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Original Research

The Empirical Effectiveness of China Digital Economy Enhancing Environmental Governance

Debao Dai[1], Yaodong Fan[2], Yunqing Zhao[1]*, Jiaping Xie[2]

[1]Management School, Shanghai University, Shanghai 200444, China
[2]Business School, Shanghai University of Finance and Economics, Shanghai 200083, China

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Abstract

At present, China is entering the era of digital economy. At the same time, "carbon peak" and "carbon neutral" are the main challenges. There is an urgent need to explore the role of the digital economy in reducing carbon emissions and environmental governance. In view of this, using the provincial panel data from 2011 to 2020, this paper makes an empirical study on the mechanism of the digital economy in environmental governance. It is found that with the growth of the digital economy, regional carbon emissions have decreased and the level of environmental governance has improved. After passing several kinds of robustness tests, this conclusion is still valid. The impact of the digital economy on environmental governance is heterogeneous. And the effect is even more obvious in the East. In addition, the transmission mechanism of strengthening environmental governance in the digital economy obviously benefits from the upgrading of industrial structure, the efficiency of capital allocation and labor allocation. Finally, according to the analysis and discussion of the results, some policy suggestions for developing countries to actively develop the digital economy and strengthen the effectiveness of environmental governance are put forward.

Keywords: digital economy, environmental governance effectiveness, net-zero emissions, intermediary effect, sustainability

Introduction

At present, the world is experiencing Industry 4.0 transformation marked by the digital economy [1], which is synonymous with intelligent manufacturing, making this field digitally transformed. Digital integration with traditional manufacturing factors such as labor force, capital and land, is a new impetus to encourage traditional departments to promote intelligence [2]. Since then, the digital economy has become an important driving force for accelerating economic transformation and industrial modernization [3]. At present, the world economy is accelerating the digital transformation. Every country has benefited a lot from the digital economy, and now it is transitioning from information diffusion to cross-border integration [4]. According to the most recent report from the China Academy of ICT, the size of the Chinese digital economy will be 39 trillion yuan in size in 2020, making up 38.6% of the nation's GDP during that time. This is three times the growth rate of the gross national product in the same period, and the digital economy

*e-mail: 13583091550@163.com

has become an important contribution to the national economic growth in China [5].

As a new financial format, the digital economy has continuously improved the level of digitalization, networking and intelligence of the economy and society through the expansion of digital industrialization and industrial digitalization [6]. It not only effectively promotes the high-quality growth and innovation ability of the city, but also shows certain environmental improvement effects [7]. China is going through industrialization and urbanization, and it has a huge demand for energy and serious pollution. Therefore, China will face a long-term and severe environmental problem [8]. Promoting green development has become the correct action to create a beautiful China in order to cope with the increasingly tight energy and environmental constraints in China. This is very important for realizing the "new progress in the construction of ecological civilization" proposed in the national "14th Five-Year Plan", and the digital economy is a key engine to achieve this goal. The concept of "digital economy" describes a series of business operations, in which the use of digital data and professional knowledge is the main factor to promote production, current technical networks are the main channel, and effective use of communication and information technology is the key catalyst to improve efficiency and improve economic structure [2]. The high technical level, high economic growth rate and high clean development level of these economic activities can provide new ideas for China to realize green development. The Chinese government has proposed and put into practice increasingly strict environmental management policies, and significant progress has been made since the "Eleventh Five-Year Plan" made environmental protection and carbon reduction for the first time a legally binding indicator for China's economic development [9]. Therefore, it is very important to study how the digital economy affects environmental governance.

What is the pollution control function brought about by the progress of the digital economy? Studying this topic will help to realize pollution control in different provinces and cities, and make the digital economy fully play its role, which are both essential to high-quality and high-level economic development.

The following areas are currently focused on relevant topics. Technology innovation [10-12], industrial structure [1, 13, 14], productivity [15], high-quality development [16], carbon emissions [17], and urban green innovation [18, 19] are the main topics of research in the digital economy. Environmental pollution [20, 21], green technology innovation [20], environmental governance [22, 23], sustainable development plans [24, 25], and corporate social responsibility [26] have all received considerable attention in the majority of environmental studies. Numerous academics have studied factor analysis [27], trade openness [28], and associated policies [29, 30] in relation to carbon emissions. Relevant influencing factors include environmental regulation [31], environmental performance [24], green technology innovation [32], and urbanization [33]. However, the complex relationship between the digital economy and environmental governance has not been paid attention to by the academic community.

The aforementioned literature reveals a lack of study on the multifaceted influence of the digital economy on environmental governance, despite earlier literature concentrating on the green innovation trend in the digital field. Although the research on the impact of the digital economy on the environment has been carried out, there are still many problems to be solved: What impact does the development of the digital economy have on China's urban environmental governance? Is there a nonlinear relationship between them? Even if the spatial effects are taken into account, is this relationship still valid? What is the mechanism of the development of the digital economy to environmental governance? Therefore, this study uses panel data of 30 provinces in China from 2011 to 2020 and studies the impact of digital economic growth on environmental governance through different econometric models. In addition, taking the optimization of urban industrial structure, the efficiency of labor force allocation and the efficiency of capital allocation as intermediary variables, this paper tests the influence of digital economy development on environmental governance.

Theoretical Analysis and Research Assumptions

Digital Economy and Environmental Governance

It mainly relies on digital technology, such as mobile Internet, big data, the Internet of Things, artificial intelligence, and has formed the impact of carbon reduction caused by the digital economy in many fields. Specifically, the following 3 aspects show it. First of all, academic circles at home and abroad acknowledge the role of the digital economy in promoting technological innovation. The viewpoint that high-quality financial growth and technological innovation are necessary for sustainable development, and the digital economy is progressively evolving into a new motor to increase these conditions has been put forward by Ding et al. [10]. Through variables such as market size and factor distribution, and by accelerating the sharing of information and ideas, the digital economy can create the possibility of starting a business and enhance the resources of enterprises [34]. Secondly, from the perspective of industrial structure, the wide application of digital technology has significantly improved the operational efficiency of industrial organizations, and traditional industries have been updated in technology, which has supported the transformation of the industrial structure dominated by labor-intensive and heavy industry into a high-tech and environment-friendly industrial structure [35]. This is the goal of the third industrial revolution. Thirdly, with the development of the digital economy, the types and organization of production resources and the efficiency of the allocation of resources and factors of production have been greatly improved. Therefore, the production mode and supply chain of traditional industries have been greatly optimized and the utilization rate has been gradually improved. This is the basis of the first research hypothesis put forward in this research.

H1: The growth of the digital economy enhances the effectiveness of environmental governance.

Mechanisms of the Effects of the Digital Economy on Environmental Governance

The economy of scale, the economy of scope, and the long-tail effect make up the core financial framework of the digital economy [36]. The transformation of labor-intensive industries, particularly heavy industries, into high-tech, environmentally friendly industries is supported by the digital economy, which has "Internet accelerated speed" as its core and the ability to alter enterprise profit models, alter current market structures, and expand the boundaries of resource allocation [37]. On the basis of this, the study suggests this hypothesis.

H_{a1}: The growth of the digital economy encourages the modernization of the industrial structure.

The digital economy can optimize the production and operation mode of enterprises, optimize the distribution of various manufacturing parameters within enterprises, and improve the efficiency of resource allocation. In addition, technological innovation is an important means for enterprises to improve resource allocation efficiency, and the progress of digital technology can also stimulate technological innovation. Based on this, this research puts forward two research hypotheses.

H_{c1}: The growth of the digital economy encourages the effectiveness of labor allocation.

Industrial Structure, Resource Allocation Efficiency, and Environmental Governance

The development of the global digital economy can effectively promote the restructuring and modernization of China's industrial structure. The main goal of improving industrial structure is to transfer resources from inefficient industries to high-efficiency industries. This process leads to the increase in high-efficiency industries and ultimately improves the productivity of all departments to a certain extent [38]. Therefore, at specific historical junctures, the negative impact of structural changes on energy utilization efficiency is a short-term, not long-term development. Generally speaking, the industrial structure is conducive to improving urban energy efficiency, promoting renewable energy and net-zero emission. Based on this, this research puts forward the hypothesis.

H_{a2}: Industrial structure performs an intermediary function in the procedure of the digital economy restraining carbon emissions.

The development of the digital economy can make the allocation of human and material resources more efficient. The main function of data elements is to improve the coordination of various production through the use of important information, thus improving the effectiveness of resource allocation [39]. According to [40], the Internet and digital technology can effectively reduce the geographical and time barriers for workers, improve their employment opportunities and expand their career choices, all of which will improve the effectiveness of human capital allocation. Based on this, this research puts forward two research hypotheses.

H_{b2}: The efficiency of capital allocation performs an intermediary function in the procedure of the digital economy restraining carbon emissions.

H_{c2}: The efficiency of labor allocation performs an intermediary function in the procedure of the digital economy restraining carbon emissions.

The research framework of this paper is shown in Fig 1. We divide the influence of the digital economy

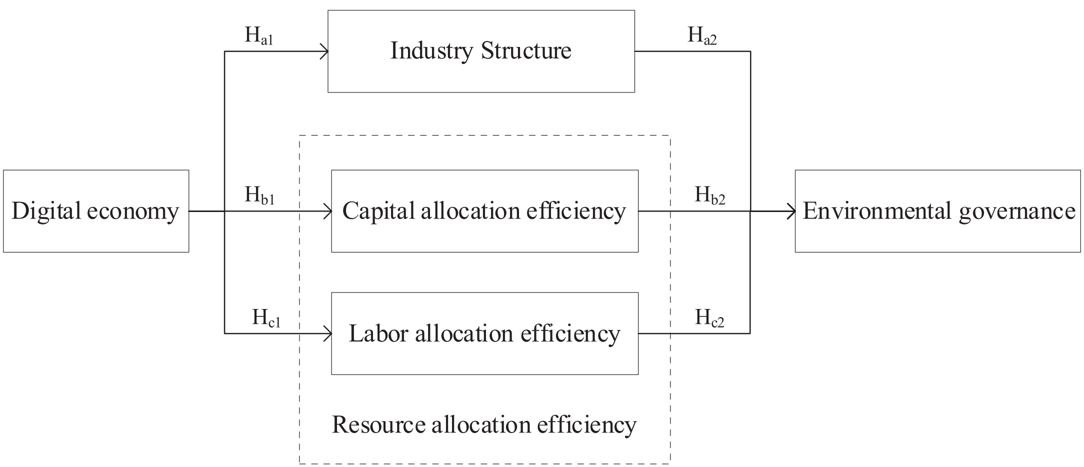

Fig. 1. Research Framework.

on environmental governance into two paths: direct influence and indirect influence. The direct impact refers to the direct impact of the digital economy on environmental governance, and the indirect impact refers to the impact of the digital economy on environmental governance by affecting industrial structure and resource allocation efficiency. In this paper, the following modeling work will be carried out according to the above structure and the diagram.

Study Design

Model Settings

The following model was created to examine how the digital economy influences carbon emissions:

$$Epi_{it} = \alpha_0 + \alpha_1 Die_{it} + \alpha_2 X_{it} + u_i + v_t + \mu_{it} \quad (1)$$

The following model was created to examine the ways the digital economy influences industrial structure and resource allocation efficiency:

$$His_{it} = \gamma_0 + \gamma_1 Die_{it} + \gamma_2 X_{it} + u_i + v_t + \mu_{it} \quad (2)$$

$$Kmis_{it} = \lambda_0 + \lambda_1 Die_{it} + \lambda_2 X_{it} + u_i + v_t + \mu_{it} \quad (3)$$

$$Lmis_{it} = \delta_0 + \delta_1 Die_{it} + \delta_2 X_{it} + u_i + v_t + \mu_{it} \quad (4)$$

The following model was built to examine the mediating impacts of industrial structure and resource allocation efficiency:

$$Epi_{it} = \eta_0 + \eta_1 Die_{it} + \eta_2 \mathrm{His}_{it} + \eta_3 X_{it} + u_i + v_t + \mu_{it} \quad (5)$$

$$Epi_{it} = \theta_0 + \theta_1 Die_{it} + \theta_2 \mathrm{Kmis}_{it} + \theta_3 X_{it} + u_i + v_t + \mu_{it} \quad (6)$$

$$Epi_{it} = \xi_0 + \xi_1 Die_{it} + \xi_2 \mathrm{Lmis}_{it} + \xi_3 X_{it} + u_i + v_t + \mu_{it} \quad (7)$$

where Epi_{it} is the explained variable, on behalf of the degree of environmental governance; Die_{it}, which refers to the digital economy, is the explanatory variable; His_{it} represents the degree of industrial structure optimization; $Kmis_{it}$ represents the efficiency of capital allocation, and $Lmis_{it}$ represents the efficiency of labor allocation; X_{it} stands for a variety of control variables, such as transport intensity, environmental regulation and environmental pollution index; α_0, γ_0, λ_0, δ_0, η_0, θ_0, ξ_0 represents intercept terms; regional fixed effects are represented by u_i, and time fixed effects by v_t; μ_{it} represents random disturbance term; province is represented by i and year is represented by t. Both the time-fixed effects and the province-fixed effects are regulated in order to properly consider the effects of policy impacts and province features.

Variable Description

Explained Variables

Environmental governance. This paper uses per capita carbon emissions to evaluate the level of urban environmental governance, reflecting the extent of environmental damage. In the modern times, one of the greatest threats to human survival is environmental degradation caused by carbon dioxide emissions [41]. Achieving carbon neutrality and environmental sustainability now depends on reducing the intensity of greenhouse gas emission. Therefore, in this study, carbon emission intensity is regarded as an indicator of environmental governance. Generally speaking, the more effective the environmental management is, the smaller the carbon emission is, and vice versa.

Explanatory Variables

With the rapid development of digital economy, it is necessary to measure its level by choosing related indicators. Therefore, a measurement method is used to calculate the digital economic index previously studied, including the number of Internet broadband user per 100 people in the prefecture-level city, the proportion of employees in computer service and software industry in urban units, the total amount of telecommunications services per capita, the number of mobile phone users per 100 people and the digital inclusive finance index. Then, the comprehensive index value is obtained by TOPSIS entropy weight method.

Intermediate Variables

(1) Industrial structure. It can be measured by many methods, including the percentage of non-agricultural industries, the grade coefficient of industrial structure [42], the molar structure change index and the percentage of high-tech industries. This study adopts the ratio of tertiary industry value added to secondary industry value added as the index of industrial structure, and the calculation method is based on the literature [43].

(2) Resource allocation efficiency. The urban physical capital mismatch index Kmis and human capital mismatch index Lmis are measured separately to reflect the degree of regional resource mismatch, drawing on the study of [44]. In this study, the absolute value of the resource mismatch index is investigated, that is, the greater the resource mismatch index, the more serious the resource mismatch problem is. There are two types of resource mismatch: under allocation (Kmis or Lmis>0) and overallocation (Kmis or Lmis<0).

Control Variables

Based on research on the digital economy and environment, this study controls factors that may affect the effectiveness of environmental governance in each region, including transportation intensity, environmental regulation [45], and environmental pollution index [46].

(1) Transportation intensity. One of the main factors that cause environmental pollution is automobile exhaust pollution caused by vehicles. In addition, considering the availability of data and the fact that road passenger volume can reflect the traffic intensity to a certain extent, this paper uses road passenger volume as a proxy variable of traffic intensity.

(2) Environmental regulations. China is a policy development-oriented country, and the state and its policies occupy an extremely important position at the level of environmental governance. Generally speaking, the more funds are invested in environmental management, the greater the supervision on the environment [47]. The percentage of investment in reducing environmental pollution to GDP is used to represent it.

(3) Environmental pollution index. Existing research generally use industrial wastewater discharge, industrial sulfur dioxide discharge and industrial solid waste discharge to measure the environmental pollution situation of an area. However, due to the lack of solid waste emission data of prefecture-level cities, the industrial wastewater emission, industrial sulfur dioxide emission and industrial soot emission of each city are selected. Based on the practice of [48], the environmental pollution index was calculated.

Spatial and Temporal Changes in the Digital Economy and Environmental Governance

Analysis of Changes

Select the digital economic indicators and carbon levels of 30 provinces (with the exception of Tibet, Hong Kong, Macau, and Taiwan) in 2011-2020. The whole country is divided into three sectors, eastern, western, and central, and there are 30 provinces [49]. The central area is composed of 8 provinces, such as Jilin Province and Shanxi Province. The eastern area includes 11 provinces such as Liaoning, Shanghai, and Shandong Province. The western area includes 11 provinces such as Yunnan and Shaanxi Province. Fig. 2 shows the overall growth of the Chinese digital economy in 2011-2020, along with the growth of the eastern, central, and western regions' digital economies, and Fig. 3 shows the development of carbon emissions in 2011-2020.

From 2011 to 2020, the digital economy can be shown to be growing, with the eastern, central, and western districts exhibiting largely stable growth. From 2011 to 2020, the level of carbon emission also shows an upward trend.

While the eastern, central, and western districts essentially stayed the same from 2011 to 2020, it is clear that the digital economy shows a rising trend during that time. However, compared to other regions, the degree of digital economy in the eastern region is significantly higher. From 2011 to 2020, carbon emissions generally showed an upward trend, with the level in the western region being significantly higher than that in the central and eastern regions. The reason is that Shanxi, a major coal province in the west, is an important energy supplier in China, and the imbalance of industrial structure is the primary reason for the high carbon emissions in Shanxi Province. Heavy industry still accounts for a considerable proportion of the secondary industry in Shanxi Province [50]. The endowment of coal resource and rich mineral resources make the industrial structure of Shanxi Province biased toward heavy industry and relatively biased towards light industry. After 2019, the growth rate accelerated, which may be due to the outbreak of COVID-19, and local restriction on purchases affected social activities, leading to a higher share of heavy industry in the industrial structure [51].

In this paper, variables are compared on the graph, as shown in Fig. 4 and Fig 5. In this way, the spatial

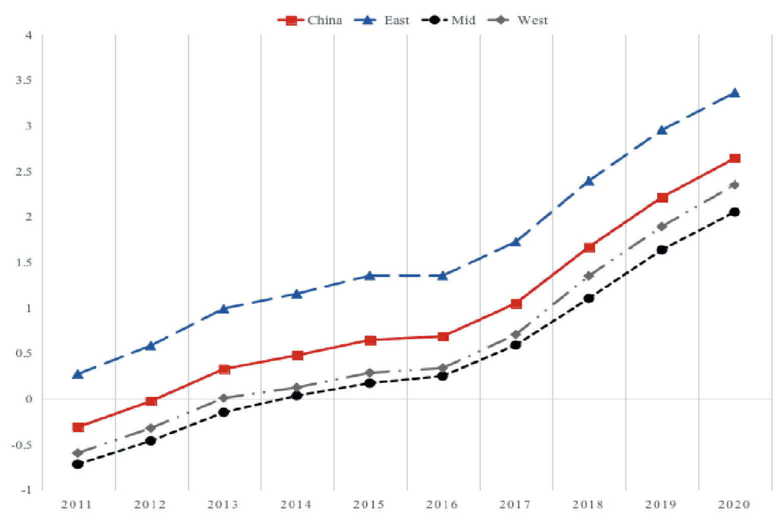

Fig. 2. Digital economy trends.

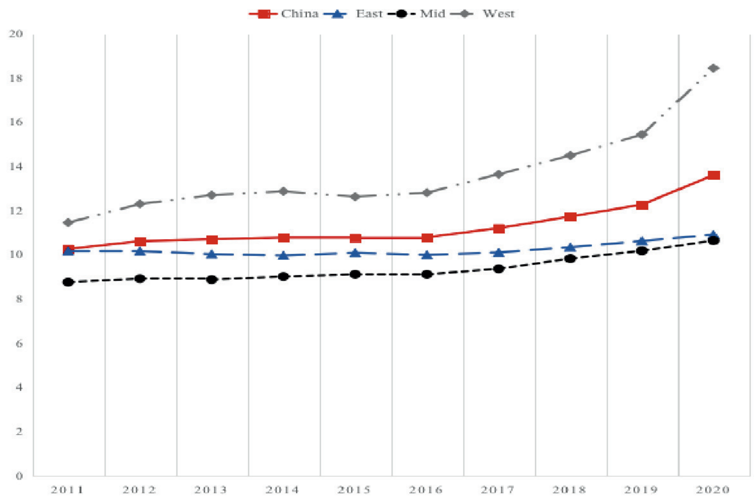

Fig. 3. Carbon emission trends.

and temporal distribution of the digital economy level and carbon emission level can be seen more intuitively. Compared with 2011, the development level of digital economy in China has improved significantly in 2020. It can be seen that in 2011 and 2020, the regions with relatively developed digital economy are concentrated in the southeast coastal provinces, including Guangdong, Jiangsu, Zhejiang and Shanghai. Carbon emissions also have obvious spatial heterogeneity and spatial correlation, and the carbon emissions in the central and northern regions are the most serious.

Artificial intelligence is a technology that simulates and imitates human intelligence to accomplish various intelligent tasks using computer systems and algorithms, and it has developed rapidly recently [52]. AI technology can process and analyze large amounts of data, and learn and extract patterns, rules and knowledge from it to help human beings make decisions, solve problems and perform tasks. It mainly includes machine learning, deep learning, natural language processing and other

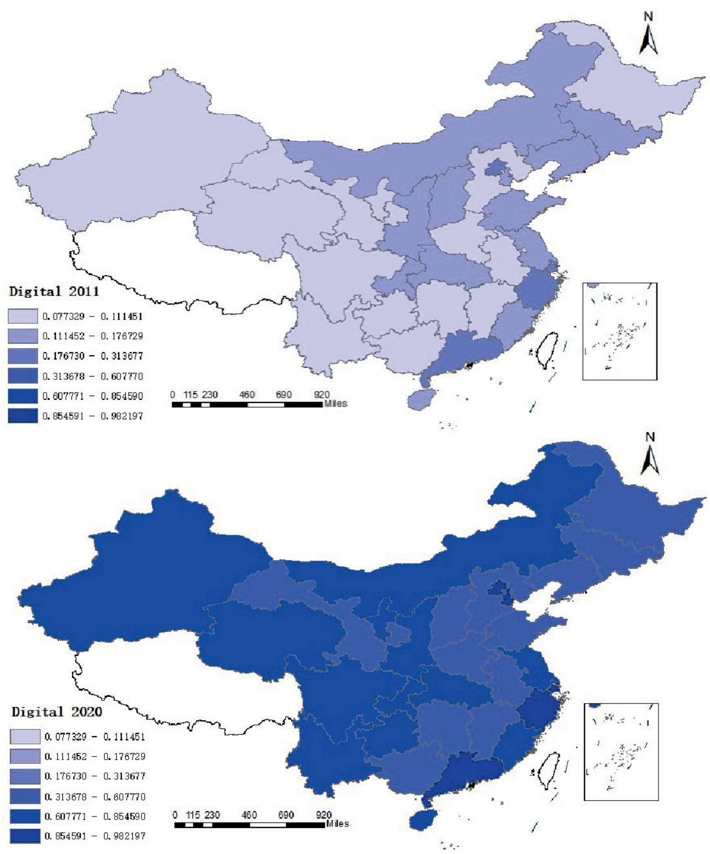

Fig. 4. Comparison of Level of Digital Economy (2011, 2020).

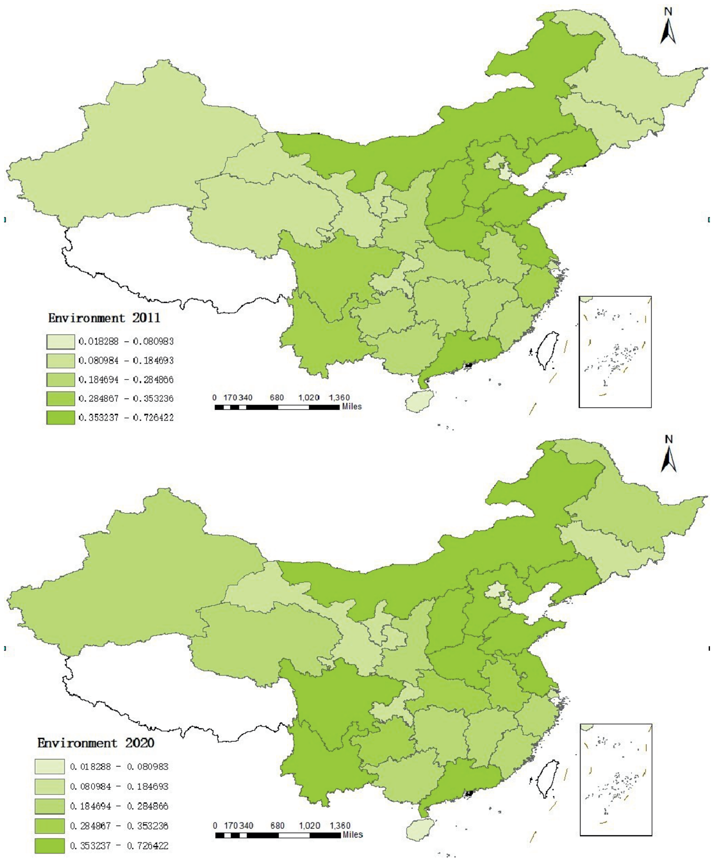

Fig. 5. Comparison of Level of Environmental Governance (2011, 2020).

technologies, and can perform tasks such as prediction, classification, clustering, etc. But it is rarely used for panel regression.

In order to preliminarily study the relationship between the digital economy and carbon emission, this paper uses convolutional neural network to regress them. The result is shown in Fig. 6. It can be seen that the rapid development of the digital economy in recent years has curbed local carbon emissions, which is conducive to achieving local net-zero emissions and promoting local environment sustainable development.

Data Description

The data of this study were collected from the CNRDS database, the China Urban Statistical Yearbook, the Ecological Badlands Statistical Annual Report, and the China Statistical Yearbook for each Chinese

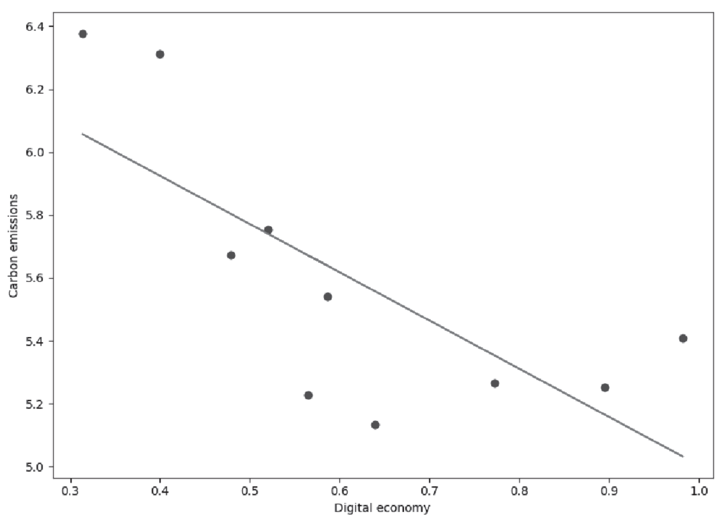

Fig. 6. Convolutional neural network regression results.

province. We used linear interpolation to fill some gaps left by missing data. 30 provinces were chosen as the samples for empirical study, besides Hong Kong, Macao, Taiwan, and Tibet. Finally, 300 effective data samples were collected.

The definition and calculation of variables are shown in Table 1, and the distribution of variables can be evaluated in Table 2.

Empirical Results and Discussion

Before the regression analysis, a Hausman test was conducted to evaluate whether the fixed effect should be adopted in the model. The fixed effect model is used in regression analysis because the research results show that the p-value is 0.0000, which effectively rejected the first hypothesis.

Impact of the Digital Economy on Environmental Governance

The double fixed effect model is used to control macroeconomic analysis, and the differences between participants will not change with the passage of time. Table 3 shows the benchmark results of the influence of the model (1). Compared with the column (2) that includes control variables, column (1) does not include any variables. From the regression results of column (1) and column (2), it can be seen that the coefficients of the digital economy are significantly negative, indicating that the development of the digital economy could reduce the carbon emission intensity, that is, assuming that H1 is established. As the development of the digital economy, the digitalization and informatization level of the whole society has been improved, and the utilization efficiency of enterprise resources has also been greatly improved, which has driven the industry to develop in the direction of green and low carbon, which is helpful to reduce the intensity of carbon emission, realize net-zero emission and strengthen the level of environmental governance of the government.

Impact of the Digital Economy on Industrial Structure, Capital Allocation Efficiency, and Labor Allocation Efficiency

Columns (1) and (2) of Table 4 display the outcomes of the regression where the industrial structure is the explanatory variable, demonstrating the strong impact

Table 1. Variable definition and calculation method.

Variable	Definition	Calculation	Unit
Epi	Environmental governance level	Carbon emissions per capita	Tons/Person
Die	Digital economy development level	Digital Economy Index	%
His	Industrial structure optimization level	The proportion of the value added of the tertiary sector and the value added of the secondary sector	%
Kmis	Capital allocation efficiency	Opposite of physical capital mismatch index	%
Lmis	Labor allocation efficiency	Opposite of the human capital mismatch index	%
Road	Traffic and transportation intensity	Road passenger traffic	Million people
Er	Environmental Regulation	Investment in environmental pollution control as a share of GDP	%
Ep	Environmental pollution	Environmental pollution index	%

Table 2. Variable descriptive statistics.

Variable	Mean	Max	Min
Epi	11.2713	49.4788	3.7410
Die	0.9388	7.4158	-1.0270
His	1.3244	5.2440	0.5270
Kmis	0.3397	2.8575	0.0093
Lmis	0.2708	1.4377	0.0000
Road	61885.8880	556510.0000	1332.0000
Er	0.0139	0.0896	0.0021
Ep	0.050	2.200	-1.448

Table 3. Impact of the digital economy on carbon emissions.

Variable	(1)	(2)
Die	-0.064*** (0.023)	-0.054** (0.021)
Road		0.061 (0.056)
Er		-0.025 (0.034)
Ep		0.075** (0.028)
Constant	0.123***	0.114***
Control	N	Y
Region	Y	Y
Year	Y	Y
R^2	0.213	0.302
N	300	300

Table 4. Impact of digital economy on industrial structure.

Variable	(1)	(2)
Die	0.069*** (0.024)	0.069*** (0.022)
Road		0.062** (0.028)
Er		0.031 (0.024)
Ep		-0.016 (0.012)
Constant	0.125*** (0.008)	0.109*** (0.012)
Control	N	Y
Region	Y	Y
Year	Y	Y
R^2	0.784	0.793
N	300	300

of the digital economy on industrial structure. When the control variables are removed from the equation, there is a positive shift of 0.069% in the industrial structure index for each 1% shift in the digital economy index. There is a positive shift of 0.069% in the industrial structure index for each 5% shift in the digital economy index when control variables are taken into account. This shows that the digital economy has a favorable impact on industrial structure optimization and that as the digital economy develops, industrial structure optimization and upgrading will be greatly aided [53].

When the capital allocation efficiency is the explanatory variable, the regression results are shown in columns (1) and (2) of Table 5. When control variables are excluded, it can be seen that a 5% transformation of digital economy development leads to an increase of 0.428% in the efficiency of capital allocation. When the control factors are taken into account, for every 5% deviation of the digital economy index, the efficiency of capital allocation has a positive deviation of 0.431%. This shows that the digital economy has a positive contribution to optimizing the efficiency of capital allocation.

The regression results in columns (3) and (4) of Table 5 use the efficiency of human resource allocation as the explanatory variable, indicating that the digital economy has a considerable influence on how to allocate human resources. Without the absence of control variables, the

Table 5. Impact of digital economy on resource allocation efficiency.

Variable	(1)	(2)	(3)	(4)
Die	0.428** (0.186)	0.431** (0.180)	-0.069** (0.032)	-0.068** (0.033)
Road		0.247 (0.224)		0.025 (0.047)
Er		-0.003 (0.044)		0.031 (0.042)
Ep		-0.049 (0.054)		0.006 (0.012)
Constant	0.396*** (0.038)	0.351*** (0.029)	0.192*** (0.013)	0.183*** (0.014)
Control	N	Y	N	Y
Region	Y	Y	Y	Y
Year	Y	Y	Y	Y
R^2	0.419	0.436	0.146	0.152
N	300	300	300	300

efficiency of human resource allocation has a negative deviation of 0.069% for every 5% deviation of the index of digital economy. When other variables are taken into account, for every 5% deviation of the digital economy index, the efficiency of human resource allocation has a negative deviation of 0.068%. This shows that the digital economy has had a negative impact on the effective utilization of human resources.

Intermediary Effect Analysis

Table 6's first two columns display the mediating effects of industrial structure, and the middle two columns and the last two columns show the mediating effects of capital allocation efficiency and labor allocation efficiency.

The impact of 1% change on carbon emissions in the digital economy is 0.377%. The research results in column (2) show that, although the optimization of industrial structure has reduced carbon emissions and played an intermediary role between the digital economy and the impact of carbon emissions, every 1% change in either aspect will have an impact on carbon emission levels of -0.377% and 0.036%. With the growth of the digital economy, the focus of economic development is constantly shifting from labor and capital-intensive industries to technology-intensive industries. With its strong penetration and wide coverage, the digital economy can break the boundaries of industrial development, promote coordinated development and continuous integration between industries, and develop new industries that meet the development characteristics of the new era on this basis. Finally, promote the transformation and upgrading of industrial structure.

According to the data in column (4) in Table 6, both the digital economy and the efficiency of capital allocation have an impact on carbon emissions, and the efficiency of capital allocation also plays an intermediary role, but the conclusion is not statistically significant. According to the survey results in column (6), both the digital economy and the efficiency of labor allocation will affect carbon emissions. Nevertheless, the efficiency of labor allocation plays an intermediary role. Every 1% change in the efficiency of labor allocation has an impact of 0.189%. The growth of the digital economy may effectively improve the efficiency of the distribution of human and material capital. The core mechanism of data elements to improve the productivity of economic operations is to use valuable information stored in data to improve the synergy among production variables and enhance the efficiency of resource allocation.

Regional Heterogeneity Analysis

The results of benchmark regression show that the growth of the digital economy is generally conducive to reducing the intensity of regional carbon emission, so is the impact of this reduction in carbon emission widespread in different regions? Therefore, we carried out sub-regional regression analysis, as shown in Table 7.

Table 6. Tests of mediating effects.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
His	-0.377*** (0.099)	-0.377*** (0.096)				
Kmis			0.027 (0.029)	0.041* (0.024)		
Lmis					0.186*** (0.070)	0.189*** (0.058)
Die	0.038*** (0.012)	0.036*** (0.011)	0.002 (0.009)	-0.001 (0.008)	0.007 (0.008)	0.006 (0.007)
Road		-0.584*** (0.088)		-0.651*** (0.088)		-0.631*** (0.088)
Er		0.737*** (0.089)		0.676*** (0.089)		0.681*** (0.088)
Ep		0.042*** (0.013)		0.070*** (0.011)		0.071*** (0.011)
Constant	0.193*** (0.015)	0.157*** (0.021)	0.154*** (0.015)	0.128*** (0.023)	0.123*** (0.019)	0.096*** (0.025)
Control	N	Y	N	Y	N	Y
Region	Y	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y	Y
R^2	0.048	0.367	0.004	0.340	0.004	0.340
N	300	300	300	300	300	300

It shows that, although the degree of impact varies, the digital economy has a considerable effect on carbon emission levels and other factors in both the eastern and central-western regions. The effects of the digital economy on industrial structure, capital allocation efficiency, labor allocation efficiency and carbon emissions in the eastern region are described in columns (1), (2), (3) and (4). At the significance level of 1%, every time the index of the digital economy shifts by 1%, the carbon emission level changes negatively by 0.018%, the industrial structure changes positively by 0.096%, the efficiency of capital allocation changes positively by 0.165% and the efficiency of labor allocation changes negatively by 0.054%. According to columns (5), (6), (7) and (8), the carbon emission level is changing by 0.014%, the industrial structure is changing by 0.032%, and the labor allocation efficiency is changing by 0.016%.

This demonstrates that the eastern region is much more affected by the digital economy than the central and western regions in terms of carbon emission levels and other variables. The eastern region has an abundant supply of funding, moderate expertise, and a favorable economic programming environment, whereas the central and western districts' economies are developing more slowly and the digital economy plays a smaller part in those regions. By encouraging the modernization of industrial structures, the development of the digital economy in the eastern region has reduced the carbon emission level and promoted regional environmental governance and sustainability. The digital economy in the central and western regions can promote carbon dioxide emissions and inhibit local environmental governance, but these effects are not particularly significant. The negative impact of the digital economy

Table 7. Regional heterogeneity analysis.

Variable	(1)	(2)	(3)	(4)
Die	-0.018*** (0.004)	0.096*** (0.008)	0.165*** (0.041)	-0.054*** (0.014)
Road	-0.265*** (0.044)	0.168*** (0.046)	-0.136 (0.286)	-0.110* (0.061)
Er	-0.008 (0.087)	0.890*** (0.189)	-2.721*** (0.825)	-0.255 (0.218)
Ep	0.025*** (0.007)	-0.076*** (0.010)	-0.036 (0.033)	-0.056** (0.022)
Constant	0.199*** (0.015)	-0.016 (0.027)	0.481*** (0.120)	0.360*** (0.048)
Control	Y	Y	Y	Y
Region	Y	Y	Y	Y
Year	Y	Y	Y	Y
R2	0.303	0.804	0.283	0.176
N	110	110	110	110
Variable	(5)	(6)	(7)	(8)
Die	0.014* (0.023)	0.032*** (0.005)	0.000 (0.013)	-0.016 (0.010)
Road	-1.197*** (0.283)	-0.131*** (0.050)	-0.631*** (0.137)	-0.162* (0.092)
Er	0.721** (0.314)	-0.055 (0.054)	0.264* (0.137)	0.081 (0.069)
Ep	0.102*** (0.031)	-0.018*** (0.005)	-0.046*** (0.016)	-0.002 (0.010)
Constant	0.185** (0.078)	0.133*** (0.015)	0.304*** (0.034)	0.183*** (0.022)
Control	Y	Y	Y	Y
Region	Y	Y	Y	Y
Year	Y	Y	Y	Y
R2	0.461	0.465	0.344	0.041
N	190	190	190	190

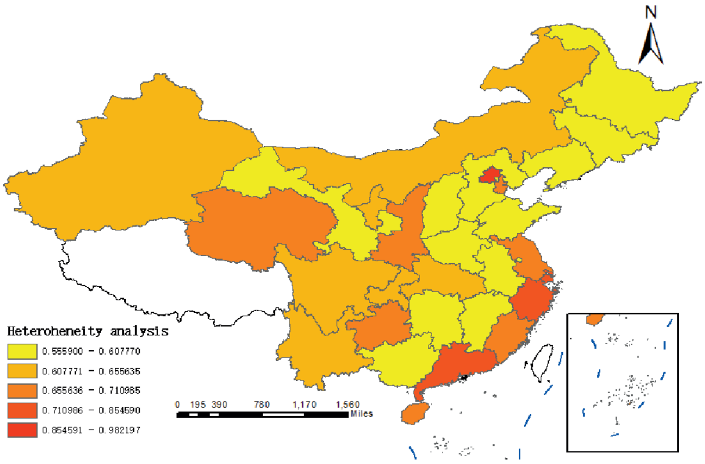

Fig. 7. Regional heterogeneity analysis.

on carbon emissions is not so significant, which may be caused by the more developed heavy industries in the central and western regions. Generally speaking, digital economy can improve the effectiveness of environmental governance and sustainability by directly reducing the emission levels and indirectly encouraging the modernization of industrial structures, the efficiency of capital allocation and the efficiency of labor allocation.

In order to show more clearly the spatial heterogeneity of the digital economy's influence on environmental governance, this paper shows indirect influence on the map as shown in Fig. 7. It can be seen that the impact of the digital economy on environmental governance has significant spatial heterogeneity, especially in Tianjin, which shows that the digital economy in this region can effectively realize net-zero emissions and promote

Table 8. Endogeneity test.

Variable	(1)	(2)	(3)	(4)
Die	0.001 (0.008)	0.036** (0.016)	-0.004 (0.008)	0.005 (0.008)
His		-0.384*** (0.118)		
Kmis			0.043** (0.018)	
Lmis				0.190*** (0.039)
Road	-0.819*** (0.242)	-0.745*** (0.235)	-0.808*** (0.234)	-0.789*** (0.239)
Er	0.644*** (0.212)	0.718*** (0.236)	0.655*** (0.214)	0.657*** (0.220)
Ep	0.072*** (0.014)	0.046*** (0.017)	0.074*** (0.013)	0.075*** (0.013)
Constant	0.157*** (0.044)	0.171*** (0.043)	0.145*** (0.045)	0.113** (0.048)
Control	Y	Y	N	Y
Region	Y	Y	Y	Y
Year	Y	Y	Y	Y
R^2	0.343	0.378	0.347	0.366
N	300	300	300	300
LM	1040.32 (0.0000)			
Wald F	6134.8			

sustainable development of this region by affecting the industrial structure and resource allocation efficiency.

Robustness Analysis

Although the fixed effects are used, there are still endogenous problems in this study due to two-way causality and missing factors. The digital economy affects the degree of regional environmental governance through industrial structure and other factors. However, to some extent, environmental governance will also affect economic development. Therefore, there is an obvious two-way causal relationship between the level of regional environmental governance and the digital economy.

In this paper, the instrumental variable method is used to test the endogeneity, trying to prevent the two-way causality and some endogenous problems caused by unavailable factors. The tool used is an index of the digital economy with time delay. On the one hand, time can be used to reflect the change of time and influence the growth of the digital economy. Generally speaking, with the progress of time, the growth degree of the digital economy is getting higher and higher, so the indicators of the digital economy lagging behind one stage meet the relevant conditions as instrumental variables. On the other hand, as a future factor, the exogenous requirement of instrumental variable is met by the fact that the digital economic index lags behind for a period of time and is not directly related to the current economic variables.

In this study, the plausibility of the instrumental variables is first evaluated using the two-stage least squares (2SLS) approach. Table 8's findings show that the models' regression coefficients seem to be strongly positive and that they meet both the tests for weak instrumental factors and the LM test with an F-value of 6134.8, which is substantially higher than 10, proving that weak instrumental variable issues are unfounded.

Error Analysis

Due to the unavailability of data, the data of Tibet, Taiwan, Hong Kong and Macao were excluded in this paper, which affected the integrity of the data to a certain extent and had an impact on the experimental results.

R-squared represents the fitting ability of the model. The highest R-squared statistics of the above regression results is 0.804, and most of them are stable at around 0.4, indicating that the model has a good fitting degree. However, to a certain extent, there are inevitable errors, which have a certain influence on the experimental results.

Conclusions

This paper examines the connection between the digital economy and urban environmental governance from the multiple perspectives of the mediating role of industrial structure upgrading, capital allocation efficiency, and labor allocation efficiency using a panel of data from 2011 to 2020 and a combination of regression analysis and fixed-effects models. The following conclusions are drawn: (1) the expansion of the digital economy can help China to manage its urban environment better and reduce its carbon footprint. After introducing instrumental variables to test the robustness, this finding still holds, and strongly supports China's carbon neutral and carbon peak actions. (2) the growth of the digital economy has promoted the modernization of industrial structures and the efficiency of resource allocation, which in turn realized net-zero emissions, promoted sustainable development and promoted environmental governance. These factors play an intermediary role. (3) due to the geographical differences, the influence of the digital economy on the level of environmental governance varies in different regions. The development of the digital economy has a far greater impact on environmental governance in the eastern region than the central and western regions. This may be because the heavy industry in the western region is more developed and the level of carbon emissions is higher, so the benefits of the digital economy on environmental governance have decreased.

Net-zero emissions, sustainability and energy efficiency are the main challenges and goals facing the world today. The results of this research are closely related to net-zero emissions, sustainable development and energy efficiency. By applying the research results to policy making, technology development and energy planning, we can better promote the realization of net-zero emissions, sustainable development and energy efficiency, which are closely related to environmental protection, climate change, energy security and sustainable economic development.

Based on the above findings, this paper puts forward the following policy suggestions: the government should introduce various policies to encourage enterprises to innovate, improve regional industrial structure, transform from labor-intensive industries dominated by heavy industry to environmentally friendly high-tech industrial structure, and optimize capital allocation.

There are some limitations in this article. First of all, the research period is from 2011 to 2020. During this period, the economic impact brought by COVID-19 can't be ruled out. Secondly, the effectiveness of environmental governance only considers the emission of CO_2, and many other greenhouse gases such as methane need to be comprehensively considered. Finally, this paper does not consider the impact of the digital economy on environmental governance of specific sector (such as services or agriculture). In fact, the impact of the digital economy on environmental governance could vary from sector to sector.

Future research can make up for these shortcomings by using artificial intelligence technology. Through the methods of machine learning and deep learning, we can extract the correlation and trend between the digital economy and carbon emissions, help identify industries and regions with high carbon emissions, and analyze the spatial and temporal distribution characteristics of carbon emissions. Using the time series analysis method, digital economy indicators and carbon emission data can be modeled and predicted, and the relationship and trend between them can be revealed.

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Conflict of Interest

The authors declare no conflict of interest.

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