Digital Finance and Pollution: Firm-Level Evidence From China

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ABSTRACT

Using combined data from the 2011–2013 China Industrial Firm Database, China Industrial Firm Pollution Emission Database, and provincial-level digital financial inclusion index, this paper investigates the impact of digital finance on firm pollution. The authors find that digital finance significantly reduces firm SO2 emission intensity. The inclusive finance attribute of digital finance is conducive to alleviating firm financing constraints and promoting firm transformation and emission reduction. Furthermore, digital finance reduces pollution through innovation compensation. Digital finance mainly affects private firms and small and medium-sized firms, while it mainly plays its role through depth of use, digital payments, and digital credit. The basic conclusions of this paper are verified by using the Internet development level and the spherical distance from Hangzhou, as instrumental variables. This paper has important policy implications for developing countries using digital financial tools to promote green economic transformation and high-quality development.

KEYWORDS

Digital Finance, Financial Constraints, Innovation, Pollution

1. INTRODUCTION

Balancing economic development and environmental protection is an important issue for sustainable economic growth (Nasir et al., 2019; Nguyen et al., 2020; Dong et al., 2020). Under the pressure of maintaining high economic growth in developing countries, economic policies are more likely to deviate from sustainable development, making environmental issues particularly prominent (Khan et al., 2020). The Chinese government has long attached great importance to environmental protection and green development. In September 2020, President Xi Jinping solemnly announced at the 75th United Nations General Assembly that China’s carbon dioxide emissions will peak by 2030 and it will strive to achieve carbon neutrality by 2060. Carbon peaking and carbon neutrality are not only the focus of China’s 14th Five-Year Plan, but also a major long-term strategy for the next few decades. The connotation of high-quality economic development is essentially different from traditional development methods, and it essentially requires more comprehensive and innovative development. One of them is to achieve industrial-structure optimization, involving a new industrial revolution and
carbon neutralization. In March 2022, Premier Li Keqiang clearly stated in the government work report that China will seek to continuously improve the ecological environment, promote green and low-carbon development, initiate an orderly process of carbon peaking and carbon neutralization, and implement a carbon peaking action plan. Implementing carbon neutralization and achieving green development have become a major strategic goals of China’s high-quality economic development.

Finance is an important core competitiveness of a country, and it should and must play an important role in the development process of achieving carbon peaking and carbon neutrality (Fan et al., 2021). Particularly in recent years, the vigorous development of digital finance has identified the optimal way of promoting the green transformation of firms. Starting with the launch of Alipay in 2004, digital finance, as a symbolic product of the combination of a new round of technological revolution and industrial transformation, was the prelude to profound changes and innovative adjustments in the financial industry. Since 2014, digital finance has ushered in explosive growth, and its scale is rapidly doubling every year. Furthermore, many traditional institutions in China, including the five state-owned commercial banks, have fully embraced digital finance, marking the official entry of China’s financial industry into the era of digital finance. Through the combination of digital technology and financial products, digital finance overcomes the shortcomings of traditional financial services, lowers the threshold of financial services, promotes the transformation of traditional financial institutions, and improves the efficiency of financial markets, which is of great significance in promoting innovation and entrepreneurship. Existing research has found that for each unit increase in the digital financial inclusion index, the number of newly registered firms in the corresponding region increases by an average of 0.246% (Guo et al., 2016). Compared with traditional finance, digital finance has the characteristics of personalization, facilitation, and scenario-based, winning the favor of many consumers. Rapidly developing digital finance has become an important competitive force in financial markets, especially in the payments field, posing challenges to traditional finance. The emerging model of digital finance has also sparked academic discussions internationally. The Review of Financial Studies, an internationally renowned journal, launched a special issue on digital finance in 2019 (Fuster et al., 2019; Tang, 2019; Chen et al., 2019).

However, compared with the rapid development of digital finance in the field of financial services and its core positioning in serving the real economy, research on the impact of digital finance on firm emission reduction is extremely scarce and insufficient. How effective is digital finance in promoting firm emission reductions? Are there differences in the emission reduction behaviors of different types of firms promoted by digital finance? What is the mechanism through which digital finance promotes firm emission reduction? What is the best way to propose precise, differentiated, and efficient digital-finance policies for the real economy? These questions must be studied urgently in the era of the digital economy. This paper uses a combined firm-level dataset from the China Industrial Firm Database, Chinese Industrial Firm Pollution Emission Database, and the province-level digital financial data to conduct a detailed analysis of the above issues from the perspective of inclusiveness and fostering innovation of digital finance.

This paper comprehensively explores the impact of digital finance on firm pollution emissions using the combined data of the China Industrial Firm Database and China Industrial Firm Pollution Emission Database from 2011 to 2013, as well as the province-level digital financial inclusion index published by the Institute of Digital Finance of Peking University. We find that the development of digital finance has significantly reduced the SO2 emission intensity of firms. With the development of digital finance, the sulfur dioxide emission intensity of firms tends to decline. There are two influence mechanisms. One is that digital finance is conducive to alleviating the financing constraints of firms. Therefore, when local governments implement stricter environmental regulations, it can help firms to carry out green transformation, thereby reducing the intensity of pollution emissions and promoting firm emission reductions. Second, digital finance, as a new form of financial business, is conducive to promoting firm innovation, thereby partially or fully compensating for the negative externalities of pollution (Porter & Van der Linde, 1991; Porter, 1999). The public nature of environmental resources
means that pollution has negative externalities. When there is no cost of pollution control, pollution originates from the lag of environmental regulations and awareness at the macro level, and originates from the instinctive nature of firms pursuing profit maximization at the micro level (King & Toffel, 2009; Zhang & Vigne, 2021). The Porter hypothesis explains the motivation of firms to innovate and reduce emissions under environmental regulation, that is, innovation compensation can partially or fully offset the cost of pollution, and a certain degree of environmental regulation will stimulate firm innovation and productivity (Porter & Van der Linde, 1991; Porter, 1999). The Porter hypothesis provides a potential logic for motivating firms to improve the efficiency of green innovation.

We cluster the standard deviations at the firm level and at the province level, and the results are robust. Heterogeneity analysis found that digital finance is mainly beneficial to state-owned and private enterprises and small and medium-sized enterprises (SMEs) in reducing emissions, which is consistent with the fact that private firms and SMEs face greater difficulty in obtaining financial support from formal financing channels and the inclusive nature of digital finance. From the perspective of digital finance sub-indices, the depth of digital finance use, digital payments, and digital credit plays a key role in firm emission reduction, whereas the impact of digital finance coverage and other sub-indices is not significant. Drawing on the existing literature, this paper uses the number of Internet users in each province and the spherical distance from each province to Hangzhou as two tools of digital finance to conduct an endogeneity test, which supports the basic conclusions of this paper.

At present, China’s economy has transformed from high-speed growth to high-quality development. In this context, digital finance, as an important new business form serving the real economy, has received increasing attention from government departments. This paper studies the relationship between digital finance and firm emission reduction, which can better guide digital finance to serve the real economy, which is of great significance in promoting the coordinated development of the financial industry and the real economy, and to a certain extent, it can promote the high-quality development of the Chinese economy. On the one hand, as an important emerging form of financial development combined with cutting-edge technology, digital finance is conducive to promoting the healthy development of digital finance by studying the specific ways in which it affects firm emission reductions, and has practical significance for the current high-quality development of China’s financial markets. On the other hand, by studying firm emission reductions, this paper shows that digital finance is beneficial to promoting firm emission reductions by easing financing constraints and promoting innovation, which can help promote green development of the whole economy. When digital finance and traditional finance continue to complement each other, finance can better serve the real economy, which in turn can promote the high-quality development of the real economy and bring China’s economy to a new stage of development.

Compared with existing research, the main contributions of this paper are twofold. First, this paper studies the impact of digital finance on pollution emissions at the firm level for the first time. This paper directly studies the impact mechanism and effect of digital finance on firm emission reduction, which reflects the fact that firms are the main source of pollution emissions, and also evaluates and tests the impact of digital finance on the emission reductions of firms. Moreover, firm heterogeneity of the impact of digital finance is observed, which is conducive to the formulation and implementation of more accurate digital finance and emission reduction policies. Second, different from the existing research related to digital finance and regional emission reduction, e.g. Wen et al. (2022), Wang et al. (2022), Wan et al. (2022), and Yang et al. (2022), this paper explores the mechanism of digital finance from the perspective of financing constraints and innovation, enriching the relevant research. This paper not only verifies that the innovative compensation effect proposed by the Porter hypothesis is conducive to firm emission reduction, but also tests the inclusive financial attribute of digital finance, that is, digital finance promotes firm emission reduction by reducing financing constraints. In areas with strong environmental regulations, firms need financial support for emission reduction and transformation and upgrading. The inclusive financial nature of digital finance is conducive to helping firms transform and upgrade in the face of stronger environmental
regulations, thereby achieving emission reductions. Overall, this paper enriches research on digital finance and pollution emissions, and is a useful complement to existing research.

The rest of this paper is structured as follows. Section 2 presents the literature review and proposes our theoretical hypothesis. Section 3 presents our empirical strategies. Section 4 presents the empirical results. The final section discusses the research conclusions and policy implications.

2. LITERATURE REVIEW AND THEORETICAL HYPOTHESIS

2.1 Literature Review

Digital finance generally refers to the use of digital technology by traditional financial institutions and Internet companies to realize financing, payments, investment, and other new financial business services (Hua & Huang, 2021). This paper mainly studies the inhibitory effect of digital finance on firm pollution emissions, and discusses its internal mechanisms from the perspective of financing constraints and firm innovation. Therefore, the research related to this paper can be roughly divided into two categories: research related to the impact of digital finance, and research related to factors affecting firm pollution emissions.

Research related to digital finance mainly focuses on the definitions of digital finance and the potential impacts of digital finance. Digital finance is a new financial format and model brought about by the advancement of digital technology. It is the deep integration of digital technology and the financial industry and is manifested in a substantial increase in connectivity and information processing speed, which is bringing revolutionary changes to traditional finance (Gomber et al., 2017; Goldstein et al., 2019). The reason for the emergence of digital finance is that traditional financial services are too expensive and inefficient. While digital finance brings structural changes, it also faces regulatory challenges (Philippon, 2016). The rapid development of digital finance has created an extremely wide range of influences. Some studies have analyzed the impact of digital finance on financial inclusion and stability (Ozili, 2018; Durai & Stella, 2019; Risman et al., 2021; Atellu & Muriu, 2022). Several studies have examined the impact of digital finance on financial efficiency (Wang et al., 2020). A few other studies focus on the impact of digital finance at the micro level, such as the impact on household consumption and the leverage of Chinese households (Li et al., 2020; Wang et al., 2022). There are also studies investigating the impact on green technology innovation (Feng et al., 2022).

The second strand of literature closely related to this paper is the research on firm pollution. Firm pollution emissions are an important indicator of environmental performance (Gray & Deily, 1996; King & Lenox, 2001; Badau et al., 2016; Basrawi et al., 2016). The public property of environmental resources makes the pollution a negative externality. When there is no pollution control cost, pollution originates from the lag of environmental regulations and awareness at the macro level, and originates from the instinctive nature of firms pursuing profit maximization at the micro level (King & Toffel, 2009; Tian & Lin, 2019). The Porter hypothesis explains the motivation of firms to pursue good environmental performance under environmental regulation, that is, a certain degree of environmental regulation will stimulate firm innovation and productivity, and innovation compensation can partially or fully offset the cost of pollution (Porter, 1991; Porter & Van der linde, 1995). The Porter hypothesis provides a potential logic for incentivizing companies to reduce emissions. Based on this, existing studies have focused on the impact of emissions trading, environmental regulation, regulatory power, international trade, FDI, market competition, and technological upgrading on firm emissions (Cai et al., 2016; Zhang et al., 2018; Cherniwchan et al., 2017; Bakhsh et al., 2018; Duanmu et al., 2018). In addition, the heterogeneity of firm pollution is receiving widespread attention. Differences in productivity, exports, investment, and financial resources between SOEs and non-SOEis in China lead to heterogeneity in emissions. For example, Huang & Chang (2019) used Chinese firm-level data to compare the potential differences in pollution costs between foreign, state-owned, and private firms.
It was found that in most industries, the pollution costs of foreign-owned firms are relatively low, whereas the pollution costs of private firms are higher. Zhang & Zheng (2019) explored the impact of financing constraints on firm pollution control in China. It was found that state-owned firms can ease fiscal constraints through external financial.

Wen et al. (2022) and Wan et al. (2022) are two studies closely related to our paper. They both studied the impact of digital finance on China’s pollution emissions using province-level data. Wen et al. (2022) found that digital finance reduces pollution by upgrading the industrial structure. Wan et al. (2022) found that digital finance reduces pollution through three mechanisms: technological innovation, structural adjustment, and capital allocation effects. The difference between this paper and their papers is that this paper uses firm-level data to obtain more accurate estimation results. At the same time, this paper tests a new mechanism of action, that is, digital finance reduces pollution by easing financing constraints.

From the above literature review, we can see that few studies have focused on the impact of digital finance on firm pollution emissions. Some studies have examined the impact of digital finance on pollution emissions at the regional level, but they cannot directly examine the impact of digital finance on firms that are directly responsible for pollution, nor can they examine the firm heterogeneity of the impact of digital finance. This paper uses data from the Chinese Industrial Firm Database and the Chinese Industrial Firm Pollution Emission Database, as well as provincial-level digital financial data to examine the impact of digital finance on firm pollution emissions, thus addressing the deficiencies of the existing literature.

2.2 Theoretical Hypothesis

Firms usually reduce pollution emissions in two ways: front-end treatment and end-of-line treatment. The former refers to the reduction of energy consumption on the input side, the improvement of production efficiency, or the improvement of the level of green technology. The latter refers to the treatment of increased pollution through the addition or improvement of pollution treatment facilities. Either way, companies need to make relatively expensive environmental investments (Qi et al., 2021). Compared with general investment, environmental investment usually has the characteristics of a long cycle, low return, and high risk, and firms need to make a large capital investment in the early stage (Chen, 2015). Therefore, environmental investment will be increased only when the financing constraints faced by firms are not severe. Numerous studies, such as Zhang & Zheng (2019), have confirmed that the lack of financial support is an important reason why polluting companies cannot reduce emissions. When companies have access to credit support, they have the funds to develop new products, and update production processes and pollution treatment facilities. At the same time, given the level of financing constraints of firms, the level of environmental investment or emission reduction of firms is also affected by external environment factors, the most important of which is environmental regulation. The most direct impact of environmental regulation is to increase the environmental cost faced by firms. Therefore, when the intensity of environmental regulation increases, on the one hand, it will increase the financing constraints of firms, and on the other hand, firms have to reduce pollution emissions. When environmental regulation causes firms to face more serious financing constraints or the losses caused by reducing pollution are too large, firms will choose to withdraw from the market. If the corresponding financing support is provided for these firms at this time, it will help these firms to ease financing constraints and reduce pollution emissions while meeting the requirements of environmental regulations. Therefore, firms also need external pressure to reduce emissions. When the degree of external environmental regulation is relatively strict, firms have greater pressure and motivation to reduce emissions. At this time, digital finance can play a greater role by alleviating financing constraints.

In fact, the important role of financial development in promoting structural transformation has been widely demonstrated (Jiang et al., 2020; Nanziri & Wamalwa, 2021), and financial development can significantly improve environmental performance (Tamazian & Rao, 2010). Recent studies have
found that, as an important financial tool for emission reduction, green credit can significantly reduce the level of firm pollution (Fan et al., 2021). As a new financial business form that combines digital technology with the financial industry, digital finance will not only reduce information asymmetry, but also help solve the problems of a high risk premium and high cost inherent in traditional finance. In addition, by lowering the access threshold, expanding the scope of services, it helps achieve inclusive finance (Guo et al., 2016; Demertzis et al., 2018). Furthermore, digital finance is also conducive to improving resource misallocation and improving resource allocation efficiency (Laeven et al., 2015). These characteristics all show that digital finance is conducive to reducing firm financing constraints and helping companies reduce emissions.

Based on the above analysis, we believe that the inclusive financial attributes of digital finance are conducive to alleviating firm financing constraints and promoting firm innovation, both of which will reduce the level of pollution emissions. The emission reduction effect of digital finance, by easing financing constraints, is more obvious when companies face environmental regulations. Therefore, this paper proposes the following three research hypotheses:

**Hypothesis 1:** Digital finance is conducive to reducing the intensity of firm pollution emissions.

**Hypothesis 2:** Digital finance reduces the intensity of firm pollution emissions by alleviating financing constraints. In areas with stronger environmental regulations, digital finance can alleviate firm financing constraints and reduce emissions.

**Hypothesis 3:** Digital finance reduces the intensity of firm pollution emissions by promoting firm innovation.

### 3. EMPIRICAL STRATEGY

#### 3.1 Model Specification

This paper uses combined data from the China Industrial Firm Database, the China Industrial Firm Pollution Emission Database, and Provincial Digital Finance Index data from 2011 to 2013 to study the impact of digital finance on the pollution emission intensity of firms. To examine the impact of digital finance on firm pollution emissions, this paper estimates the following baseline regression model:

\[
\ln \ln pollution_{it} = \alpha + \theta \ln df_{pt} + \beta X + FE_i + FE_p + \epsilon_{it} \quad (1)
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\ln \ln pollution_{it} = \alpha + \theta \ln df_{pt} + \beta X + FE_i + FE_p + FE_j + \epsilon_{it} \quad (2)
\]

where \(i\) represents the firm, \(p\) represents the province, \(j\) represents the four-digit industry of the Chinese industry classification (GB/T 4754-2011), and \(t\) represents the year. \(pollution_{it}\) indicates the sulfur dioxide emission intensity of firm \(i\) in year \(t\). \(df_{pt}\) represents the digital finance index of province \(p\) in year \(t\). \(X\) indicates the control variables at the firm level and the provincial level. \(FE_i\) represents firm fixed effects, which are used to control for firm characteristics that do not change over time. \(FE_p\) indicates the year fixed effect that controls annual trends and common shocks. This paper further controls the time-varying four-digit industry fixed effects in equation (2), \(FE_j\), which is used to control the common industrial policies faced by all provinces implemented by the central government. \(\epsilon_{it}\) is the disturbance term. In the baseline regression, this paper clusters the standard errors at the firm level, and in the robustness test, standard errors are clustered at the provincial level. Therefore, \(\theta\) is the core coefficient of interest in this paper, which represents the percentage change in the pollution intensity of firms brought about by a 1% increase in digital finance.
3.2 Variables and Data

**Dependent variable:** Firm sulfur dioxide emission intensity (lnso2). We use the natural log of the ratio of sulfur dioxide emissions to industrial output to measure firm sulfur dioxide emission intensity.

**Independent variable:** Provincial digital finance index (lndf). The data are from the Institute of Digital Finance at Peking University. The original data for compiling the digital finance index are from the big data on digital inclusive finance from Ant Financial Services. The index system is constructed based on account-level data from Ant Group and contains information on digital finance, including: 1) Alipay account coverage; 2) third-party digital payments, both online and offline, via Alipay; and 3) online investment, credit, and insurance via Ant Group’s FinTech platform. This index system covers three dimensions of digital financial services: coverage breadth, use depth, and digital support services. In the total index, there are six categories of sub-index: payments, insurance, monetary funds, investment, credit investigation, and credit. In short, the specific steps for calculating the digital financial index are as follows. First, normalize each variable to remove the influence of dimensions. Second, use the coefficient of variation method to determine the weight of each variable. Finally, obtain the digital financial index by taking the weighted average of all variables. A detailed description of the digital finance index can be found in Guo et al. (2020).

**Control variables:** See below:

1. **Firm size (lnsize):** We use the natural log of total assets to measure firm size.
2. **Firm capital intensity (lnklr):** We use the natural log of fixed assets per worker to measure firm capital intensity.
3. **Firm age (lnage):** We use the natural log of (current year minus the year of firm establishment + 1) to measure firm age.
4. ** Provincial GDP per capita (lnpcgdp):** The data are obtained directly from the National Bureau of Statistics of China.
5. ** Provincial government scale (lnfiscal):** We use the log of the ratio of provincial fiscal expenditure over GDP to measure provincial government scale.
6. ** Provincial innovation capability (lnrd):** We use the natural log of provincial R&D expenditure over GDP to measure provincial innovation capability.
7. ** Provincial human capital (lnhcapital):** We use the natural log of the number of college students per 10,000 in each province to measure provincial human capital.
8. ** Provincial population intensity (lndensity):** We use the natural log of the ratio of total population over geographical area to measure provincial population intensity.
9. ** Provincial FDI (lnfdi):** We use the natural log of the ratio of FDI inflows over GDP to measure provincial FDI.
10. ** Provincial trade openness (lnopen):** We use the natural log of the ratio of trade volumes over GDP to measure provincial trade openness.

The firm-level sulfur dioxide emission data come from the China Industrial Firm Pollution Database. The industrial output value required to calculate the firm sulfur dioxide emission intensity and the firm-level control variables such as firm size, capital intensity, and firm age are obtained from the China Industrial Firm Database. Data on control variables at the provincial level were obtained from the official website of the National Bureau of Statistics of China.

3.3 Descriptive Statistics

The number of observations of the SO2 emission intensity variable is 89,175, the number of observations of the variable of firm employment is 129,109, and the number of observations of the variable of firm capital intensity is 127,797. The number of observations for the remaining variables is 131,906. To visually inspect the development of digital finance, this paper presents the overall
digital finance index and the sub-indexes of coverage breadth and usage depth in Figures 1 and 2, respectively. Figure 1 shows that during the period from 2011 to 2020, on the one hand, China’s digital finance generally showed an increasing trend, and on the other hand, there were obvious differences in the level of digital finance between provinces. At the same time, the growth rate of digital finance is slowing gradually. Figure 2 shows that the coverage breadth and usage depth of digital finance are also increasing gradually, and these two sub-indices also exhibit significant differences between

Figure 1. Trend of digital finance index

![Figure 1. Trend of digital finance index](image)

Figure 2. Trends of coverage breadth and usage depth of digital finance

![Figure 2. Trends of coverage breadth and usage depth of digital finance](image)
provinces. At the same time, the coverage breadth of digital finance has grown more steadily, whereas the usage depth has fluctuated slightly.

4. EMPIRICAL ANALYSIS

4.1 Baseline Regression

Table 1 reports the baseline regression results of the impact of digital finance on the intensity of firm pollution emissions. The first three columns control the firm fixed effects and the year fixed effects, and the final three columns further control the time-varying industry

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Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively, and the brackets below the coefficient indicate the standard error of clustering at the firm level.
fixed effects. Columns (1) and (4) only include provincial digital finance variables, columns (2) and (5) further include firm control variables, and columns (3) and (6) further include provincial control variables. The results in column (3) show that the estimated coefficient of digital finance is $-0.026$, indicating that a 10% increase in digital finance will reduce the SO$_2$ emission intensity of firms by 0.26%, and this effect is significant at the 1% level. After controlling for the time-varying industry fixed effects, the results in column (6) show that a 10% increase in digital finance significantly reduces the firm’s SO$_2$ emission intensity by 0.32%. It preliminarily supports the conclusion that digital finance is conducive to reducing firms’ sulfur dioxide emission intensity. In all regressions, the coefficient of firm size represented by the number of employees is significantly negative, indicating that the larger the firm, the lower the sulfur dioxide emission intensity. The capital intensity coefficient is significantly negative, indicating that the higher the capital intensity of the firm, the lower the sulfur dioxide emission intensity, which is consistent with the intuition. Labor-intensive firms usually have higher pollution emissions than capital-intensive firms. The coefficient of firm age is significantly negative, indicating that the older the firm, the lower the pollution emission intensity, which is consistent with the intuition. From the perspective of the control variables at the provincial level, only the two variables of human capital and openness of the province have significant effects, and the effects of other variables are not significant. The higher the proportion of human capital, the lower the pollution emission intensity of firms. This is easy to understand. Provinces with higher human capital are more likely to transform and upgrade. The higher the proportion of trade to GDP in the province, the greater the intensity of firm pollution emissions, which deviates from intuition. Most studies have found that trade openness can reduce pollution emissions, but some studies have found that trade openness may increase pollution by distorting the domestic economic structure (Asako, 1979).

4.2 Robustness Test

4.2.1 Clustering Standard Errors at the Provincial Level

The baseline regression is clustered at the firm level. To test the robustness of the results, this section clusters the standard errors at the provincial level. Results are reported in columns (1) and (2) of Table 2. The impact of digital finance on firm SO$_2$ emission intensity is significantly negative at the 5% level, indicating that the baseline regression is robust.

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<td>-0.032**</td>
<td>-0.017**</td>
<td>-0.021**</td>
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<td>(0.013)</td>
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4.2.2 Considering the Influence of Extreme Values

In this paper, the main variables are winsorized at the 1% level to exclude the possible dominant effect of extreme values on the results, and the results show that the impact of digital finance on the intensity of SO₂ emissions from firms is still robust. The results are reported in columns (3) and (4) of Table 2.

4.3 Heterogeneity Analysis

We next examine the heterogeneity of the impact of digital finance on firm pollution emissions. This paper mainly examines heterogeneity in three dimensions: differences in ownership, differences in scale, and differences in digital finance in different dimensions.

4.3.1 Results by Ownership

Table 3 reports the regression results of different firm ownership types. Digital finance mainly has a significant negative impact on the sulfur dioxide emission intensity of state-owned enterprises (SOEs) and private-owned enterprises (POEs), and has no significant impact on foreign-invested enterprises (FIEs). Digital finance reduces the SO₂ emission intensity of private companies by 0.021%. This may be because, on the one hand, compared with Chinese-owned firms, foreign-invested firms have a higher level of internationalization and technology, and have a lower level of environmental pollution, so digital finance has less impact on foreign-invested firms. On the other hand, state-owned firms can obtain financial support from formal financing channels such as banks, whereas private firms find it more difficult to obtain financial support from formal financing channels. Therefore, digital finance has a more significant effect on the reduction of the SO₂ emission intensity of private firms.

4.3.2 Results by Firm Size

This paper examines the impact of digital finance on the pollution emissions of firms of different scales. The full sample is divided into large-scale firms and small-scale firms according to the median of the total industrial output value of firms. The results are shown in Table 4. The results show that at the 10% level, digital finance has a significant negative impact on firms of different scales, but the impact on small-scale firms is slightly greater than that on large-scale firms. Digital finance reduces the sulfur dioxide emission intensity of small-scale firms by 0.031%, and only reduces the pollution intensity of large-scale firms by 0.021%. Moreover, the impact on small-scale firms is significant at the 5% level, compared with the 10% level for large firms. As such, digital finance mainly affects small-scale firms. This is consistent with the intuition that digital finance helps SMEs to obtain

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financing support more easily and conveniently, so digital finance significantly reduces the SO₂ emission intensity of small-scale firms.

4.3.3 Different Dimensions of Digital Finance

The Institute of Digital Finance of Peking University has compiled the digital financial inclusion index of 31 provincial administrative units across the country, as well as the coverage breadth, depth of use, and digitalization index of digital financial inclusion, as well as payments, insurance, monetary funds, credit services, investment, credit, and other sub-indices. This paper firstly examines the different impacts of digital financial inclusion on the pollution emission intensity of firms from the perspectives of coverage breadth, depth of use, and digitalization degree index, and then examines the heterogeneous impact of digital financial inclusion using specific classification indexes. Due to the serious lack of monetary funds and investments, only three sub-indices of payments, insurance, and credit are retained in the sub-indices. The first two columns of Table 5 report the impact results for the breadth of coverage, depth of use, and digitization index, and the last two columns report the estimated results for payments, insurance, and credit. The results show that the depth of the use of digital inclusive finance significantly reduces the intensity of SO₂ emissions of firms, and the impact of coverage breadth and digitization degree is not significant. Digital payments and credit significantly reduce the SO₂ emission intensity of firms, whereas the impact of insurance sub-index is not significant.

4.4 Endogeneity Analysis

The baseline regression results in this paper may suffer from two sources of potential endogeneity. One is the endogeneity generated by reverse causality, that is, firms with lower pollution intensity may have the potential to transform and upgrade their operations, and therefore are more likely to adopt digital finance. As this paper uses a provincial digital financial index that aggregates firm-level data, in essence, the endogeneity caused by reverse causation in this paper is greatly weakened. The other is the endogeneity of omitted variables. Unobserved important explanatory variables at the firm level may simultaneously determine the transformation and upgrading of firms and their pollution emission decisions. This paper adopts the instrumental variable method to try to solve the possible endogeneity issue in this paper. This paper uses two instrumental variables. One is the number of Internet users in each province, and the other is the spherical distance between the capital of each province and Hangzhou. The logic of using the Internet as an instrument is very intuitive. Internet technology is the basis for the emergence and development of digital finance. The more developed the Internet in a province, the higher the likely degree of development of digital finance. The logic of
using the spherical distance between the provincial capital and Hangzhou as an instrument is that the development of digital finance in Hangzhou as a digital financial capital will have a spatial spillover effect, where the closer the province is to Hangzhou, the greater the spillover effect.

The results of the endogeneity test are reported in Table 6. The first two columns use the number of Internet users as an instrumental variable, and the latter two columns use the spherical distance from Hangzhou as an instrumental variable. The results show that after using the instrumental variables, the impact of digital finance on the pollution emission intensity of firms is still significant at the 5% level, and the F-statistic value of the first stage is greater than 10, indicating that the instrumental variables are valid, confirming the robustness of the baseline regression results.

### 4.5 Mechanisms

This paper examines two mechanisms by which digital finance affects the intensity of firm pollution emissions. One is to provide inclusive finance to help small and medium-sized firms obtain more financial support, reduce financing constraints, and promote the transformation of firms to green production. Numerous studies, such as Zhang & Zheng (2019), have confirmed that the lack of financial support is an important reason why polluting companies cannot reduce emissions. When companies have access to credit support, they have the funds to develop new products, and update production processes and pollution treatment facilities. However, companies will not reduce emissions with financial support alone; external pressure is also needed. When the degree of external environmental regulation is relatively strict, firms have greater pressure and motivation to reduce emissions. At this time, digital finance can play a greater role by easing financing constraints. Therefore, on the one
hand, this paper tests whether digital finance reduces firm financing constraints, and at the same time tests whether digital finance plays a greater role in areas with stronger environmental regulations.

Column (1) of Table 7 shows that digital finance has a significant negative impact on firm financing constraints, that is, digital finance is conducive to reducing firm financing constraints. Column (2) shows that the coefficient of financing constraints is significantly positive, indicating that the higher the financing constraints, the higher the pollution emissions of firms. Furthermore, the interaction between digital finance and financing constraints is significantly negative, indicating that digital finance reduces the marginal effect of financing constraints, thereby promoting firms to reduce pollution. Columns (1) and (3) show that environmental regulation can exacerbate firm financing constraints. Column (3) further shows that in areas with stricter environmental regulations, digital finance has a greater effect on reducing firm financing constraints, which is consistent with expectations. The stricter the environmental regulations, the greater the financing constraints faced by firms, and the greater the space and role of digital finance in alleviating firm financing constraints. Column (4) shows that environmental regulation significantly reduces the intensity of firm pollution emissions. In areas with stricter environmental regulations, the role of digital finance in reducing the intensity of firm pollution emissions is also greater. Therefore, in general, Table 7 shows that digital finance promotes the transformation and upgrading of firms by alleviating the financing constraints of firms in the face of environmental regulations, and facilitates emission reduction.

The second mechanism examined in this paper is whether digital finance promotes firm innovation, thereby compensating for the cost of environmental pollution. This paper combines the previous sample data with data on firm patent applications. Due to the lag in patent grants, this paper uses patent filings as an indicator of innovation output. To preserve the number of observations, missing values of patent filings were assigned a value of zero. The results are reported in Table 8. The results in columns (1) and (3) show that at the 5% level, digital finance significantly improves the innovation level of firms, and a 1% increase in the digital finance index will increase the number of patent applications by 0.102% or 0.061%. In columns (2) and (4), the coefficient of innovation is significantly negative, indicating that innovation reduces pollution, and the coefficient of the interaction between digital finance and innovation is negative, indicating that digital finance magnifies the inhibitory effect of innovation on pollution, that is, digital finance reduces firm pollution through innovation.
5. CONCLUSION AND POLICY IMPLICATIONS

5.1 Main Conclusion

This paper uses the provincial-level digital finance index compiled by the Institute of Digital Finance of Peking University and the firm-level production and pollution emission data merged from the China Industrial Firm Database and the China Industrial Firm Pollution Emission Database to study
the impact of digital finance on firm pollution intensity of SO2. The study finds that digital finance significantly reduces firm pollution emissions. This paper identifies two mechanisms by which digital finance affects firm emission reductions, the financing constraint mechanism, and the innovative compensation mechanism. The inclusive financial nature of digital finance is conducive to providing financial support for firms, which in turn helps firms to transform and upgrade in the face of stronger environmental regulations and reduce the intensity of pollution emissions. Furthermore, digital finance encourages firms to carry out technological innovation and compensates for the negative externalities of environmental pollution, which supports the theoretical prediction of the Porter hypothesis. Heterogeneity analysis shows that digital finance mainly has a significant negative impact on the sulfur dioxide emission intensity of state-owned and private-owned enterprises and small and medium-sized enterprises, and has no significant impact on foreign-invested firms. This reflects the inclusive financial attributes of digital finance, which helps private firms and small and medium-sized firms to obtain financing support more easily and conveniently. Therefore, digital finance significantly reduces the sulfur dioxide emission intensity of private firms and small and medium-sized firms. From the subdivision index, the depth of the use of digital inclusive finance significantly reduces the SO2 emission intensity of firms, and the impact of coverage breadth and digitalization is not significant. Digital payments and credit significantly reduce the SO2 emission intensity of firms, whereas the impact of the insurance sub-index is not significant. The results are robust regardless of whether the standard deviations are clustered at the firm level or the province level.

5.2 Policy Implications

This paper not only has important implications for China’s future green development, but also has important reference value for the green transformation of other developing countries. At the just-concluded 20th National Congress of the Communist Party of China, President Xi Jinping delivered an important report. The report focuses on green development as a separate chapter, and the two most important measures are to accelerate the green transformation of development methods and to further promote the prevention and control of environmental pollution. The research in this paper provides an important idea for China in promoting green development, that is, to promote the green transformation of manufacturing enterprises through the development of digital finance. As a combination of the digital economy and the financial industry, digital finance is a new form of financial business and a new model that can ease firm financing constraints, promote firm innovation, and empower firms to undergo green transformation. In terms of specific measures, it is necessary to continuously expand the coverage and strengthen the depth of use of digital finance. The use of digital finance in the central and western regions is still relatively small because of the existence of the digital divide in particular. Therefore, the construction of digital infrastructure in these regions should be increased. For low-skilled workers, the government should provide specialized digital economy and digital finance skills training. In the meantime, the promotion and application of digital technology in the financial industry should also be strengthened to further improve financial efficiency and promote inclusive finance, so that every firm can enjoy the convenience and benefits brought by digital finance.

Other developing countries can also benefit from the development of digital finance. Due to the imperfect financial system, firms in developing countries generally face financing constraints, which limits green transition in these countries. Therefore, it is very important for these countries to vigorously develop digital technology and use it to transform the financial industry and promote the development of digital finance. Digital finance not only eases corporate financing constraints, but also promotes corporate innovation. In terms of specific measures, developing countries can cooperate with China through the Belt and Road Initiative, and absorb and learn from China’s experience in the development of the digital economy and digital finance. At the same time, developing countries should cultivate digital economy professionals and build digital infrastructure, provide a good supply of human capital for the development of digital finance, and promote the deep integration of the digital economy and the real economy.
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CONFLICT OF INTEREST

The authors declare no conflict of interest.
REFERENCES


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