ISSN: 2710-0723

The Impact of Pilot Policies for Smart Cities on Carbon Emissions in Cities along the Eastern Coast of China

Siyu Zhang*, Xinyi Long, Ziqi Zhang, Yuyan Niu
Anhui University of Finance and Economics, Bengbu, Anhui, 233030, China
*1982127326@qq.com

Abstract

Based on panel data from 111 prefecture level cities in the eastern coastal region of China from 2006 to 2021, this article regards the three batches of smart city pilot policies implemented since 2012 as a "quasi natural experiment", uses the asymptotic difference in differencesAA (DID) method to explore their impact on carbon emissions in the eastern coastal region of China, and verifies the scientific and credibility of the research results through multiple robustness tests. Then, heterogeneity analysis and mechanism analysis are conducted to explore the impact mechanism of smart cities on carbon reduction according to policies. The research results indicate that, firstly, the pilot policy of smart cities is beneficial for reducing carbon emissions in the eastern coastal areas of China, and this result remains robust after robustness tests such as PSM-DID (propensity score matching), placebo test, and exclusion of other policy interferences. Secondly, the pilot policies of smart cities have different carbon emission reduction effects in cities with different characteristics, and have more significant carbon emission reduction effects on small cities, non resource-based cities, and high GDP cities. Thirdly, the pilot policy of smart cities promotes the green and low-carbon development of cities in the eastern coastal areas of China by enhancing technological level and optimizing industrial structure.

Keywords

Smart City; Carbon Emissions; Eastern Coastal Regions; Asymptotic Double Difference.

1. Introduction

With the rapid development of China's economy and its high dependence on fossil fuels and other energy sources, China has become the country with the largest carbon emissions in the world. In the 2022 Global Environmental Performance Index jointly released by Yale University and Columbia University, China ranked 94th out of 178 countries and regions, slightly improving compared to before, but the environmental pollution problem is also not optimistic. Over the past few decades, China's carbon emissions have grown exponentially, far surpassing developed countries such as the United States, Japan, and Germany.

Since the reform and opening up, the Chinese economy has rapidly taken off. With the establishment of various economic zones along the coast, eastern coastal cities have become the most developed regions in the domestic economy. At the same time, environmental pollution is becoming increasingly serious. Therefore, the government has introduced many related policies, including pilot policies for smart cities, to alleviate environmental problems. The development of cities in the industrial era will inevitably lead to an increase in carbon emissions, but in the digital economy era, will the construction of smart cities empowered by digital technology have an impact on China's carbon emissions? What mechanisms are used to achieve this impact? The differences in development and carbon emissions between different cities are worth studying.

ISSN: 2710-0723

Based on the above background, this project intends to study the impact of smart city construction on urban carbon emissions and explore its impact mechanism. Taking the eastern coastal region as an example, it will provide effective reference for regions that have implemented and have not implemented smart city pilot policies.

The Singapore Smart Nation 2025 Plan (2015-2025) is the world's first blueprint for building a smart nation. In February 2021, the "Guiding Opinions of the State Council on Accelerating the Establishment and Improvement of a Green, Low Carbon and Circular Development Economic System" was issued, requiring the comprehensive promotion of green construction throughout the entire process, the establishment and improvement of a green, low-carbon and circular development economic system, ensuring the achievement of carbon peak and carbon neutrality goals, and promoting China's green development to a new level. In April 2021, the National Development and Reform Commission issued the document "Key Tasks for New Urbanization and Urban Rural Integration Development in 2021", which clearly stated that "building new smart cities" is included in the key tasks for new urbanization and urban-rural integration development in 2021.

This article will explore the carbon emission reduction effect of smart city pilot policies on cities in the eastern coastal areas of China based on theoretical analysis and empirical research. The specific objectives are as follows: (1) To investigate the impact of smart city pilot policies on carbon emissions in the eastern coastal areas of China. This article regards the policy as a "quasi natural experiment" and uses the progressive double difference method to quantify the impact of the policy on carbon emissions in the eastern coastal areas. (2) Evaluate the mechanism of the impact of smart city pilot policies on carbon emissions in eastern coastal cities. This article conducted heterogeneity analysis and mechanism analysis in the empirical research process, exploring whether the carbon reduction effect of smart city pilot policies varies in different characteristic cities, and through which channels it affects the carbon emissions of pilot cities. (3) Based on the research findings, feasible suggestions are proposed from multiple perspectives for different situations in different cities to promote the effective combination and coordination of smart city construction and carbon emission management.

2. Literature Review

With the increasingly severe global climate change, urban carbon emissions have gradually become a focus of attention for countries around the world. Smart cities, as a new model of urban development, improve urban management and service efficiency by utilizing advanced information and communication technologies, thereby promoting sustainable urban development. As the world's largest developing country, China vigorously promotes pilot policies for smart cities, aiming to reduce urban carbon emissions and achieve green and low-carbon development through technological innovation and policy guidance.

In recent years, scholars at home and abroad have conducted extensive research on pilot policies for smart cities and urban carbon emissions. Through sorting, it has been found that the literature related to this article mainly focuses on the following three categories:

The first type is the study of factors affecting urban carbon emissions. The factors that affect urban carbon emissions include spatial structure, technological innovation, industrial structure, digital economy, and population factors. In terms of spatial structure, Li Shu found that from the perspective of spatial evolution characteristics, the regional feature of China's carbon emission intensity being higher in the north and lower in the south is gradually breaking, and the local spatial correlation test further confirms the fact that the spatial agglomeration of China's carbon emission intensity is gradually weakening [8]. In terms of technological innovation, He Weijun et al. used panel data from the Yangtze River Economic Belt from 1999 to 2019, and applied the global super efficiency SBM model, extended STIRPAT model, mediation effect model, and threshold model to examine the relationship between human capital, green technology innovation, and total factor carbon emission efficiency. The research results indicate that the accumulation of human capital not only directly promotes the optimization of total factor carbon emission efficiency in the Yangtze River Economic Belt, but also indirectly promotes it through green technology innovation. In terms of industrial structure, Liu Jianqiang et al. found that the spatial effect of regional carbon emissions is significant; From a global perspective, population aging will promote carbon emissions, while industrial structure upgrading will suppress carbon emissions; From the perspective of direct and indirect effects, population aging and industrial structure upgrading will respectively promote and suppress local carbon emissions, but their spatial spillover effects are not significant and there are regional differences. Further verification through the mediation effect model confirms that industrial structure upgrading is a mediating variable for the impact of population aging on carbon emissions [9]. In terms of the digital economy, Zhang Zhengyan et al. found that the development of the digital economy effectively reduces per capita carbon emissions, carbon emission increments, and carbon emission growth rates. There is an inverted "U" - shaped relationship between the digital economy and carbon emission intensity, and the relationship between the digital economy and carbon emission intensity and marginal carbon emission intensity shows regional characteristics. At the provincial level, there is no significant spatial effect of the impact of the digital economy on marginal carbon emission intensity. The impact of the digital economy on carbon emission growth rate is based on the masking effect of industrial structure optimization, population agglomeration, and urbanization [23]. In terms of population factors, Li Handong et al. based on the combination neural network (LSTM-IPSO-BP) model, found that the continuous decline in China's future population will lead to an increase in carbon emission intensity, and the rate of population decline is positively correlated with carbon emission intensity [6].

The second type is the research on the implementation effect of pilot policies for smart cities. The construction of smart cities provides greater assurance for public safety. The implementation of pilot policies for smart cities has a significant positive effect on the level of urban safety. As the policy implementation time progresses, the positive effect gradually strengthens. Smart city policies have a more significant impact on mega cities and cities in the eastern region, with a significantly greater impact on non provincial capital cities than on provincial capital cities [18]. Based on panel data from 197 prefecture level cities in China from 2008 to 2017, Qi Ji et al. studied the impact of smart city construction on local air quality and found that smart city construction has a significant effect on reducing $CO2$ and $SO2$ emissions [11]. The construction of smart cities has also significantly improved the level of urban medical and health services as well as basic education services. It has a significant impact on the level of medical and health services in the western region, and on the level of basic education services in the eastern, central, and northeastern regions. Yu Desheng and Wang Shujie found that the pilot policies of smart cities have significantly increased the quantity and quality of green innovation in enterprises; The pilot policy of smart cities promotes the "incremental improvement" of green innovation in enterprises by enhancing urban financial support and alleviating financing constraints for enterprises.

The third category is research on the impact of smart city construction on urban carbon emissions. Zhang Bingbing et al. used three batches of pilot cities promoting smart city construction since 2012 as quasi natural experimental subjects, and used the difference in differences (DID) method to identify the impact of smart city pilot policies on urban carbon emissions. The research results indicate that the pilot construction of smart cities is beneficial for reducing carbon emissions; Heterogeneity analysis shows that pilot policies are more conducive to reducing carbon emissions in the Beijing Tianjin Hebei urban agglomeration, non resource-based cities, and non old industrial base cities [20]. Based on panel data of Chinese

ISSN: 2710-0723

prefecture level cities from 2005 to 2019, Liu Lijuan found that pilot policies for smart cities can significantly reduce regional carbon emission intensity, promote green and low-carbon development of cities, and play a role by improving the level of green technology innovation and optimizing energy consumption structure. In addition, Zhang Youzhi et al. found that the construction of smart cities can significantly suppress urban carbon emission intensity and has robustness; The impact of smart city construction on carbon emission intensity varies across different regions; The transformation and upgrading of industrial structure and the enhancement of technological innovation capability are effective paths for reducing carbon emission intensity in the construction of smart cities; The intensity of government environmental regulations can effectively promote the carbon reduction effect of smart city construction [22]. At present, scholars have come to the same conclusion through different research methods or subjects that the construction of smart cities is beneficial for reducing carbon emissions.

This article focuses on the eastern coastal region and aims to explore the impact of smart city pilot policies on carbon emissions in cities along the eastern coast of China, in order to provide reference for policy optimization and future research in the eastern coastal region.

3. Theoretical Analysis and Research Hypotheses

With the increasingly serious global climate change problem, the Chinese government has made energy conservation and emission reduction one of the important strategies for national development. In this context, smart cities, as a new model of urban development, are gradually gaining attention due to their advantages in improving energy efficiency, optimizing resource allocation, and reducing environmental pollution. As the most economically developed region in China, the eastern coastal areas have consistently high carbon emissions. Therefore, implementing smart city pilot policies to reduce carbon emissions is of great significance.

Smart cities promote advanced information technologies such as big data, the Internet of Things, and cloud computing to achieve intelligent management of urban infrastructure and improve energy efficiency. For example, smart grids can monitor and regulate electricity demand in real-time, avoiding energy waste; Intelligent transportation systems can optimize traffic flow, reduce congestion and exhaust emissions. In addition, smart cities also encourage the use of clean energy sources such as solar and wind power to replace traditional fossil fuels. For example, in the smart city pilot project on Chongming Island in Shanghai, a large number of solar street lights and charging piles were installed to promote the use of electric vehicles, significantly reducing carbon emissions. The application of these technological innovations not only reduces energy consumption, but also improves energy utilization efficiency, providing strong support for urban sustainable development.

Industrial upgrading is also an important way to reduce carbon emissions. The cities in the eastern coastal areas are dominated by manufacturing and service industries, and the pilot policy of smart cities promotes industrial transformation and upgrading by attracting high-end manufacturing and modern service industries. These industries usually have higher added value and lower energy consumption levels, which helps to reduce carbon emissions per unit of GDP. Meanwhile, smart cities also encourage enterprises to adopt clean production technologies to reduce carbon emissions during the production process. For example, in the smart city pilot program, Suzhou Industrial Park has introduced a group of high-tech enterprises that adopt advanced production technologies, improve resource utilization efficiency, and reduce carbon emission intensity. The pilot policy for smart cities also aims to reduce reliance on gasoline powered vehicles by building a comprehensive public transportation system, promoting green modes of transportation such as shared bicycles and electric vehicles. For example, the number of shared bicycles in Shenzhen has exceeded 100000,

ISSN: 2710-0723

becoming one of the important ways for citizens to travel. In addition, smart cities also optimize transportation routes through intelligent transportation systems, reduce unnecessary driving mileage, and further reduce carbon emissions. In addition to the above measures, the pilot policies for smart cities also enhance citizens' environmental awareness through vigorous promotion of policy guidance and publicity education. The government has introduced a series of preferential policies to encourage citizens to purchase energy-saving products and use clean energy. For example, Beijing provides subsidies and license plate discounts to citizens who purchase new energy vehicles, which stimulates the sales of new energy vehicles. In addition, through publicity and education, citizens have gradually formed the habit of green travel, reduced the frequency of private car use, and further reduced carbon emissions. In summary, the pilot policies for smart cities have effectively reduced carbon emissions in the eastern coastal areas through measures such as technological innovation, industrial upgrading, and green travel. The implementation of these measures not only helps to solve environmental pollution problems, but also promotes the sustainable development of cities. In the future, with the continuous advancement of technology and the continuous improvement of policies, smart cities will play a greater role in reducing carbon emissions.

Based on this, the following hypothesis is proposed.

H1: The construction of smart cities can significantly reduce carbon emissions in coastal cities in eastern China.

As an economically developed region, the eastern coastal areas of China are facing significant carbon emission pressure. Smart cities provide a vast market space for green technology innovation by integrating advanced science and technology. For example, smart grids can promote the consumption of clean energy and reduce dependence on fossil fuels. Intelligent transportation systems can optimize travel modes and reduce transportation carbon emissions. The application of these technological innovations provides strong support for low-carbon development in the eastern coastal areas. Meanwhile, smart cities have also attracted a large number of high-quality talents and innovative resources, promoting the development of green industries. In addition to technological innovation, smart cities also encourage enterprises to engage in green innovation through policy guidance and market mechanisms. For example, policies such as establishing green funds and providing tax incentives can incentivize enterprises to research and apply low-carbon technologies. The implementation of these policies has promoted the commercialization and industrialization of green technologies, further reducing carbon emissions. The implementation of these measures not only reduces energy consumption, but also improves the sustainable development level of the city. Of course, the construction of smart cities also faces some challenges in reducing carbon emissions. For example, issues such as technological innovation, technological maturity, and capital investment. To address these challenges, the government and enterprises need to strengthen cooperation and jointly promote the improvement and application of technological levels. Finally, it is necessary to strengthen regional cooperation among coastal cities to jointly address global challenges such as climate change.

Based on this, the following hypothesis is proposed.

H2: The construction of smart cities promotes the improvement of urban technological level and reduces urban carbon emissions.

The carbon emissions are jointly influenced by the total economic development, industrial structure, and energy structure, and the use of energy is an important link between carbon emissions and economic development. Optimizing the energy consumption structure is an important way to reduce urban carbon emissions. Smart cities reduce dependence on fossil fuels by promoting clean energy and improving energy efficiency. For example, the application of clean energy such as solar energy and wind energy in smart cities is becoming increasingly

ISSN: 2710-0723

widespread. At the same time, the construction of smart grids has improved the stability and reliability of the power system, providing strong support for the consumption of clean energy. The application of these technological innovations has made the urban energy consumption structure cleaner and more efficient. Smart cities also encourage businesses and residents to use clean energy through policy guidance. For example, implementing policies such as differential electricity prices and providing subsidies to incentivize businesses and residents to choose clean energy and use it on demand. The implementation of these policies has gradually increased the proportion of clean energy in energy consumption, further promoting the transformation of energy consumption structure. The construction of smart cities also promotes the intelligence of energy management. Through data-driven decision support, city managers can better understand energy consumption and develop scientific energy management strategies. The implementation of these measures provides strong support for optimizing the energy consumption structure. Of course, optimizing the energy consumption structure requires joint efforts from the government and the market. The government should formulate scientific energy policies to guide the healthy development of the energy market. At the same time, enterprises and all sectors of society should actively participate and jointly promote the optimization of energy consumption structure. The construction of smart cities strengthens information dissemination and policy implementation. Against the backdrop of highly developed information technology, residents' environmental awareness is gradually increasing, which can indirectly promote the optimization of energy consumption structure, achieve efficient energy utilization and low-carbon development.

Based on this, the following hypothesis is proposed.

H3: The construction of smart cities promotes the optimization of energy consumption structure and further reduces urban carbon emissions.

4. Research Design

4.1. Model Setting

The implementation of the smart city pilot policy can be seen as an exogenous policy shock, and China's implementation of the smart city pilot policy is divided into three batches to be implemented at different times. Therefore, in order to more rigorously explore the impact of the smart city pilot policy on carbon emissions in the eastern coastal areas of China, this article defines the pilot cities established in the three batches as the experimental group, and the non pilot cities as the control group (specific grouping will be described in detail below). A multi period double difference model is used to evaluate the policy effect, and the specific structure of the model is:

$$Y_{it} = \beta_0 + \beta_1 DID_{it} + \varphi X_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{1}$$

Where, i and t represent the city and year respectively; Y_{it} represents the dependent variable, which is carbon emission intensity; DID_{it} represents the virtual variable of the smart city pilot policy, reflecting whether city i implemented the smart pilot policy in year t; X_{it} is a series of control variables; β_0 is a constant term; β_1 is an estimated coefficient that reflects the net effect of smart pilot policies on carbon emissions; φ represents the coefficient of the control variable; μ_i represents the fixed effect of the city; ν_t represents the fixed effect of the year; ε_{it} represents a random perturbation term.

ISSN: 2710-0723

4.2. Variable Selection

4.2.1. The Dependent Variable

The dependent variable of this article is carbon emissions (LNCO2), which is the logarithm of the total carbon emissions of each prefecture level city. The data comes from the "China Carbon Accounting Database". As the data is only up to 2019, this article uses time series forecasting to complete the data. The specific calculation method is:

$$LNCO2 = \ln(CO_{2total}) \tag{2}$$

4.2.2. Explanatory Variables

The core explanatory variable of this article is the virtual variable (DID_{it}) of the smart city pilot policy, which reflects the net effect of the implementation of the smart city pilot policy and is the interaction term between the smart city and the pilot time (i.e. $DID_{it} = city_i \times year_t$). A value of 1 indicates that city i implemented the smart pilot policy in year t; A value of 0 indicates that city i did not implement the smart pilot policy in year t. Specifically, if City i is a pilot city, then $city_i = 1$ serves as the experimental group, and if City i is a non pilot city, then $city_i = 0$ serves as the control group; $year_t = 1$ indicates the year and after the implementation of the policy; The rest of $year_t = 0$.

4.2.3. Control Variables

This article refers to the practices of scholars such as Liu Lijuan, Tian Tao, and Zhang Bingbing, and selects the following indicators as control variables: population density, economic development level, financial development, urban greening level, industrial structure, education level, and technology level. The specific variable definitions and symbols are shown in Table 1.

4.3. Data Sources and Descriptive Statistics

Table 1. Variables and Descriptive Statistics

Variable Name	Symbol	Variable definition	Observation	Mean	SD	Min	Max
Carbon emissions	lnCO2	Natural logarithm of carbon dioxide emissions	1792	3.352	0.832	0.355	6.031
Smart city timing policies	DID	city(0,1)*year(0,1)	1792	0.305	0.46	0	1
Population density	lhum	The natural logarithm of the ratio of total population to administrative area	1792	6.099	0.654	4.521	8.058
Economic development level	lneco	Natural logarithm of per capita regional GDP	1792	10.69	0.674	8.628	13.06
Financial development	lnfin	The natural logarithm of the actual amount of foreign investment used in that year	1792	10.37	1.631	2.708	14.15
Urban greening level	lngreen	Natural logarithm of green coverage area in built-up areas	1792	40.55	6.346	0.38	92.87
Industrial structure	str	The proportion of the output value of the tertiary industry to the regional GDP	1792	42.09	9.086	15.65	80.49
Educational level	lnedu	Natural logarithm of education expenditure	1792	13.02	0.903	9.844	16.08
Technological level	lnst	Natural logarithm of science and technology expenditure	1792	10.36	1.62	4.205	15.53

This article takes 113 prefecture level cities along the eastern coast of China from 2006 to 2022 as research samples, with data sourced from the "China Urban Statistical Yearbook," "China Statistical Yearbook," "China Carbon Accounting Database," and statistical yearbooks of each sample city over the years. Partial missing data is supplemented by linear interpolation or the

ISSN: 2710-0723

mean of other cities in the same province year. During the data collection process, we found that there were many missing data in Sansha City and Danzhou City in Hainan Province. Therefore, after excluding one municipality directly under the central government (Shanghai), Sansha City, Danzhou City, as well as Hong Kong, Macao, and Taiwan, the scope of this study covers 111 prefecture level cities, of which 58 prefecture level cities are the experimental group and 53 prefecture level cities are the control group. Table 1 shows the names, definitions, and descriptive statistics of specific variables:

4.4. Correlation Analysis

In order to quantify and study the relationships between multiple variables selected by the institute, help understand whether and how these variables are related to each other, and preliminarily determine whether the data is suitable for the difference in differences model, correlation analysis was used to analyze the selected variables. According to Table 2, all results were significant at the 1% level, indicating that there is a very significant relationship between variables, which may point to potential causal relationships or common determining factors. It was preliminarily determined that the data is suitable for the model in this article.

Table 2. Correlation Analysis

	lnCO2	lnhum	lneco	linfin	lngreen	str	lnedu	lnst
lnCO2	1							
lnhum	0.410***	1						
lneco	0.512***	0.341***	1					
linfin	0.542***	0.540***	0.599***	1				
lngree	0.257***	0.187***	0.360***	0.280***	1			
str	0.159***	0.274***	0.492***	0.321***	0.217***	1		
lnedu	0.610***	0.422***	0.675***	0.523***	0.261***	0.531***	1	
lnst	0.569***	0.449***	0.799***	0.670***	0.328***	0.509***	0.849***	1

Note: * * * represents a significance level of 1%.

5. Empirical Analysis

5.1. Benchmark Regression

This article uses a multi-stage DID model to assess the impact of smart city construction on carbon emissions. The benchmark results are shown in Table 3, where the first column shows the results without control variables, the second column shows the results without control variables but with time and city fixed effects, and the third column shows the results with control variables and time and city fixed effects. The results showed that the estimated coefficient was negative and passed the significance level test, indicating that the implementation of the smart city pilot policy resulted in a significant reduction of about 10.4% in carbon emissions in the experimental group compared to the control group, indicating that the smart city policy can promote the reduction of urban carbon emissions. Therefore, hypothesis 1 holds true.

ISSN: 2710-0723

Table 3. Benchmark Regression Results

Variable	(1)	(2)	(3)
	lnCO2	lnCO2	lnCO2
DID	-0.651***	-0.091*	-0.104**
	(-6.6527)	(-1.7249)	(-2.0257)
lnhum			-0.004
			(-0.0233)
lneco			0.232***
			(-3.0247)
linfin			-0.008
			(-0.8257)
lngreen			0.001
			(-0.4707)
str			-0.004
			(-1.1711)
lnedu			-0.037
			(-0.4628)
lnst			0.039
			(-1.5915)
_cons	3.154***	1.020***	-0.897
	(-44.9698)	(-27.5376)	(-0.6137)
Urban fixed effects	No	Yes	Yes
Fixed year effect	No	Yes	Yes
sample size	1792	1792	1791
R2	0.129	0.942	0.945

Note: * * * represents a significance level of 1%, and the values in parentheses are t-values.

5.2. Parallel Trend Test

Before policy implementation, the experimental group and the control group must meet the parallel trend assumption, which means that the carbon emissions change trends of the two groups are consistent, ensuring the consistency of the double difference estimation results. Considering the phased implementation of the smart city pilot policy, in order to better demonstrate the dynamic effects of the smart city pilot policy, a multi period double difference method is used for parallel trend testing, with the previous period before the pilot as the base period. From the analysis results, it can be seen that both the experimental group and the control group did not pass the significance level test before the implementation of the smart city pilot policy, that is, there was no significant difference in carbon emissions between cities in the eastern coastal areas of China before the implementation of the smart city pilot policy, indicating that they passed the parallel trend test. In the year of policy implementation and the following three years, the estimated coefficient for carbon emissions is not significant, and the difference in carbon emissions between the experimental group and the control group is not significant. This indicates that the role of smart cities in promoting carbon emissions reduction after policy implementation is relatively small, and the policy has a time lag; But in the fourth year and beyond of policy implementation, the pilot cities for smart cities have significantly reduced the carbon emissions of cities along the eastern coast of China.

5.3. Robustness Test

5.3.1. Placebo Test

To eliminate the randomness of the results, a counterfactual placebo test was conducted in this section. To ensure that the implementation of the smart city pilot policy is a random shock, 58

ISSN: 2710-0723

cities were randomly selected from the sample cities as the pseudo experimental group, and the remaining cities as the pseudo control group. Pseudo policy dummy variables were generated for regression to obtain the estimated coefficients and P-values of the implementation of the smart city pilot policy on urban carbon emissions. To avoid the influence of other small probability times on the results, repeat the regression analysis 500 times. From the kernel density curve and the distribution of P-values, it can be seen that the regression coefficients are approximately normally distributed, and the vast majority of the results are not significant. Additionally, the estimated values of the baseline regression coefficients are located at the high tail of the pseudo regression coefficient distribution, which is a low probability event in the placebo test. Therefore, it further confirms that the pilot policies of smart cities promote the reduction of urban carbon emission intensity, which is not due to unobservable factors, indicating the robustness of the results.

5.3.2. PSM-DID Robustness Test

Table 4. PSM-DID Regression Results

Variable	Benchmark regression	PSM-DID
	lnCO2	lnCO2
did	-0.104***	-0.052**
	(-5.7326)	(-2.5643)
lnhum	-0.004	-0.089
	(-0.0424)	(-0.8357)
lneco	0.232***	0.192***
	(-6.5657)	(-4.7312)
lnfin	-0.008	0.002
	(-1.1459)	(-0.3252)
lngreen	0.001	0.001
	(-0.6792)	(-0.9454)
str	-0.004**	-0.002
	(-2.5635)	(-1.0932)
lnedu	-0.037	-0.209***
	(-0.9779)	(-4.3425)
lnst	0.039***	0.044***
	(-3.5724)	(-3.5986)
_cons	1.012	3.860***
	(-1.4865)	(-4.8167)
R^2	0.945	0.973
Urban fixed effects	Yes	Yes
Fixed year effect	Yes	Yes

Note: * * * represents a significance level of 1%, and the values in parentheses are t-values.

To address the bias caused by observable and unobservable variables, the PSM-DID (propensity score matching double difference) method is used to more accurately evaluate the effectiveness of smart city pilot policy interventions. The construction of the PSM-DID model in this article is as follows: firstly, the logic model is selected, and the cities that serve as pilot cities for smart cities during the sample investigation period are listed as the control group. Population density, economic development level, and other variables are listed as control variables. The propensity score matching method is used, and the cross-sectional nearest neighbor matching method is used to find the optimal control group that meets the common support conditions for the smart city pilot. The non common support parts are removed to obtain a new dataset; Continuing with the matching balance test, as shown in Figure 5, the balance test passed; Based on the new dataset, use multi period DID to re estimate the impact of policies. From Table 4, it can be seen that the explanatory variable DID has a significant negative impact on carbon emissions at the

5% level. This result validates the robustness of the benchmark regression results and further demonstrates the robustness of the hypothesis of reducing carbon emissions through the implementation of smart city pilot policies.

5.3.3. Exclude Other Policy Interference

The impact of smart city pilot policies on carbon emissions is process oriented, and in the process of policy implementation and effectiveness, countries and localities may introduce policies with similar goals. In other words, the net effect of smart city pilots may also be affected by energy-saving and emission reduction fiscal policies, low-carbon city pilot policies, and innovative city pilot policies closely related to carbon emissions. The energy-saving and emission reduction policies have been implemented since 2011, and a virtual variable called 'fiscale' is constructed to represent the impact of energy-saving and emission reduction policies; The low-carbon city pilot policy was implemented in 2010, and a dummy variable low_carbon was constructed to represent the impact of the low-carbon city pilot policy; The pilot policy for innovative cities has been implemented since 2008, and a virtual variable 'create' has been constructed to represent the impact of the policy. Table 5 shows the estimated results after excluding energy-saving and emission reducing cities, low-carbon cities, innovative cities, and three types of policy interference. It can be seen that the DID estimation coefficients of the virtual variables for the smart city pilot policy are all negative, and at the 10% level, they can reduce carbon emissions, indicating that the impact of smart cities on carbon emissions in the eastern coastal areas of China is still robust.

Table 5. Regression Results Excluding Other Policy Interference

Variable	Fiscal policies for energy conservation and emission reduction	Pilot policies for low-carbon cities	Pilot policies for innovative cities	Three policies
	lnCO2	lnCO2	lnCO2	lnCO2
DID	-0.100*	-0.108**	-0.083*	-0.117*
	(-1.9479)	(-2.0954)	(-1.9332)	(-1.8794)
fiscal	-0.069			-0.06
	(-1.0539)			(-0.9880)
low_carbon		-0.093*		-0.081
		(-1.9084)		(-1.6030)
creat			-0.083	-0.067
			(-1.6064)	(-1.5227)
control variable	Yes	Yes	Yes	Yes
_cons	-0.948	-0.869	-0.768	-0.812
	(-0.6437)	(-0.6057)	(-0.5248)	(-0.5609)
Urban fixed effects	Yes	Yes	Yes	Yes
Fixed year effect	Yes	Yes	Yes	Yes
sample size	1791	1791	1791	1791
R^2	0.945	0.946	0.946	0.946

Note: * * * represents a significance level of 1%, and the values in parentheses are t-values.

5.4. Heterogeneity Analysis

The previous analysis confirmed the existence of carbon reduction effects in the pilot policies of smart cities. To further investigate whether there are differences in carbon reduction effects among cities with different characteristics, heterogeneity analysis will be conducted on three

ISSN: 2710-0723

types of characteristic samples: city size, urban resource base, and urban economic performance. The results are shown in Table 6.

Table 6. Heterogeneity Analysis Results

Variable	Population size		Resource base		Economic performance	
	Large cities	Small cities	Non resource cities	Resource cities	High GDP	Low GDP
	(1)D11	(2)D12	(3)D21	(4)D22	(5)D31	(6)D32
DID*D1	-0.032	-0.187**				
	(-1.083)	(-2.256)				
DID*D2			-0.171***	0.071		
			(-7.460)	(0.576)		
DID*D3					-0.099***	-0.129
					(-2.981)	(-1.659)
_cons	0.001	1.100	0.330	4.715	-8.112***	6.400***
	(0.001)	(0.503)	(0.371)	(1.599)	(-3.847)	(4.609)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Urban fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Fixed year effect	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	895	895	1,327	464	887	884
R^2	0.926	0.950	0.946	0.965	0.952	0.959

Note: * * * represents a significance level of 1%, and the values in parentheses are t-values.

5.4.1. Heterogeneity Analysis based on City Size

The importance of urban scale is reflected in multiple aspects, not only related to the economic development and social progress of the city, but also affecting regional coordination, resource allocation, and policy-making at multiple levels. This article constructs a population size dummy variable (D1) and divides the sample into two categories, large cities (D11) and small cities (D11), based on the median of the sample. It deeply analyzes the differences in the impact of smart city pilot policies on carbon intensity under population size heterogeneity.

The regression results are shown in columns (1) and (2) of Table 6. The pilot policy of smart cities has a significant carbon reduction effect on small cities, but its impact on large cities is not significant. Possible reasons are that the industrial structure of small cities is relatively single, with low-carbon industries such as light industry and service industry being the main focus. This makes it easier for small cities to optimize and upgrade their industrial structure when promoting smart city construction, thereby reducing carbon emissions; Small cities have a strong drive for technological innovation, and when faced with resource and environmental constraints, they often have a stronger drive for technological innovation. They may be more inclined to adopt new technologies and methods to reduce carbon emissions and improve resource utilization efficiency; Small cities have stronger execution capabilities. When implementing smart city pilot policies, due to their relatively simple management structure and shorter policy transmission chain, they may be easier to achieve rapid response and effective implementation of policies. This allows small cities to enjoy the benefits brought by policies more quickly, including the effectiveness of carbon reduction. In contrast, the industrial structure of large cities is usually more complex and diverse, covering high energy consuming and high emission industries such as heavy industry and energy. These industries may require longer transformation periods and greater investment to promote the construction of smart cities, so the carbon reduction effect may be relatively lagging behind; Although large cities have strong capabilities in technological innovation, due to their large scale and complex systems, new technologies may face more challenges and difficulties in promotion and

ISSN: 2710-0723

application, which may result in less significant carbon reduction effects in smart city construction compared to small cities; Due to their large scale and complex management, large cities may face more challenges and obstacles in the process of policy implementation.

5.4.2. Heterogeneity Analysis based on Urban Resource Base

The urban resource base, as a key element, profoundly affects the resource utilization efficiency and industrial structure layout of economic entities, and thus has a profound impact on the long-term sustainable development of the city. Based on this understanding, this article closely relies on the policy orientation of the National Sustainable Development Plan for Resource based Cities (2013-2020), and divides the research sample into two categories: non resource based cities (D21) and resource based cities (D22). Through this division, this article aims to analyze the heterogeneous impact of smart city pilot policies on carbon emissions in different types of cities from the unique perspective of urban resource base.

As shown in columns (3) and (4) of Table 6, the pilot policy of smart cities has a significant carbon reduction effect on non resource-based cities, but its impact on resource-based cities is not significant. Possible reasons: Non resource cities are often dominated by low-carbon industries such as high-tech and service industries, which have lower dependence on energy and are more likely to adopt energy-saving and consumption reducing technologies. With the promotion of smart city pilot policies, non resource cities can achieve faster optimization and upgrading of industrial structure, improve resource utilization efficiency, and reduce carbon emissions; Non resource cities usually have strong technological innovation capabilities and application levels, which can quickly absorb and transform advanced technologies and management experience of smart cities. By introducing advanced energy-saving technologies, intelligent management systems, etc., non resource cities can achieve significant results in reducing carbon emissions. In contrast, resource-based cities often focus on traditional high energy consuming industries such as heavy industry and energy, which are highly dependent on resources and have high carbon emission intensity. Although the pilot policies of smart cities have also promoted the informatization and intelligence development of these cities to some extent, their carbon emission reduction effects may be relatively limited due to the inherent characteristics of industrial structure; Resource based cities often have a high dependence on natural resources, and the carbon emissions generated during resource extraction and processing are significant. In the implementation of smart city pilot policies, although carbon emissions can be reduced through technological upgrades and management optimization, the emission reduction effect may be relatively limited due to the inherent characteristics of resource endowment.

5.4.3. Heterogeneity Analysis based on Urban Economic Performance

The importance of urban economic performance is self-evident. It is not only a core indicator for measuring a city's development level and comprehensive strength, but also directly related to the quality of life of urban residents, the sustainable development of the city, and its position in global or regional competition. This article constructs a population size dummy variable (D3) and divides the sample into two categories, high GDP cities (D31) and low GDP cities (D32), based on the median of the sample. The aim is to analyze the differences in the impact of smart city pilot policies on carbon intensity from the perspective of urban economic performance.

As shown in columns (5) and (6) of Table 6, the pilot policy of smart cities has a significant carbon reduction effect on high GDP cities, but its impact on low GDP cities is not significant. Possible reasons: High GDP cities usually have a stronger economic foundation and can invest more funds and resources to support the construction of smart cities. These investments may include technology research and development, infrastructure construction, talent introduction, etc., in order to better achieve carbon emission reduction goals; The industrial structure of high GDP cities is often more diversified and advanced, including more low-carbon, green industries

ISSN: 2710-0723

and high-tech industries. These industries have relatively low energy demand and are easier to achieve technological innovation and transformation upgrading, thereby reducing carbon emissions; High GDP cities usually have stronger technological innovation capabilities, able to develop more advanced energy-saving and emission reduction technologies and products, and apply them to actual production. The application of these technologies can significantly improve energy efficiency and reduce carbon emissions. The social awareness of high GDP cities is usually higher, and residents and businesses are more aware of the importance of smart city construction and the urgency of carbon reduction. This kind of cognition helps to promote the active participation of all sectors of society in the construction of smart cities and carbon reduction work, forming a good social atmosphere and driving force. In contrast, low GDP cities may face problems such as funding shortages and technological backwardness, making it difficult to effectively promote the construction of smart cities and their carbon reduction effects; The industrial structure of low GDP cities may be relatively single, dominated by traditional high energy consuming and high emission industries, making it difficult to reduce carbon emissions through industrial restructuring; Low GDP cities may lack sufficient technological innovation capabilities, making it difficult to introduce and digest advanced energy-saving and emission reduction technologies.

In summary, the pilot policies for smart cities have a more significant carbon reduction effect on small cities, non resource-based cities, and high GDP cities. There are different influencing factors hidden in it. In order to enhance the carbon reduction effect of smart city pilot policies in different cities, it is necessary to conduct in-depth research and analysis on these possible influencing factors, and take corresponding measures to improve and perfect them.

5.5. Mechanism Analysis

The results based on the theoretical analysis in the previous text indicate that implementing the pilot policy of smart cities can significantly reduce carbon emissions in the eastern coastal areas of China, and have passed parallel trend and robustness tests. How does the pilot policy of smart cities reduce carbon emissions in the eastern coastal areas of China? What is its mechanism of action? According to the theoretical analysis in the previous text, the pilot policy of smart cities may reduce urban carbon emissions by promoting the improvement of urban technological level and optimizing industrial structure. The mechanism variables of technological level improvement (technological level) and industrial structure optimization (the proportion of the tertiary industry to the regional GDP) are used to empirically analyze the possible effects of the pilot policy of smart cities on suppressing carbon emissions in the eastern coastal pilot areas of China. This section will use the mediation effect model to analyze the mechanism of action. The constructed mediation effect model is as follows:

$$Y_{it} = \beta_0 + \beta_1 DID_{it} + \varphi X_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{3}$$

$$M_{it} = \alpha_0 + \alpha_1 DID_{it} + \delta X_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{4}$$

$$Y_{it} = \gamma_0 + \gamma_1 DID_{it} + \gamma_2 M_{it} + \lambda X_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{5}$$

Where, i and t respectively represent the city and year; Yit represents the dependent variable, which is carbon emissions; DIDit represents the virtual variable of smart city pilot policies, reflecting whether the city has implemented smart pilot policies in the year; Xit is a series of control variables; Mit represents the mediating variables, namely urban technology level improvement (lnst) and industrial structure (str). Urban technology level improvement (lnst)

ISSN: 2710-0723

is represented by the ratio of science and technology expenditure to regional GDP, while industrial structure (str) is represented by the ratio of the output value of the tertiary industry to regional GDP. $\alpha_0, \beta_0, \gamma_0$ are constant terms; β_1 reflects the impact of smart city pilot policies on carbon emissions in pilot cities; α_1 reflects the degree of impact of smart city pilot policies on the improvement of technological level and industrial structure in pilot cities; γ_1 reflects whether there is a mediating effect in the improvement of technological level; γ_2 reflects whether there is a mediating effect in the optimization of industrial structure; μ_i represents the fixed effect of the city; ν_t represents the fixed effect of the year; ε_{it} represents a random perturbation term. The mechanism test results of the pilot policy of smart cities to reduce carbon emissions in the eastern coastal areas of China are shown in Table 7.

Table 7. Mechanism Inspection Results

	(1) lnst	(2) lnCO2	(3) str	(4) lnCO2
DID	0.151*** (0.041)	-0.104*** (-0.018)	0.149*** (0.076)	-0.097*** (-0.018)
lnst		0.040*** (0.011)		
str				0.004*** (0.002)
_cons	-12.184*** (0.957)	2.106*** (0.446)	92.900*** (6.470)	2.014*** (0.452)
Sample size	1791	1791	1791	1791
R^2	0.932	0.949	0.902	0.949
Adjust R^2	0.927	0.945	0.894	0.945
Control variable	Yes	Yes	Yes	Yes
Urban fixed effects	Yes	Yes	Yes	Yes
Fixed year effect	Yes	Yes	Yes	Yes

Note: * * * represents a significance level of 1%, and the values in parentheses are robust standard errors.

5.5.1. Mechanism for Enhancing Technological Level

In column (1) of Table 7, the estimated coefficient of DID is significantly positive, indicating that the smart city pilot policy has significantly increased the expenditure on science and technology, that is, significantly improved the scientific and technological level of the pilot cities. The coefficients in column (2) of Table 7 are all significant, indicating that there is a mediating effect in the improvement of technological level, which suggests that the pilot policies of smart cities can reduce carbon emissions in the eastern coastal areas of China by improving technological level. The pilot policy for smart cities encourages companies, research and development institutions, and universities to innovate by providing policy and financial support, as well as strengthening social participation and public awareness, in order to generally improve the level of technology. The improvement of technological level effectively reduces carbon emissions through the comprehensive effects of promoting low-carbon consumption development, enhancing resource and energy efficiency, promoting regional coordination, and applying advanced carbon reduction technologies. Assumption 2 holds true.

5.5.2. Industrial Structure Optimization Mechanism

The results in column (3) of Table 7 indicate that the pilot policies for smart cities have significantly increased the output value of the tertiary industry and promoted the optimization of the industrial structure. The estimated coefficients in column (4) of Table 7 are all significant, indicating that the pilot policies of smart cities promote the optimization of industrial structure,

ISSN: 2710-0723

thereby reducing carbon emissions in the eastern coastal areas of China. Smart city policies can comprehensively promote industrial structure upgrading, traditional industries can achieve more resource sharing, improve industrial cooperation efficiency, lay the foundation for industrial innovation, promote industrial structure optimization, increase the proportion of the tertiary industry, reduce the consumption of coal resources, and directly reduce carbon emissions. Assumption 3 holds true.

6. Conclusion and Suggestions

This article is based on panel data from 111 prefecture level cities in the eastern coastal region of China from 2006 to 2021, and uses methods such as progressive double difference and PSM-DID to empirically test the impact of smart city pilot policies on urban carbon emissions. The conclusion of this article indicates that the pilot policies for smart cities have significantly reduced the carbon emissions of pilot cities in the eastern coastal areas of China. Heterogeneity analysis shows that the pilot policies of smart cities have a better carbon emission reduction effect on small cities, non resource-based cities, and high GDP cities. Mechanism analysis shows that the pilot policy of smart cities reduces carbon emissions in pilot cities by promoting technological advancement and optimizing industrial structure.

The research conclusion of this article has the following implications for further promoting the pilot construction of smart cities, reducing carbon emissions, and achieving green and low-carbon urban development:

Firstly, adhere to policy guidance and steadily promote urban development. This study shows that the pilot policies of smart cities have significantly reduced the carbon emissions of pilot cities in the eastern coastal areas of China. This discovery emphasizes the importance of smart cities as a sustainable development strategy for cities, especially in the context of addressing global climate change. Therefore, the government should continue to increase its support for the construction of smart cities, promote successful experiences and models, and regard smart cities as one of the main paths to achieve green and low-carbon urban development.

Secondly, based on the characteristics of the city, scientifically and accurately implement policies. The heterogeneity analysis in this article indicates that there is heterogeneity in the carbon reduction effects of smart city pilot policies. Therefore, when promoting the pilot of smart cities, full consideration should be given to the differences in city size and types, and differentiated policy implementation plans should be formulated. For small cities with low population density, attention should be paid to improving urban management efficiency and service levels through intelligent means; For non resource-based cities, emphasis can be placed on developing information technology and green industries; For high GDP cities, it is necessary to further optimize the industrial structure, promote economic transformation and upgrading, and achieve higher quality carbon emissions reduction.

Thirdly, grasp the key mechanisms and adjust the plan reasonably. The mechanism analysis in this article indicates that the pilot policy of smart cities reduces the carbon emissions of pilot cities by promoting technological advancement and optimizing industrial structure. This discovery emphasizes the core role of technological innovation and industrial restructuring in reducing carbon emissions in smart cities. Therefore, in the process of promoting the construction of smart cities, we should increase investment in technological innovation and support the research and application of green and low-carbon technologies; At the same time, we will actively promote the adjustment of industrial structure towards a more low-carbon and environmentally friendly direction, such as developing green industries such as new energy, energy conservation and environmental protection, and reducing dependence on traditional high energy consuming industries. These measures will help establish a sustainable carbon

ISSN: 2710-0723

reduction mechanism and lay a solid foundation for achieving green and low-carbon development in cities.

Acknowledgments

This research was supported by Anhui University of Finance and Economics Student Innovation and Entrepreneurship Training Programme Project (202310378120).

References

[1] Dong Yanting, Wang Luo zhong. Smart City Construction and Urban Public Service Level: A Quasi Natural Experiment Based on Smart City Pilot Projects [J]. Urban Issues, 2021, (10): 56-64.

[2] Ge Liyu, Yu Jingyuan. Smart City Construction and Urban Carbon Emissions: Verification Based on Digital Technology Empowerment Path [J]. Technological Progress and Countermeasures, 2022, 39 (23): 44-54.

[3] He Xiaogang, Gai Jiahui. The Road to Intelligent Low Carbon: The Carbon Reduction Effect of Smart Cities [J]. Chinese Economics, 2022 (04): 154-180+292-294.

[4] Huang Heping, Xie Yunfei, Li Ning. Does the construction of smart cities promote low-carbon development-- Quasi natural experiment based on national smart city pilot [J]. Urban Development Research, 2022, 29 (05): 105-112.

[5] He Weijun, Li Wenqin, Deng Mingliang. Human capital, green technology innovation, and total factor carbon emission efficiency of the Yangtze River Economic Belt [J]. Technological Progress and Countermeasures, 2022, 39 (09): 23-32.

[6] Li Handong, Xiang Zihang, Cui Xuefeng. Prediction of China's carbon emission intensity driven by population factors [J]. Journal of Beijing Normal University (Natural Science Edition), 2023, 59 (05): 822-829.

[7] Li Shan, Zhan Yong. Research on Carbon Emission Reduction Effect of Smart City Construction from the Perspective of Industrial Transformation and Upgrading [J]. Journal of Shanghai University of Finance and Economics, 2022, 24 (05): 3-18+107.

[8] Li Shu. Spatial econometric analysis of regional carbon emission intensity and its influencing factors in China [D]. Beijing Jiaotong University, 2019.

[9] Liu Jianqiang, Ma Xiaoyu. Population aging, industrial structure upgrading, and carbon emissions: spatial econometric analysis based on the STIRPAT model [J]. Finance and Economics, 2021, (07): 54-62.

[10] Liu Lijuan. The impact of smart city construction on carbon emissions [J]. Technology and Industry, 2023, 23 (23): 93-103.

[11] Qi Ji, Yi Yanchun, Cheng Pei, Geng Yixin. The impact of smart city construction on air quality: a quasi natural experimental study [J]. Secretary, 2023, (01): 25-35.

[12] Shi Daqian, Ding Hai, Wei Ping, Liu Jianjiang. Can the construction of smart cities reduce environmental pollution? [J]. China Industrial Economy, 2018, (06): 117-135.

[13] Su Jie, Liu Mingjie. The Impact of Smart City Construction on Carbon Emission Performance [J]. China Management Informatization, 2023, 26 (03): 181-184.

[14] Wang Family, Wang Xinyi. Research on the Impact of Smart Cities on Low Carbon Economic Development: Evidence from Chinese Prefecture level Cities [J]. Shanghai Urban Management, 2023, 32 (02): 16-26.

[15] Wang Yali, Hou Linqi, Zhu Jinhe. Can Urban Innovation Help the Development of Low Carbon Economy - Evaluation and Mechanism Analysis of the Impact of Innovative City Pilot Policies on Carbon Intensity [J]. Science and Technology Progress and Countermeasures, 2022, 39 (18): 39-49.

[16] Wang Jun, Yu Zhiwen. How environmental decentralization affects the carbon emission intensity of cities: based on urban heterogeneity analysis[J]. Journal of Beijing Institute of Technology (Social Sciences Edition), 2023, 25 (03): 41-52.

ISSN: 2710-0723

[17] Xu Yangping. Research on the Impact of Smart City Construction on Low Carbon Development [D]. Zhejiang University of Science and Technology, 2022.

[18] Yang Su, Wang Wenting. Research on the Impact of Smart City Pilot Policies on Urban Safety Level: A Perspective Based on Regional Heterogeneity [J]. China Safety Production Science and Technology, 2023, 19 (01): 169-175.

[19] Yu Desheng, Wang Shujie. The impact of smart city construction on corporate green innovation: an empirical study based on quasi natural experiments [J]. Journal of Natural Sciences, Hunan Normal University, 1-12.

[20] Zhang Bingbing, Chen Siqi, Cao Lijuan. Is the city low-carbon due to 'smart'-- Exploration of Pilot Policies for Smart Cities [J]. Economic Review, 2022, (06): 132-149.

[21] Zhang Rongbo, Zhong Changbiao. Smart City Pilot, Pollution Transfer and Green Low Carbon Development -- New Evidence from Chinese Counties [J]. China Population, Resources and Environment, 2022,32 (04): 91-104.

[22] Zhang Youzhi, Wang Jingyi, Xia Pengfei, Liu Yinke. Research on the Impact of Smart City Construction on Carbon Emissions [J]. Journal of Xi'an Petroleum University (Social Sciences Edition), 2023, 32 (05): 27-36.

[23] Zhang Zhengyan, Li Yuxin. Research on the Impact of Digital Economy on Carbon Emissions in China [J]. Financial Theory and Practice, 2022, 43 (05): 146-154.

[24] Liu K, Meng C, Tan J, et al. Do Smart Cities Promote a Green Economy? Evidence from a Quasi-experiment of 253 Cities in China [J]. Environmental Impact Assessment Review. 2023, 99:107009.

[25] Liu Y, Li Q, Zhang Z. Do Smart Cities Restrict the Carbon Emission Intensity of Enterprises? Evidence from a Quasi-Natural Experiment in China [J]. Energies. 2022, 15(15):5527.

[26] Ma Z, Wu F. Smart City, Digitalization and CO2 Emissions: Evidence from 353 Cities in China[J]. Sustainability. 2023, 15(1):225.

[27] Pang B, Fang C L, Liu H M. Quantitative Study on the Dynamic Mechanism of Smart Low-Carbon City Development in China [J]. Sustainability. 2016,8(6):507.

[28] Qian L, Xu X, Zhou Y, Sun Y, et al. Carbon Emission Reduction Effects of the Smart City Pilot Policy in China[J]. Sustainability. 2023, 15(6):5085.

[29] Song T, Dian J, Chen H. Can Smart City Construction Improve Carbon Productivity? -A Quasi-natural Experiment Based on China's Smart City Pilot [J]. Sustainable Cities and Society. 2023, 92:104478.

[30] Wang L, Xie Q, Xue F, et al. Does Smart City Construction Reduce Haze Pollution [J]. International Journal of Environmental Research and PublicHealth, 2022, 19(24):16421.

[31] Wu SP. Smart Cities and Urban Household Carbon Emissions: A Perspective on Smart City Development Policy in China [J]. Journal of Cleaner Production, 2022, 373:133877.

[32] Xue F, Zhou M, Liu J. Are Cities Saving Energy by Getting Smarter? Evidence from Smart City Pilots in China[J]. Sustainability, 2023, 15(4):2961.

[33] Yigitcanlar T, Kamruzzaman M. Does Smart City Policy Lead to Sustainability of Cities[J]. Land Use Policy, 2018,73:49-58.

[34] Zhang E, He X, Xiao P. Does Smart City Construction Decrease Urban Carbon Emission Intensity? Evidence from a Difference-in-Difference Estimation in China [J]. Sustainability. 2022, 14(23):160 97.