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Impact of the Digital Economy on Carbon Intensity

-- Empirical Analysis based on Heterogeneity and Moderating Effects

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Abstract. Under the background of "dual-carbon" target, digital economy, as a rapidly developing economic form, can play a certain role in promoting carbon emission reduction. This paper utilizes the panel data of 30 provinces in China from 2012 to 2020 to empirically investigate the impact of digital economy on carbon emission intensity. The empirical results show that the digital economy has a significant inhibitory effect on carbon emission intensity; the heterogeneity analysis shows that the inhibitory effect of the digital economy on carbon emission intensity is more significant in the central region, the region with a lower level of green carbon sinks, and the region with a higher level of development of digital infrastructure; and the analysis of the moderating effect shows that the level of industrialization and the degree of government intervention have a negative and positive moderating effect, respectively, on the inhibitory effect of the digital economy on carbon emission intensity. The analysis of the regulating effect shows that the level of industrialization and the degree of government intervention have negative and positive regulating effects on the digital economy's suppression of carbon emission intensity, respectively. Therefore, we should vigorously develop the digital economy, strengthen the construction of digital infrastructure, and promote the digital economy to play the role of carbon emission reduction.

Keywords: Digital Economy; Carbon Intensity; Moderating Effect.

1. Introduction

Since the Industrial Revolution, rapid economic development has also brought about serious environmental problems, with greenhouse gases (GHG), mainly carbon dioxide, contributing to global warming. In September 2020, General Secretary Xi Jinping proposed at the 75th session of the United Nations General Assembly that carbon dioxide emissions should strive to peak by 2030, and that efforts should be made to achieve carbon neutrality by 2060, a goal that could be achieved by 2020, with a view to achieving "dual-carbon" goals. Governments and scholars are actively seeking solutions to achieve the "dual-carbon" goal, and the digital economy may be one of the effective channels. The digital economy may reduce overall energy consumption by facilitating industrial transformation, thus achieving carbon reduction. In this day and age, the digital economy is an important engine for boosting China's high-quality economic development. *The Research Report on the Development of China's Digital Economy (2023)* released by the Institute of Information and Communication Research shows that the scale of China's digital economy will reach 50.2 trillion yuan in 2022, indicating that the country's digital economy is booming. Then, whether the digital economy can effectively empower carbon emission reduction and how the digital economy empowers carbon emission reduction hasbecome questions that need to be discussed and answered urgently.

Regarding the research on digital economy and carbon emission reduction, the analysis in the existing literature is mainly divided into four categories containing the following: first, different scholars use different indicators to measure the level of carbon emission reduction. From the perspective of efficiency, Jiang Sanliang and Jia Fangfang (2023)[1] believe that the digital economy can enhance the efficiency of carbon emissions and have a positive impact on neighboring land; from the perspective of incremental, growth rate and per capita carbon emissions, Zhang Guanyan and Li Yuxin (2022)[2] believe that the development of the digital economy is conducive to the reduction of the incremental amount of carbon emissions, the growth rate and the reduction of per capita carbon emissions. Secondly, about the mechanism of digital economy's impact on carbon emission reduction,

digital economy affects carbon emission reduction through the paths of technological change[3] , industrial structure upgrading[4] , energy utilization efficiency[5] , international trade[6] , resource allocation[7] and green technology innovation[8] . Thirdly, regarding the analysis of heterogeneity, Kong Lingying et al. (2022) [9] believe that the inhibiting effect of digital economy on carbon emissions is more significant in the eastern part of the country and the urban agglomeration area, while Fan Hejun et al. (2023)[10] analyzed that the inhibiting effect of digital economy on carbon emissions is more significant in the non-central and non-resource-oriented cities.

Compared with the existing literature, the possible marginal contributions of this paper are:(1) To measure the carbon emission level from the perspective of carbon emission intensity, to empirically analyze the inhibitory effect of the digital economy on carbon emission intensity, and to select appropriate instrumental variables and robustness methods for testing. (2) Discuss the regional heterogeneity of the carbon emission reduction effect of the digital economy, which is different from the conclusions drawn by scholars in the existing literature; further analyze the heterogeneous effects of the level of green carbon sinks and the level of digital infrastructure construction, which are less discussed in the existing literature. (3) Further introduce the level of industrialization and the degree of government intervention as moderating variables to analyze the moderating effects of both on the carbon emission reduction role of digital economy, so as to make up for the research gap in this area.

2. Theoretical Analysis and Research Hypotheses

2.1. Impact of the Digital Economy on Carbon Intensity

The development and application of the digital economy have strong economic and environmental benefits, and can empower carbon emission reduction in the following four aspects. First, from the perspective of the carbon emissions trading market, enterprises can conveniently and quickly find carbon emissions-related data, laying good conditions for carbon emissions trading, which is conducive to the improvement of the degree of marketization and the market scale, and the establishment of a perfect carbon emissions trading market, making it easier to achieve the goal of energy conservation and emission reduction for the whole industry. Secondly, from the perspective of individuals, the wide application of online education and online shopping makes residents participate in fewer offline activities and consume fewer energy resources, and at the same time contributes to the development of low-carbon concepts and behaviors and the promotion of green consumption. Third, from the perspective of enterprises, the digital economy can improve the productivity of enterprises to reduce energy consumption, reduce resource waste by monitoring carbon emission levels, promote the greening of enterprise production, and realize the effect of carbon emission reduction. Fourth, from the perspective of industry, digital economy greatly promotes industrial upgrading and transformation, transforms the traditional industrial industries that are heavily polluted and consume large amounts of energy to environmentally friendly industries, accelerates the optimization of energy structure, and promotes the reduction of carbon emission intensity. Based on the above analysis, this paper puts forward the following hypothesis 1:

H1: The digital economy has a significant dampening effect on carbon emission intensity.

2.2. Analysis of the Moderating Effects of the Level of Industrialization and the Degree of Government Intervention

The industrial sector is one of the industries that produce the most carbon emissions, and the level of carbon emissions is also higher in regions with higher levels of industrialization. Even if the digital economy can play a role in reducing carbon intensity, this process will be inhibited by higher levels of industrialization, i.e., it is difficult to play an effective role in reducing carbon emissions in the digital economy.

To realize the carbon peak goal by 2030, government intervention and leadership are very necessary. The government can intervene in the mechanism of the digital economy to reduce the level of carbon

emissions, such as promoting the upgrading and transformation of industrial structure, promoting the development of low-carbon emerging industries, and supervising and regulating the carbon emissions trading market, so as to contribute to the weakening of carbon emissions intensity. At the same time, it can also help to improve the level of digital economy development, so that the digital economy can play a better role in suppressing carbon emission intensity. Based on the above analysis, this paper puts forward the following hypotheses 2 and 3:

H2: The level of industrialization has a negative moderating effect on the suppression of carbon emission intensity in the digital economy.

H3: The degree of government intervention has a positive moderating effect on the suppression of carbon emission intensity in the digital economy.

2.3. Heterogeneity Analysis of the Carbon Emission Reduction Effect of the Digital Economy

2.3.1. Analysis of Regional Heterogeneity

The carbon emission reduction effect of the digital economy is affected by the level of regional economic development, industrial capacity structure, policy implementation, environmental governance, etc., and there are certain differences in different geographical regions. If the country is divided into three regions according to geographic location: east, central and west, the eastern region has a high level of economic development, the development of digital economy started early, the digital economy has entered the late stage of updating and optimizing the traditional industry, and the new digital industry has entered the late stage of spawning and development, the industrial institutions have been better optimized and upgraded, and the high-emission and high-energy-consuming enterprises are mostly transformed into low-carbon, energy-saving, and green-friendly enterprises, and the intensity of carbon emission has dropped to a lower level. At this time, the carbon emission intensity has dropped to a lower level, and the carbon emission reduction effect of the digital economy is not obvious. The level of economic development in the central region is at a medium level, the degree of development of the digital economy is not high, the proportion of traditional old industrial enterprises is high and dominated by labor-intensive industries with high energy consumption, and the optimization of industrial structure and the digital transformation of enterprises as a whole have not yet been successful and are at an immature stage. For the central region, the application of digital economy can effectively energize economic development and carbon emission reduction targets, and can achieve greater results. The western region, due to geographic location and other disadvantages, low economic level, low level of digital economy development, low energy use efficiency, imperfect digital infrastructure construction, backward technological innovation, serious brain drain phenomenon, more local high-carbon emission enterprises and a certain number of foreign enterprises to transfer pollution, is still in the middle stage of industrialization. At this time, it is difficult for the digital economy to promote industrial upgrading and production efficiency, and it is difficult to offset the emissions of energy consumption, so it is difficult to effectively play the role of carbon emission reduction.

2.3.2. Analysis of Heterogeneity in the Level of Green Carbon Sinks

In fact in many cases the utility of green spaces is the opposite of what urban planners intended, with the construction of urban green spaces increasing carbon emission levels [11] . The reason for this phenomenon is that there is a lot of energy loss in the construction and maintenance of green spaces, such as the use of energy for lighting, carbon emissions from transportation, energy consumption during irrigation, fertilization, pesticide application, and pruning, all of which result in the release of large amounts of carbon dioxide. If the amount of carbon sequestered in the green space system is less than the amount of emissions, the carbon balance will be difficult to maintain, and the green space will change from a carbon sink to a carbon source in the city, and will not be able to play the role of carbon emission reduction. The carbon sequestration and carbon emissions of different types of green space vegetation are different, and it is difficult to realize the purpose of emission reduction if the planning of green space system is not reasonable. When urban green space is large, the carbon

emissions released during construction and maintenance may also be large, and it is more difficult to offset the carbon emissions effectively reduced by the digital economy.

2.3.3. Analysis of Heterogeneity in the Level of Digital Infrastructure Development

Digital infrastructure plays a fundamental and critical role in the development of the digital economy, and is the driving force and engine of digital economic development. Digital infrastructure can empower the digital transformation of traditional physical infrastructure from low efficiency and low informatization to high efficiency and high informatization, making it responsive to the high-speed development of the digital era, while accelerating industrial integration and conduction to promote the high-quality and high-performance development of the digital economy. It can be seen that in regions with a higher level of digital infrastructure construction, the boosting effect of digital infrastructure on the growth of digital economy is more significant, and the emission reduction effect of digital economy on carbon emission intensity is more significant. Based on the above analysis, this paper proposes the following hypothesis 4.

H4: The dampening effect of the digital economy on carbon emission intensity is more significant in central regions, regions with lower levels of green carbon sinks, and regions with higher levels of digital infrastructure development.

3. Research Design

3.1. Modeling

First, to test hypothesis 1, i.e., whether the digital economy has a significant inhibitory effect on carbon emission intensity, this paper constructs the following two-way fixed effect model.

$$CEI_{it} = \beta_0 + \beta_1 Dig_{it} + \beta_c X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

where the subscript i denotes the province, t denotes the year, and $\beta_0$denotes the constant term, and CEI_{it} is the explanatory variable and denotes the carbon intensity of province i in year t, Dig_{it} is the core explanatory variable, indicating the level of development of the digital economy of province i in year t, X_{it} denotes other control variables affecting carbon emission intensity, including population density (POP), innovation level (RD), urbanization level (UR), industrial structure (OIS) and human capital level (HC), and μ_i denotes the individual fixed effects, γ_t denotes the time fixed effects, and ε_{it} denotes the random error term.

To test hypothesis 2, which examines the moderating effects of the level of industrialization and the degree of government intervention on the suppression of carbon emission intensity by the digital economy, the following regression model is set up:

$$CEI_{it} = \beta_0 + \beta_1 Dig_{it} + \beta_2 Z_{it} + \beta_3 Dig_{it} \times Z_{it} + \beta_c X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (2)$$

where Z_{it} is the moderating variable, denoting the industrialization level (IND) or the degree of government intervention (GOV) of province i in year t, $Dig_{it} \times Z_{it}$ denotes the interaction term between the digital economy and the moderating variable, and the meanings of other variables are the same as in equation (1). On the basis that the coefficient of Formula (1) of the aforementioned benchmark regression model passes the test and is significantly negative, if the coefficient of the interaction term in formula (2) is significant, then the adjustment effect exists. When $\beta_1$andβ_3 have the same sign, it indicates that the moderating variable strengthens the relationship between digital economy and carbon emission intensity, and vice versa.

3.2. Description of Variables

3.2.1. Explained Variables

Carbon Emission Intensity (CEI), expressed as the ratio of the total annual CO2 emissions to the regional GDP of each province, takes into account the influence of different levels of economic development in each region, and better reflects the regional carbon emission level. For the measurement of total carbon emissions, this paper refers to the CO2 emission factor method provided by the United Nations Intergovernmental Panel on Climate Change (IPCC), which is commonly used internationally, and selects eight types of energy consumption, namely coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil and natural gas, to calculate carbon dioxide emissions. The specific calculation formula is as follows:

$$CE = \sum E_{ij} \times \alpha_j (i = 30;\ j = 1,2,\dots 8)$$

where CE denotes total CO2 emissions, E_{ij} denotes the consumption of energy type j in province i; α_j is the carbon emission coefficient for energy source j.

3.2.2. Explanatory Variables

Table 1. Indicator system for the level of development of the digital economy

Level 1 indicators	Secondary indicators	Indicator weights/%	Indicator properties
Digital infrastructure	Internet broadband access ports (10,000)	5.49	forward
	Number of web pages (10,000)	21.73	forward
	Number of domain names (10,000)	12.42	forward
Internet development	Internet penetration (%)	2.68	forward
	Cell phone penetration rate (units/100 people)	2.93	forward
Digital industry development	Total telecommunication business (billions of dollars)	11.10	forward
	Information transmission, software and information technology services town units Employed persons (10,000)	12.60	forward
	Revenue from software operations (billions of dollars)	10.97	forward
	Information transmission, software and information technology services enterprises E-commerce sales (billions of dollars)	17.39	forward
Digital Inclusive Finance	Digital Inclusive Finance Index	2.68	forward

Digital economy development level (Dig). At present, the quantification of the level of digital economic development has not yet formed a unified standard, this paper chooses to construct multilevel indicators and establish a digital economic development indicator system, and conducts dimensionality reduction through the entropy method to measure the digital economy. By drawing on the practice of Zhao Tao et al. (2020) [12] , from the four dimensions of digital infrastructure, Internet development, digital industry development and digital inclusive finance, 10 second-level

indicators, such as Internet broadband access ports, Internet penetration rate, total telecommunication business, digital inclusive finance index, are selected to construct the digital economy development indicator system, and the index of the level of development of the digital economy is measured on the basis of this indicator system. The weights of the indicators are calculated by entropy value method, and the results of the calculation of the weights of the indicators and the digital economy development indicator system are shown in Table 1.

3.2.3. Control Variables.

Based on the purpose of the study and with reference to previous literature, this paper selects five aspects as control variables: population density, innovation level, urbanization level, industrial structure and human capital level. Population density (POP) is expressed as the ratio of the total population of the region to the area of the regional administrative division; innovation level (RD) is expressed as the logarithmic value of the number of invention patent applications received; urbanization level (UR) is expressed as the ratio of the urban population to the total population; industrial structure (OIS) is expressed as the ratio of the tertiary industry's output value to the secondary industry's output value; and human capital level (HC) is expressed as the ratio of the number of students in colleges and universities to the total population. Human capital level (HC) is expressed as the ratio of the number of students enrolled in higher education to the total population.

3.2.4. Moderating Variables

In this paper, the level of industrialization and the degree of government intervention are selected as moderating variables. The industrialization level (IND) is represented by the ratio of industrial value added to gross regional product (GRP), and the degree of government intervention (GOV) is represented by the ratio of fiscal expenditure to GRP.

3.3. Data Sources

The research object of this paper is the provincial panel data of 30 provinces (excluding Tibet, Hong Kong, Macao and Taiwan) from 2012 to 2020, which are mainly from the official website of the National Bureau of Statistics (NBS), the statistical yearbooks of each province, and the previous years of the China Statistical Yearbook, the China Urban Statistical Yearbook, the China Energy Statistical Yearbook, the China Environmental Statistical Yearbook, and the Peking University Digital Inclusive Finance Index, with a small number of missing data are made up by the ARMA method.

4. Empirical Analysis

4.1. Analysis of Two-way Fixed Effects Results

Table 2 reports the regression results of the impact of digital economy on carbon emission intensity, where model (1) is the regression result without adding control variables and model (2) is the regression result after considering adding control variables. From the regression results of model (1), it can be seen that without adding control variables, the impact of digital economy on carbon emission intensity is significantly negative at 1% significance level, indicating that the development of digital economy can have a significant negative effect on carbon emission intensity; from the regression results of model (2), it can be seen that, after the introduction of control variables, the digital economy has a significantly negative impact on carbon emission intensity at 5% significance level, indicating that digital economy development can indeed significantly reduce the carbon emission intensity. It shows that the development of digital economy can indeed significantly reduce carbon emission intensity. The development of digital economy can improve the efficiency of energy use, optimize industrial structure, promote technological innovation, and thus inhibit carbon emission intensity.

Table 2. Results of two-way fixed effects

explanatory variable	(1)	(2)
Dig	-2.668***	-1.293 **
	(-7.65)	(-2.46)
control variable	NO	YES
area fixed effect	YES	YES
time fixed effect	YES	YES
constant	2.496***	11.131*
	(8.76)	(1.66)
R^2	0.191	0.978
observed value	270	270

Note: z-values in parentheses, *, ** and *** indicate significance levels at 10%, 5% and 1%, respectively, below.

4.2. Heterogeneity Analysis

4.2.1. Analysis of Regional Heterogeneity

Table 3. Analysis of regional heterogeneity

	the east	central section	western part
	(1)	(2)	(3)
Dig	-0.044	-9.380 ***	-3.069
	(-0.13)	(-4.69)	(-1.44)
control variable	YES	YES	YES
area fixed effect	YES	YES	YES
time fixed effect	YES	YES	YES
constant	11.197	-25.529**	25.322***
	(1.30)	(-2.27)	(3.22)
R^2	0.977	0.994	0.979
observed value	99	72	99

The 30 sample provinces studied in this paper are divided into three regions: east, center and west for regression, and the results are shown in Table 3. From the regression results in Table 3, it can be seen that in the central region, the impact of the digital economy on carbon emission intensity is significantly negative at the 1% significance level, indicating that the carbon emission reduction effect of the digital economy significantly exists in the central region. The reason may be that the central region is still in the early stage of industrial structure transformation, and the development of digital economy is still in the stage of rapid growth, which can effectively promote the optimization and upgrading of industrial structure and significantly reduce carbon emissions. The negative and insignificant coefficient of the digital economy in the eastern and western regions may be due to the

fact that the eastern region has a strong economic foundation, its industrial structure transformation has entered the middle and late stages, and the carbon emission level has been reduced to a lower level, so the inhibitory effect of the digital economy development on the intensity of carbon emissions is not significant. In the western region, due to geographical location and other reasons, the development of digital economy started late and is still in the early stage, so the digital economy cannot significantly inhibit carbon emission intensity.

4.2.2. Analysis of Heterogeneity in the Level of Green Carbon Sinks

In this paper, the green carbon sink level is expressed by the logarithm of the greening coverage of urban built-up areas. In this paper, the green carbon sink level of each province in different years is sorted, and the areas below the median are classified as low green carbon sink level areas, and the areas higher than or equal to the median are classified as high green carbon sink level areas, and the results of the heterogeneity analysis are shown in Table 4. From the regression results in Table 4, it can be seen that the digital economy has a significantly negative impact on carbon emission intensity at the 5% significance level, both in low green carbon sink level areas and high green carbon sink level areas, and the carbon emission reduction effect in low green carbon sink level areas is significantly larger than that in high green carbon sink level areas. The possible reason is that urban green space still consumes a lot of resources in the process of building construction and management maintenance, resulting in the release of a large amount of carbon dioxide, and when the carbon emissions are greater than the amount of carbon sequestration, the green space does not play a role in carbon emission reduction. When the area of green space is large, the carbon emissions released during management and maintenance may be larger, which may result in a situation of high green coverage but high carbon emission intensity at the same time, and the play of the emission reduction efficacy of the digital economy at this time will be limited by the high area of green space. Therefore, the inhibiting effect of digital economy on carbon emission intensity is lower in areas with high green carbon sink level than in areas with low green carbon sink level.

Table 4. Heterogeneity analysis of green carbon sink levels

	Low level of green carbon sinks	High level of green carbon sinks
	(1)	(2)
Dig	-2.716**	-1.272 **
	(-2.21)	(-2.11)
control variable	YES	YES
area fixed effect	YES	YES
time fixed effect	YES	YES
constant	4.402	11.202
	(0.62)	(0.95)
R^2	0.988	0.989
observed value	135	135

4.2.3. Analysis of Heterogeneity in the Level of Digital Infrastructure Development

In this paper, the level of digital infrastructure construction in each province in different years is ranked, and the areas below the median are classified as low digital infrastructure construction level areas, and the areas above equal to the median are classified as high digital infrastructure construction level areas, and the results of the heterogeneity analysis are shown in Table 5. From the regression results in Table 5, it can be seen that the digital economy has a significant negative effect on carbon

emission intensity at the 5% significance level in regions with high digital infrastructure development level, while it is not significant in regions with low digital infrastructure development level. The reason may be that digital infrastructure is a strong foundation for the development of digital economy, if the level of digital infrastructure construction is low, the development of digital economy is slow, and the inhibition effect of digital economy on carbon emission intensity cannot be realized, so the emission reduction effect of digital economy in the region with low level of digital infrastructure construction is not significant. On the contrary, the high level of digital infrastructure development in the region with a high level of digital economic development, can quickly, widely and fully enjoy the dividends brought about by the development of the digital economy, the digital economy's carbon emission reduction role can be effectively played, so the digital economy in the region can significantly reduce the intensity of carbon emissions.

Table 5. Heterogeneity analysis of the level of digital infrastructure development

	Low level of digital infrastructure development	High level of digital infrastructure development
	(1)	(2)
Dig	-0.675 (-1.00)	-2.620 ** (-2.51)
control variable	YES	YES
area fixed effect	YES	YES
time fixed effect	YES	YES
constant	2.702 (0.30)	13.230 (1.06)
R^2	0.986	0.983
observed value	135	135

4.3. Analysis of Regression Results of Moderating Effects

Table 6. Results of moderating effects

explanatory variable	(1)	(2)
Dig ×moderator variable	6.696** (1.97)	-17.082 *** (-3.07)
Dig	-2.186** (-2.3)	2.071* (1.84)
moderator variable	2.706*** (3.82)	4.081*** (4.22)
control variable	YES	YES
area fixed effect	YES	YES
time fixed effect	YES	YES
constant	9.228 (1.42)	-0.012 (-0.00)
R^2	0.980	0.980
observed value	270	270

This paper further introduces the level of industrialization and the degree of government intervention as moderating variables, and the regression results of the moderating effects of the two in the process of suppressing carbon emission intensity in the digital economy are shown in Table 6. Model (1) in Table 6 shows the regression results of the moderating effect of the level of industrialization, and the regression coefficient of the interaction term is significantly positive at the 5% significance level, which indicates that the level of industrialization has a significant weakening effect on the relationship between the digital economy and the intensity of carbon emissions, probably because the increase in the level of industrialization inhibits the role of carbon emission reduction of the digital economy. Model (2) in Table 6 shows the regression results of the moderating effect of the degree of government intervention, and the regression coefficient of the interaction term is significantly negative at the 1% significance level, indicating that the degree of government intervention has a significant contribution to the relationship between the digital economy and the intensity of carbon emissions, probably because the government intervention strengthens the role of carbon emission reduction in the digital economy.

4.4. Robustness Tests

To further validate the robustness of the benchmark regression results, the following three methods are used in this paper, and the results are shown in Table 7.

First, replace the explanatory variables. Since the total carbon emissions of each region are affected by the number of population and the activities of people, this paper adopts the per capita carbon emissions to replace the carbon emissions intensity. Column (1) shows that the digital economy has a significantly negative impact on carbon emission intensity at the 1% significance level, which is basically consistent with the previous results.

Second, truncation. In order to eliminate the influence of extreme values on the sample estimation results, a 2% truncation is applied to the carbon emission intensity data. The results, as shown in column (2), indicate that the digital economy has a significantly negative impact on carbon emission intensity at the 1% significance level, verifying the robustness of the regression results.

Table 7. Robustness test

explanatory variable	(1)	(2)	(3)
Dig	-16.957 ***	-1.621***	-1.578***
	(-5.04)	(-2.73)	(-2.66)
control variable	YES	YES	YES
area fixed effect	YES	YES	YES
time fixed effect	YES	YES	YES
constant	-56.418	-2.865	12.300
	(-1.32)	(-0.66)	(1.58)
R^2	0.962	0.974	0.979
observed value	270	270	270

Third, sample exclusion. In 2012, the State Council of China issued the "12th Five-Year Plan" and the "12th Five-Year Plan for Energy Conservation and Emission Reduction", and the changes in carbon emission levels in the year of the release of the policy will not react to the policy quickly, so the data for 2012 will be excluded from this paper. As the changes in carbon emission level in the year of policy release will not respond to the policy quickly, the data of carbon emission intensity in

2012 will be different from other years, so the data of 2012 is excluded from this paper. As shown in column (3), the impact of digital economy on carbon emission intensity is significantly negative at the 1% significance level, and the robustness of the regression results is checked.

4.5. Endogeneity Test

Endogeneity problems may exist because of possible mutual causation and omitted variables. In this paper, we adopt an instrumental variable approach to deal with the endogeneity problem, drawing on Huang Qunhui et al. [13] , where the number of post offices per million people in each province in 1984 is used as the instrumental variable. Given that this is cross-sectional data, the interaction term between the Internet penetration rate with one period lag and this is chosen as the instrumental variable for the digital economy of each province, and the results are shown in Table 8. The results in column (1) show that the one-stage regression results indicate that the effect of instrumental variables on endogenous variables is significantly negative at the 1% significance level, with a strong correlation. The results in Column (2) show that the results of the two-stage regression indicate that after controlling for the endogeneity issue, the digital economy has a significantly negative impact on carbon intensity at the 5% significance level, which is generally consistent with the results of the benchmark regression in the previous section. In addition, there is no over-identification problem due to the fact that the number of endogenous and instrumental variables in this paper is the same.

Table 8. Results of instrumental variable estimation

explanatory variable	Phase I	Phase II
Dig		-4.093** (-2.32)
IV	-0.001*** (-3.11)	
control variable	YES	YES
area fixed effect	YES	YES
time fixed effect	YES	YES
constant	-3.777*** (-3.31)	0.664 (0.09)
R^2	0.947	0.975
observed value	270	270

5. Conclusion and Policy Recommendations

This paper takes the panel data of 30 provinces in China from 2012 to 2020 as the research samples, empirically examines the impact of digital economy on carbon emission intensity by using two-way fixed effect model, moderating effect and other methods, and obtains the following conclusions: (1) Digital economy has a significant inhibitory effect on carbon emission intensity, and the above conclusions are still valid after the robustness test and endogeneity test. (2) There is obvious heterogeneity in the inhibitory effect of digital economy on carbon emission intensity. In terms of regional heterogeneity, the carbon emission reduction effect of the digital economy is significant in the central region and insignificant in the eastern and western regions; in terms of heterogeneity in the level of green carbon sinks, the effect is more significant in the lower level of green carbon sinks; in terms of heterogeneity in the level of digital infrastructure construction, the effect is significant in the higher level of digital infrastructure construction, and insignificant in the lower region. (3) The

level of industrialization has a negative moderating effect on the suppression of carbon emission intensity by digital economy, and the degree of government intervention has a positive moderating effect on the suppression of carbon emission intensity by digital economy. In view of the above conclusions, this paper puts forward the following suggestions:

First, we will continue to vigorously develop the digital economy and give full play to its carbon emission reduction effect. We will promote the construction of digital infrastructure, the development of the Internet and the development of the digital industry, increase penetration and expand coverage, and improve the disparity between urban and rural development and the imbalance in regional development. Promote digital industrialization and industrial digitization, accelerate the in-depth integration of the digital economy with the real economy, improve technological innovation capabilities, and prompt digital technology to play a leading and driving role. It will further promulgate relevant policies and documents, accelerate the construction of digital China, and promote the orderly and vigorous development of the digital economy.

Second, based on regional differences, development strategies should be adopted according to local conditions. For the central region, the level of development of the digital economy should be further enhanced to promote the transformation of the industrial structure to the later stage of the acceleration of progress, and help the digital economy to empower carbon emission reduction. For the western region, the government should give certain policy inclination, increase investment in digital infrastructure construction, vigorously develop the digital economy, and at the same time help enterprises upgrade and transform to promote green and low-carbon development. In the eastern region, residual high-emission enterprises should be urged to carry out transformation, while continuing to adhere to the development of the digital economy, playing a spatial spillover effect and penetration effect, radiation driven by the central and western regions, to realize the overall reduction of carbon emission levels.

Thirdly, the ecological benefits of urban green space should be assessed by the standard of carbon revenue and expenditure, and refined control should be carried out. Focusing on the size of carbon reduction and emissions, we should not pursue the expansion of green space, pay attention to the control of energy consumption during construction and management, and reasonably reduce carbon emissions from resource consumption, machinery and transportation facilities. According to the differences in carbon sequestration and emissions of different types of vegetation, reasonable planning and combination should be carried out, paying attention to planting density, hierarchical structure and age matching. In short, it is necessary to consider the matter from multiple angles in order to better utilize the role of carbon sequestration and emission reduction.

Fourthly, the construction of digital infrastructure will be further accelerated, and the strategic layout will be strengthened to continuously energize the digital economy. It has coordinated the layout of information infrastructure represented by 5G and gigabit optical networks, constructed first-class arithmetic networks and intelligent Internet of Things systems, widely applied digital technologies such as artificial intelligence, cloud computing and big data to all aspects of the economy, society and people's livelihoods, promoted the digitization of transportation, municipal and other infrastructures, and pushed forward the digital transformation of the city, so as to empower the development of the digital economy.

Fifthly, the Government is actively taking reasonable interventions in various areas to help the digital economy empower carbon emission reduction. It has played a role in the many paths of the digital economy to curb carbon emissions by promoting the carbon emissions trading market to increase the degree of marketization and strengthen supervision and regulation; helping enterprises in their digital transformation and promoting their green production; and promoting the upgrading of industrial institutions and the development of industrial integration. Flexibly utilizing various fiscal and taxation policies to promote the development of the digital economy through fiscal expenditure, policy assistance and regulation of the market, so as to enhance the role of the digital economy in curbing the intensity of carbon emissions.

Sixthly, we should take the new road of industrialization with Chinese characteristics and promote high-quality green industrial development. It is necessary to abandon the traditional path of industrialization, which seeks to achieve economic growth at the expense of energy consumption and the environment, promote the transformation of traditional industries, vigorously develop new industries, accelerate the optimization of the industrial structure, and reduce pollution emissions. We will deeply implement the innovation-driven development strategy, increase investment in scientific and technological research and development, and enhance the innovation capacity of green technology. It will promote the deep integration of the digital economy and the real economy, accelerate green and low-carbon development, and push forward the green development of industrial digitization.

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