 \ln pgdp_{it-1} + \beta_4 invest_{it-1} + \beta_5 gov_{it-1} + \beta_6 fdi_{it-1} + \varepsilon_{it}$$

1

where $Pollution_{it}$ is the logarithm of the industrial pollutant index. a_i denotes unobservable factors that do not change with time among cities. *index* is the logarithm of digital financial inclusion index. *lnpgdp* is the logarithm of local per capita GDP. *invest* denotes the level of investment in fixed assets. *gov* denotes the scale of fiscal expenditure, which is used to approximate the financial support from local governments. Finally, *fdi* denotes the level of foreign capital utilization / GDP.

To identify the impact of digital finance on pollution emissions, we need to deal with two types of problems. The first is the reverse causality problem. A region's carbon emission ranking itself may promote the development of local digital finance. Second, we are still concerned with other unobservable factors. Although we have controlled the regional economic development level, public investment, and financial support, other unobservable factors may cause the mitigation of industrial carbon emissions.

For the reverse causality problem, we adopt the following strategies. First, this paper uses the first-order lag term for all explanatory variables. We evaluate how digital finance, economic development level, and public investment in the previous year affect current carbon emission mitigation, weakening the reverse causality problem to a certain extent (Wooldridge 2010). Secondly, we use the internet penetration rate as the digital finance inclusion index's instrument variable. Because the internet builds a foundation for digital finance, the internet penetration rate is closely related to the changes in digital finance. After controlling the local economic level, public investment level, and fiscal support, we believe that no direct correlation channel exists between internet penetration rate and industrial pollutant emission, making internet penetration rate an effective instrument variable.

We apply the following two strategies to alleviate concerns regarding other factors that may affect carbon emissions. First, we can control factors that do not vary with time by using the fixed effect model. Second, the per capita GDP and the level of public investment used in this paper are treated by de-averaging, so we avoid the unstable estimation effect caused by multiple collinearities. Table 2 presents the descriptive statistics of the variables. From Table 2, we can see noticeable regional differences in the development degree of digital finance and pollution emissions among cities.

Table 2 Descriptive statistics of main variables.

Variable	Observations	Mean	Std. Dev.	Min	Max
index	2335	4.9866	0.5149	3.0568	5.7735
coverage_breadth	2335	4.9116	0.5675	0.6206	5.7395
usage_depth	2335	4.9761	0.5128	2.5249	5.8050
lns1	2181	10.1752	1.3082	0.6931	14.2384
lns2	2131	9.8393	1.1037	5.0499	15.4582
lns3	2134	9.7550	1.1721	4.2767	15.4582
lnpgdp	2335	10.5894	0.7762	6.6378	13.1851
invest	2335	0.6073	0.6784	0.0422	17.8336
gov	2335	0.2235	0.2405	0.0030	3.8747
fdi	2335	0.0033	0.0044	0.0000	0.1148
2085	0.2075	0.1729	0.0018	1.8902	
lns8	2229	4.4585	0.1806	3.1974	4.8114
lns9	2193	4.5209	0.2296	1.8703	5.8944
pm25	1472	36.6060	16.5040	2.8506	86.4799

4. Empirical Results

4.1 Baseline result of digital finances' impact on carbon emission mitigation

The baseline of this paper is the fixed effect model with panel data. According to table 3, the results show that the more developed the digital finance, the greater the carbon emission mitigation, with or without controls. The mitigation effects on industrial nitrogen oxide emissions and industrial dust emissions are statistically significant. The table also shows that carbon emission mitigation is sensitive to economic development. The impact of carbon emission mitigation is lower in areas with a high level of economic growth. In addition, government expenditure impact on carbon emission mitigation is not significant, indicating an insignificant level of government intervention.

As shown in table 3, the index increased by 1%, the industrial nitrogen oxide emissions decreased by 0.51%, and the industrial smoke and dust emissions decreased by 0.43%. Considering that each city's digital inclusive finance index has increased from 55.52 in 2011 to 240.52 in 2019, we can see a 169.83% decrease in industrial nitrogen oxide emissions and a 143.19% decrease in industrial smoke and dust emissions.

Table 3 Relationship between total index and carbon emission mitigation.

	(1)	(2)	(3)	(4)	(6)	
	F.lns1	F.lns2	F.lns3	F.lns1	F.lns2	F.lns3
index	0.3636**	-0.5928***	-0.4397**	0.2375	-0.5138**	-0.4346**
	(0.1717)	(0.1775)	(0.1800)	(0.1810)	(0.2032)	(0.1998)
lnpgdp				0.0561	0.1103**	0.0557
				(0.0868)	(0.0462)	(0.0496)
invest				-0.0273	-0.0123	-0.0805**
				(0.0359)	(0.0397)	(0.0370)
gov				0.0806	0.0140	0.0891
				(0.0827)	(0.0921)	(0.1138)
fdi				-5.7529	-8.0979*	-6.5870
				(5.8647)	(4.2450)	(6.1516)
Year-FE	Yes	Yes	Yes	Yes	Yes	
City-FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2138	2088	2090	1942	1893	1896
R Squared	0.6308	0.3016	0.4433	0.6377	0.3161	0.4630
Notes: Robust t-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1.						

4.2 Detailed dimensions of digital finance effects on carbon emission

Since the digital financial inclusion index comprises coverage breadth, depth of use, and sub-indicators, we further analyze which aspect of digital finance causes carbon emission mitigation. In other words, we want to know if the mitigation effect is due to more people participating in digital finance, more diversified services provided by digital finance, or a combination of several factors. Table 4 shows the effect of the development degree of these two dimensions on carbon emission mitigation. Columns (1)–(3) examine the impact of the coverage breadth of digital finance on carbon emission mitigation, and columns (4)–(6) examine the effect of the usage depth of digital finance on carbon emission mitigation. Table 4 shows that improving digital finance coverage and depth of use is conducive to alleviating regional pollution emissions. Based on regressions on industrial nitrogen oxide and industrial dust emission, the use of digital finance depth has a more robust effect. Specifically, with every increase of digital finance depth, more users are involved in green finance, which ultimately provides a better financial environment for carbon emission mitigation activities.

Table 4 Digital finance sub-index and carbon emission mitigation.

	(1)	(2)	(3)	(4)	(5)	(6)
	F.lns1	F.lns2	F.lns3	F.lns1	F.lns2	F.lns3
coverage_breadth	0.1163	-0.0834	-0.1465*			
	(0.0776)	(0.0817)	(0.0802)			
usage_depth				-0.0863	-0.5380***	-0.3715**
				(0.1121)	(0.1752)	(0.1605)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes	Yes	Yes
City-FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1942	1893	1896	1942	1893	1896
R Squared	0.6377	0.3124	0.4619	0.6373	0.3212	0.4642
Notes: Robust t-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1.						

Besides directly describing digital finance's impact on carbon emissions, we also investigate the digital finance impact on the growth of emissions mitigation in table 5. We do not find a significant relationship between digital finance and industrial sulfur dioxide emission in the previous section. But table 5 shows that the industrial sulfur dioxide emission mitigation growth rate is relatively fast in more inclusive digital finance areas.

Table 5 Digital finance sub-index and carbon emission mitigation growth rate.

	(1)	(2)	(3)	(4)	(5)	(6)
	F.dlns1	F.dlns2	F.dlns3	F.dlns1	F.dlns2	F.dlns3
coverage_breadth	-0.4182***	-0.1052	-0.0006			
	(0.1604)	(0.1609)	(0.1004)			
usage_depth				0.4963*	0.0503	-0.9597
				(0.2997)	(1.8304)	(1.4115)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes	Yes	Yes
City-FE	Yes	Yes	Yes	Yes	Yes	Yes
Obsevations	1887	1789	1792	1887	1789	1792
R Squared	0.0320	0.0070	0.0070	0.0318	0.0070	0.0073
Notes: Robust t-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1.						

4.3 Instrumental variables

To avoid the endogenous problem caused by the reverse causality, we adopt the urban internet penetration rate as an instrumental variable. Column (1) of table 6 reports the first-stage regression results. Last year's internet penetration rate is significantly related to the current year's digital financial inclusion, and the F value is 36.463. Thus, we are not concerned with the weak instrument problem. The last three columns of table 6 respectively show the results of instrumental variables estimation for the logarithm of industrial sulfur dioxide emissions, industrial nitrogen oxide emissions, and industrial smoke and dust emissions. According to table 6, the coefficients are negative, indicating that regions with more developed digital finance have better carbon emission mitigation effects, despite a decrease in statistical significance.

Table 6 Instrumental variables

	(1)	(2)	(3)	(4)
	F.index	F.lns1	F.lns2	F.lns3
internet	-0.1459***			
	(0.0241)			
index		-1.404	-0.8363	-2.5344**
		(1.1078)	(1.1203)	(1.1487)
Cragg-Donald Wald F statistic	36.463			
Control	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes
City-FE	Yes	Yes	Yes	Yes
Observations	1850	1850	1801	1804
Notes: Robust t-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1.				

4.4 Mechanism

The above analyses show that more digital-finance-inclusive regions have better carbon emission mitigation effects and lower industrial sulfur dioxide emissions rates. The coverage and depth of digital finance are two specific ways to reduce carbon emissions. What is the mechanism by which digital finance affects carbon mitigation? As we explained in the literature section, the mechanism of digital finance affecting carbon emission mitigation includes financially supporting emission mitigation facilities with green finance and increasing individual environment awareness. Therefore, we will verify this mechanism next.

If digital finance motivates individuals to control their daily activities and then mitigates carbon emissions, we should see that digital finance has a significant impact on individual awareness. In the following analysis, we use the centralized treatment rate of sewage treatment plants and the harmless treatment rate of domestic garbage as proxies to test this mechanism. In table 7, we regress the logarithm of each city's centralized treatment rate of sewage treatment plants (lns8) and that of the harmless treatment rate of domestic garbage (lns9), with the same control variables in the baseline regression. Table 7 columns (1)-(2) examine the correlation between digital finance inclusion and individual awareness proxies. Columns (3)-(6) show the effects of coverage breadth and application depth on the individual awareness proxies. Both the general index and the sub-index positively impact the individual awareness proxies.

Table 7 Digital financial inclusion index and proxies for individual awareness

	(1)	(2)	(3)	(4)	(5)	(6)
	F.lns8	F.lns9	F.lns8	F.lns9	F.lns8	F.lns9
index	0.1691***	0.1652**				
	(0.0507)	(0.0753)				
coverage_breadth			0.0884***	0.0988***		
			(0.0301)	(0.0364)		
usage_depth					0.0611	-0.0272
					(0.0422)	(0.0623)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes	Yes	Yes
City-FE	Yes	Yes	Yes	Yes	Yes	Yes
Obsevations	1990	1965	1990	1965	1990	1965
R Squared	0.2476	0.1389	0.2512	0.1431	0.2381	0.1332
Notes: Robust t-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1.						

4.5 Other outcome: Air quality

The previous section discussed that digital finance could mitigate industrial pollution emissions by improving individual awareness. In this section, we further consider the effect of digital finance on air quality as a robustness test. Specifically, we continue to use our previous model and add PM2.5 to measure air quality. We take PM2.5 as a dependent variable to investigate the correlation between the development of digital finance and air quality. Table 8 reports the results, in which columns (1)–(3) respectively show the relationship between digital financial indexes and air quality. The regressions of PM2.5 show that the general index and depth of digital financial inclusion have no significant impact on air quality. Still, the coverage of digital finance significantly reduces PM2.5 at the statistical level of 5%. Table 8 illustrates the extent to which the coverage of digital finance can help improve air quality.

Table 8 Digital financial inclusion index and air quality

	(1)	(2)	(3)
	F.pm25	F.pm25	F.pm25
index	-0.3448		
	(1.8670)		
coverage_breadth		-2.4065**	
		(1.0054)	
usage_depth			0.8937
			(1.1003)
Control	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes
City-FE	Yes	Yes	Yes
Obsevations	1241	1241	1241
R Squared	0.2363	0.2432	0.2367
Notes: Robust t-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1.			

5. Conclusions And Policy Implications

In the *14th Five-Year Plan for National Economic and Social Development and the Outline of Long-term Goals for 2035****[3]***, the road map of carbon neutrality points out the digital economy. New energy and innovation are the key pillars to achieving the goal of carbon neutrality. In 2020, the latest *Index Climate Action Roadmap****[4]*** released by the Global Climate Action Summit pointed out that the solutions of digital technology in the fields of energy, manufacturing, agriculture, land, construction, services, transportation, and traffic management can help the world reduce carbon emissions by 15%. Policymakers and academic researchers have gradually realized that digital finance can be a tool to promote sustainable development.

In this paper, we investigate the relationship between digital finance and industrial emission reduction by matching the city-level data from the Peking University Digital Inclusive Finance Index with the industrial pollution emission information. We find that the development of digital finance can significantly mitigate industrial emissions, and the coverage and depth of digital finance can dramatically help with carbon emission reduction. In analyzing the mechanism, we find that the development of digital finance can improve individual awareness and promotes green finance, thus helping to reduce carbon emissions.

To further promote carbon neutrality, we suggest encouraging integration for digital payment platforms. Government should not restrict or ban digital service lines, but rather government should provide more rooms for platforms to grow. As our study has shown, the coverage and depth of digital finance have spillover effects on the sustainable environment. The expansion of digital finance services can benefit shareholders in the long run.

This study has the following policy implications. First, we suggest speeding up the construction of digital cities. Our empirical results show an average of 17.3% decrease in the industrial pollution emissions caused by digital finance. Continuously improving the effectiveness and accuracy of digital finance can promote the development of green financial products and further enhance the quality and efficiency of the green environment.

Second, the market can match supplies with the demand sides of green digital finance without government intervention. Our study shows that government spending is not statistically significantly related to pollution emission, particularly for developing countries. We do not see a positive impact from government intervention, which may need further studies.

Finally, we suggest that government can provide fiscal support to digital finance, such as tax deductions. Unlike traditional manufacturing services, digital finance providers incur fewer transition costs and are less physically invested in their product lines. Thus, a high tax rate could drive away digital finance and cause developing countries to be less attractive to digital suppliers. If the local government does consider the positive spillover effects and wants to keep leading digital finance corporations, rising digital tax may not be a good policy. Further research may be needed to explore the optimal taxation for digital finance to maximize society shareholders' utilities.

[3] "Proposals of the Central Committee of the Communist Party of China on Formulating the Fourteenth Five-Year Plan for National Economic and Social Development and the Long-Term Goals for 2035." Xinhua News Agency, 3 Nov. 2020, http://www.gov.cn/zhengce/2020-11/03/content_5556991.htm.
[4] See http://www.indiaenvironmentportal.org.in/content/430452/roadmap-for-global-climate-action/.

Declarations

Acknowledgments

We thank Dr. YijianHu, Dr. Yiping Wu and Dr. Nathan Schiff for their helpful comments.

Ethical Approval

Not applicable. This study does not involve humans and/or animals.**Consent to Participate**

Individuals consent to participate in this study and agree to having their data published in Environmental Science and Pollution Research journal.

Consent to Publish

All Authors hereby consents to publication of this paper in Environmental Science and Pollution Research journal. All Authors warrants that this paper has not been published before in any form, that this paper is not being concurrently submitted to and is not under consideration by another publisher, that the persons listed above are listed in the proper order and that no author entitled to credit has been omitted.

Authors Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Cai Zhou and Jinghong Zhou. The first draft of the manuscript was written by Cai Zhou and Jinghong Zhou. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author, Jinghong Zhou.

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