A Study on the Mechanism of the Impact of Digital Economy on the Carbon Performance of Industrial Enterprises

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Abstract: Digital economy is an essential engine to realize the "dual-carbon" goal in China. Clarifying the relationship between digital economy and carbon performance of industrial enterprises is of great significance in promoting the realization of the "dual- carbon" target. In order to better explore the mechanisms of the digital economy and industrial enterprise carbon performance, this article is based on the fixed effect model and selects 2471 A-share listed industrial enterprises in 2010 to 2019 data as research samples. First, through the benchmark regression, we discuss the relationship between the two, then test the mediation effect of innovation, and finally, we further discuss the heterogeneity. After empirical analysis, it is concluded that: i. The digital economy can remarkably improve the carbon performance of industrial companies; ii. The level of corporate innovation is an important channel for the digital economy to increase the carbon performance of industrial companies; iii. The impact of the digital economy on the improvement of the carbon performance of industrial companies is more obvious in the samples of the non-state-owned, manufacturing industries and the companies with stronger environmental regulations.

Keywords: Digital economy, carbon performance, innovation

1. Introduction

To reduce global carbon emissions, General Secretary Xi Jinping suggested the "dual-carbon" target of "carbon peaking" by 2030 and "carbon neutral" by 2060. China accounts for nearly 70% of the world's total carbon emissions, with industrial enterprises accounting for 66.75% of them. It is clear that industry accounts for the majority of China's energy use and carbon emissions, making industrial companies the most efficient places to cut emissions and save energy for the achievement of China's "double carbon" aim.

The fast rise of the internet economy has given China's economy a fresh lease on life. The digital economy can promote the modernization and strategic transformation of industrial companies to smart, low-carbon and green technologies. Zhang et al.[1] analyzed the effectiveness of the digital economy on urban emission reduction from the perspective of "two objectives", and concluded that economic objectives weaken urban emission reduction effects and environmental objectives enhance urban low-carbon effects. Jiang et al. [2] found that the digital economy reduces regional carbon emissions by expanding socioeconomic scale and enhancing

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green innovation capacity. Few studies have focused on how the digital economy affects the reduction of carbon emissions from industrial firms, despite the fact that existing research has shown that it can reduce carbon emissions at the city level.

This study investigates the effects of the digital economy on the carbon performance of industrial organizations with data from listed businesses from 2010 to 2019 at the micro level of enterprises. The impact of the digital economy on industrial firms' carbon emissions is examined theoretically. We include "the level of innovation" as a mediating variable in the regression model and look at the heterogeneity of the effects of the digital economy on businesses' carbon emissions from three angles: industry, environmental regulation, and the nature of enterprise property rights. We discuss the key principles of the digital economy in depth in order to decrease carbon emissions. It provides theoretical backing for forthcoming studies on enhancing the carbon performance of Chinese industrial organizations.

2. Theoretical analysis and research hypothesis

2.1. Digital economy and corporate carbon performance

The digital economy integrates information technology into the real economy to enhance the level of efficiency and the optimization of the economic structure. Academics are now focusing on how the digital economy can enable businesses to reduce their energy consumption as a strategy to improve their carbon performance. First, from the standpoint of contemporary green ecology, the progress of digitization in information, artificial intelligence, network control, and other related technologies embedded in the digital economy increases the information link between financial institutions and low-carbon green enterprises. It helps financial institutions screen out low-pollution and low-energy-consuming enterprises. Additionally, it successfully reduces organizational uncertainty regarding the conduct of green innovation R&D and increases the effectiveness of green technology innovation. Second, from the standpoint of energy efficiency, the rapid development of the digital economy can successfully raise the level of technological innovation and total factor productivity of businesses, which can raise their energy utilization efficiency, lower their inefficient energy consumption [3] and, ultimately, help them reach their goal of lowering their carbon emissions. Finally, from the standpoint of the manufacturing process, the digital economy can optimize an organization's product production process, support the organization's upgrade to intelligence and digitalization, realize the precise control of the entire enterprise product process from R&D to sales, monitor the energy consumption in all links, and reducing resource waste [4]. From the existing studies, it is known that digital economization of enterprises can decrease carbon emissions, which will enhance an enterprise's carbon performance. In light of this, in this study, the following hypothesis is made:

H1: The digital economy can improve the carbon performance of industrial companies.

2.2. The influence mechanism of the digital economy on carbon performance

The academic community has argued for the value of the real digital economy in fostering innovation from both the city perspective and the firm perspective through a review of previous studies. From the point of view of the city, the digital economy boosts the efficiency of industrial production by encouraging the optimization of industrial structure, increasing resource utilization, and lowering energy consumption, improving cities' capacity for innovation [5]. In the view of enterprises, businesses can increase their levels of innovation by fostering digital transformation, improving internal operational efficiency, obtaining government subsidies, and gaining more external attention from the market. The digital economy has a non-linear incremental "boundary effect" on the ability of manufacturing businesses to innovate [6]. In addition, the digital economy can also help businesses employ big data, the Internet of Things, and simulation technologies to optimize their production chains, which will improve their innovation efficiency and energy utilization efficiency, reduce carbon emissions, and improve their carbon performance. Can the digital economy then enterprise innovation level as a means of enhancing carbon performance? The following hypotheses are put out in this article in light of this:

H2: The digital economy enhances carbon performance through increased innovation in industrial firms.

3. Research design

3.1. Model setting

The following research model is created to examine how the digital economy affects carbon performance:

$$CEPI_{it} = \beta_0 + \beta_1 Dig_{it} + \beta_2 \sum Control_{it} + \sum Year + \sum Ind + \varepsilon_{it} \quad (1)$$

In which the explained variable $CEPI_{it}$ represents the carbon performance of firm i in year t, the explanatory variable Dig_{it} represents the degree of the digital economy of firm i in year t, and $\sum Control_{it}$ denotes the group of regulating variables, $\sum Year$ denotes the time fixed impact, denotes the industry fixed effect, and ε_{it} denotes the phrase for random disruption.

3.2. Variables definition

Explained variable: carbon performance of an enterprises (CEPI). Drawing on studies such as Yan et al. [7], the ratio of enterprise's million operating incomes and carbon emissions is used to measure the enterprise's carbon performance. In this paper, we estimate enterprise carbon emissions approximately with the help of enterprise business costs and industry carbon emissions, measure industry carbon emissions using the China Energy Statistical Yearbook of total industrial energy consumption, and compile industry main business cost statistics using the China Industrial Economic Statistical Yearbook. The formula for calculating enterprise carbon performance is as following:

$$CEPI = \frac{Business\ revenue}{\frac{Industry\ carbon\ emissions}{Industry\ main\ business\ cost} \times Businesscost \times 100} \quad (2)$$

Explanatory variable: digital economy (Dig). This paper is based on microenterprise research and draws on practices such as Qi et al. [8] to measure the digital economy by choosing the percentage of total enterprise intangible assets to the year-end intangible asset information given in the notes to the financial reports of listed companies relevant to the digital economy.

Mediating variable: the level of corporate innovation (RD). This paper chooses the proportion of R&D investment to business income to weigh the enterprise's R&D innovation level.

Control variables: net profit ratio of total assets (ROA); fixed assets ratio (Far); current assets ratio (Lr); firm size (Size); equity concentration (Top1); nature of ownership (Soe); the ratio of independent directors (Indratio); cash ratio (Cr); and gearing ratio (Lev). In addition, this paper controls for industry and time fixed effects.

3.3. Data sources

To exclude the influence of the new crown epidemic, this study chooses all industrial businesses with A-shares listed between 2010 to 2019, whose enterprise-level data are obtained from the CSMAR database and industrial carbon emission data from the China Energy Statistical Yearbook. At the same time, the sample data were processed as follows: i. excluding the ST stock and *ST enterprise samples; ii. excluding the samples with serious missing variables; iii. the continuous variable data were processed to 1% and 99% tail reduction to remove the impact of extreme values. The final data for 15561 samples was obtained, and the data processing software was stata17.

4. Empirical analysis

4.1. Baseline regression analysis

Table 1 displays the results of the conventional regression and robustness tests for the influence of the corporate digital economy on enterprise carbon performance. The regression in column (1) does not include any fixed effects or control variables, and the correlation coefficient of Dig is notable at the 10% level; the regression in column (2) does include year fixed effects, and the correlation coefficient of Dig proves significant at the 1% level; the regression in column (3) does include industry fixed effects, year fixed effects, and control variables, and the correlation coefficient of Dig is noteworthy at the 10% level. The aforementioned findings demonstrate that industrial firms' carbon performance is significantly improved by the digital economy of businesses, thus verifying hypothesis 1.

Table 1 Baseline regression and robustness tests

	(1) CEPI	(2) CEPI	(3) CEPI	(4) CEPI	(5) Dig	(6) CEPI	(7) CEPI
Dig	0.023*	0.032***	0.016**	0.017**		0.087***	
	(0.012)	(0.011)	(0.008)	(0.008)		(0.032)	
m-Dig					0.523***		
					(0.194)		
g-Dig							0.000***
							(0.000)
ROA				12.292***	-1.673	23.240***	12.938***
				(1.134)	(2.882)	(1.813)	(1.278)
Far				-1.562**	-2.478	-4.553***	-0.689
				(0.687)	(1.913)	(0.846)	(0.850)
Lr				-1.300*	1.328	-3.092***	-0.668
				(0.665)	(1.960)	(0.880)	(0.848)
Size				0.414***	-0.859*	-0.234**	0.357*
				(0.147)	(0.503)	(0.106)	(0.191)
Top1				2.448**	0.869	-1.008***	-2.608***

				(1.091)	(1.138)	(0.208)	(0.597)
Soe				-1.120*	-1.848	0.536	1.871
				(0.616)	(3.190)	(0.697)	(1.257)
Lev				-1.702***	-0.044	-4.239***	-1.533**
				(0.585)	(1.406)	(0.534)	(0.715)
_cons	16.184***	12.575***	1.673***	-7.335**	23.384**	8.679***	-3.979
	(0.057)	(0.177)	(0.643)	(3.550)	(11.581)	(2.478)	(4.636)
Year	No	Yes	Yes	Yes	Yes	Yes	Yes
Ind	No	No	Yes	Yes	Yes	Yes	Yes
N	15561	15561	15561	15561	10110	15561	8960
R^2	0.001	0.234	0.454	0.480	0.027	0.817	0.479
Cragg-Donald Wald F statistic					73.371		

4.2. Robustness tests

4.2.1. Instrumental variable method

Considering the possible measurement error, omitted variables, and the reciprocal causality of enterprise digital economization and enterprise carbon performance. In this article, the average value (m-Dig) of the digital economy level of other enterprises in the same industry in the same year in the same province is chosen as the instrumental variable. The weak instrumental test results for the instrumental variable demonstrate that the Cragg-Donald Wald F statistic worth is 73.3705, which is more than 10, meaning that the instrumental variable passes the weak instrumental test. The findings of the first step of regression utilizing the instrument variable 2 SLS are displayed in column (5) of Table 1. The regression coefficient of m-Dig and Dig is notable at the 10% level, meeting the requirements of the correlation of the instrument variable. The regression findings of the second stage is shown in column (6) , and the regression coefficient of Dig and CEPI is significant at the level of 1%. The aforementioned results demonstrate that there is still a significant positive association with the digital economy and its carbon performance even after adjusting for the endogenous problem. The regression's findings agree with the initial regression.

4.2.2. Substituting explanatory variable

Variable replacement is a common method used in robustness testing. The digital economy of enterprises is a dynamic change index, so this paper use the practice of Qi et al. [8], selecting the intangible assets at the end of the year to measure the digital economy, to replace the digital economy index of enterprises with the annual change rate of the digital economy. It can be observed from Table 1 column (7), the regression of g-Dig and CEPI is substantially positive at the 1% level, which is in keeping with the results of the preceding study.

4.3. Analysis of channel

Wen et al.[9] are drown in this paper to build a mediating effect model and test the channels through which the digital economy influences the carbon performance of industrial enterprises:

$$\mathrm{M_{it}} = \alpha_0 + \alpha_1 Dig_{it} + \alpha_2 \sum Control_{it} + \sum Year + \sum Ind + \varepsilon_{it} \quad (3)$$

$$\mathrm{CEPI_{it}} = \theta_0 + \theta_1 Dig_{it} + \theta_2 \mathrm{M_{it}} + \theta_3 \sum Control_{it} + \sum Year + \sum Ind + \varepsilon_{it} \quad (4)$$

M is the mediating variable. Model (3) examines how the digital economy affects business innovation, while Model (4) amends the first model by including the mediating variable M. The baseline regression findings are shown in column (1) of Table 2, and the regression of Dig and RD is substantially positive at the 5% level, as shown in column (2). Column (3) demonstrates that the Dig regression coefficient is significantly positive at the 5% level, the RD regression coefficient is significantly positive at the 1% level, and the Bootstrap sampling test results do not include zero at the 95% confidence interval, suggesting that the degree of corporate innovation plays a mediating role. Hypothesis H2 is correct.

Table 2 Channel inspection

	(1) CEPI	(2) RD	(3) CEPI
Dig	0.017**	0.009**	0.018**
	(0.008)	(0.004)	(0.008)
RD			0.156***
			(0.041)
_cons	-7.335**	3.190	-7.439
	(3.550)	(2.364)	(4.539)
Control	Yes	Yes	Yes
Year	Yes	Yes	Yes
Ind	Yes	Yes	Yes
N	15561	13759	13759
R^2	0.480	0.128	0.479
Bootstrap	_bs_1	[0.019 0.028]	
	_bs_2	[0.014 0.037]	

4.4. Heterogeneity tests

4.4.1 Property heterogeneity

This research splits the sample firms into two categories, state-owned and non-state-owned, according to the nature of the property rights, to further examine the difference in carbon performance of the influence of the digital economy on enterprises with various property rights nature. Table 3's columns (1) and (2) show that the digital economy has a considerable favorable influence on non-state industrial businesses' carbon performance at the 1% level, while the influence is negative and not positive in state-owned industrial enterprises. This is probably because state-owned businesses are subject to state control, receive adequate financial support from the government, face less competitive market pressure, and a weak motivation to improve carbon performance through innovation. Therefore, the effect of the digital economy on the carbon performance of state-owned businesses is negative. However, non-state enterprises, to follow the pace of national low-carbon development in the competitive market, must improve their innovation ability, so as to improve carbon performance and practice low-carbon operations.

4.4.2 Industry heterogeneity

This paper focuses on the impact of the digital economy on the carbon performance of enterprises in the industrial sector, which is divided into manufacturing and non-manufacturing industries. Manufacturing is the backbone of the economy, reflecting our creativity, competitiveness, and comprehensive national power, and any policy effects are first manifested in manufacturing firms, while the effects in other industries will gradually appear over time. Based on this, this paper divides industrial industries into manufacturing and non-manufacturing industries for group regression. The carbon performance of digital economy and manufacturing firms is notably positive at the level of 5%, as can be shown from Table 3's columns (3) and (4), with no appreciable influence on non-manufacturing enterprises. It is clear that the digital economy has a greater impact on the carbon performance of manufacturing firms than it does on non-manufacturing enterprises.

4.4.3 Environmental regulation heterogeneity

In this paper, taking reference from Du et al. [10], the total marketization index from the China Marketization Index Database published by the National Economic Research Institute in Beijing is used to measure the strength of environmental regulation. According to their mean values for group regression, the sample is split into two groups: those with strong environmental control and those with poor environmental regulation. Table 3's columns (5) and (6) show that there is a significant environmental regulation difference in the impact of the digital economy on firm's carbon performance. In the team with strong environmental regulation, the digital economy is significantly positive with the firm's carbon performance at the 5% level, while there is no significant effect in the group with weak environmental regulation. This may be because businesses in regions with strong environmental regulations are more influenced by local environmental protection policies, and they are more likely to reduce pollution emissions and improve their carbon performance by increasing energy-saving and emission reduction-related innovation investments. Conversely, enterprises in regions with weaker environmental regulations are less influenced by relevant environmental protection policies, and they are less environmentally conscious and less motivated to reduce emissions.

Table 3 Analysis of heterogeneity

	(1) State-owned	(2) Non-State-owned	(3) Non-Manufactu-ring	(4) Manufact-uring	(5) Weak environmental regulation	(6) Strong environmental regulation
Dig	-0.008	0.024***	0.0096	0.018**	0.014	0.019**
	(0.011)	(0.009)	(0.0083)	(0.008)	(0.012)	(0.010)
_cons	-7.093	-2.241	10.0073	9.184**	-13.364***	-6.509
	(4.471)	(5.016)	(6.1552)	(3.604)	(5.145)	(5.048)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes	Yes	Yes
N	5172	10389	1246	14315	7281	8280
R2	0.546	0.475	0.219	0.491	0.471	0.513

5. Conclusions

Using the perspective of industrial firms' carbon performance, this paper first examines the internal mechanisms of the influence of the digital economy on industrial firms' carbon performance at the theoretical level. It then uses the data for industrial firms listed from 2010 to 2019 as research samples to empirically examine the impact relationship, the channel of influence, and the heterogeneity between the digital economy and industrial firms' carbon performance. The following conclusions were eventually reached: i. Following a series of robustness tests, the conclusion that the digital economy can considerably benefit industry is confirmed; ii. The innovation level is the primary means that the digital economy delivers carbon performance for industrial firms, and the digital economy enhances business innovation and reduces corporate carbon emissions through digitalization, which in turn improves corporate carbon performance. The influence of the digital economy in improving the carbon performance of industrial enterprises is of greater importance in the sample of non-state-owned, manufacturing, strong environmental regulation. iii. These conclusions offer a theoretical foundation for encouraging the growth of China's digital economy, encouraging energy efficiency and emission reduction in industrial companies, and enhancing industrial enterprises' carbon performance.

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