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Can Low-Carbon City Pilot Policies Reduce Environmental Pollution? Evidence From Prefecture-Level Data in China

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Abstract

Based on the second batch of low-carbon city pilot policies in 2013 as a quasi-natural experiment, this study adopts the panel data of 212 cities in China from 2007 to 2017, and uses the difference-in-differences model (DID) to carry out a policy evaluation of the pollution reduction and emission reduction effects of the low-carbon pilot policies and further analyzes the transmission mechanism. Based on the DID method, the actual impacts of the government's low-carbon call policy and low-carbon governance policy on the urban ecological environment are examined. It is found that compared with non-pilot cities, low-carbon governance construction in low-carbon pilot cities significantly reduces pollutant emissions in the region. Analysis of the transmission mechanism reveals that urban low-carbon governance strengthens the strength of environmental policies and reduces urban carbon and pollutant emissions through the low-carbon treatment of urban waste and the low-carbon industrial structure. The test of regional heterogeneity found that the effect of pollution reduction and emission reduction is more significant in the eastern cities, high population concentrated cities and more economically developed cities. The results are still significant after replacing the explanatory variables with sulphur dioxide content and excluding extreme outliers. Therefore, the emission reduction policy has a significant contribution to improving the urban environment and reducing pollution emissions.

Keywords

Low-carbon pilot cities, difference-in-differences, pollution reduction and emission reduction.

1. Introduction

Reducing pollution and emissions is an important way and inevitable requirement for today's China to achieve its 100-year modernisation goal and achieve the modernisation of its ecological civilisation.In September 2020, President Xi Jinping delivered an important speech at the 75th session of the UN General Assembly, stating that China will increase the strength of its national autonomous contribution, adopt stronger policies and measures, and that carbon dioxide emissions will strive to peak in 2030, which means that there will be no further increase in the total carbon volume. China will also endeavour to achieve carbon neutrality by 2060. Efforts will be made to achieve carbon neutrality by 2060, which means that carbon emissions and carbon treatment will be offset together to achieve zero carbon dioxide emissions. China is speeding up the process of green reform with energy saving and emission reduction as the primary goal, and many positive incentives and negative penalties have been piloted intensively, among which low-carbon pilot policies aiming at low energy consumption and low pollution have attracted much attention. In order to achieve the goal of ecological civilisation modernisation, the National Development and Reform Commission (NDRC) has detailed the objectives and set up three batches of low-carbon pilot provinces and cities to explore a series of effective and replicable low-carbon policies or actions, which are of great significance in

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mitigating the increase in China's carbon emissions and achieving the goal of low-carbon development. In this context, empirical research on the practical effects of low-carbon pilot policies is of great theoretical and practical significance for promoting the construction of low-carbon cities and promoting the construction of ecological civilisation.

The first batch of low-carbon pilot policies were established in 2010, when the NDRC identified eight cities and five provinces as the first batch of low-carbon pilots. Then in 2012 and 2017, the second and third batch of pilot lists were announced respectively. Currently, there are 6 low-carbon provinces and 81 low-carbon cities in the country, including 24 pilot cities in the east, 18 in the centre and 17 in the west. The location of pilot cities is more evenly distributed, with at least one low-carbon pilot city in each of the 31 provinces, municipalities and autonomous regions on the mainland. The selection of pilot cities is based on a strict declaration and approval system, whereby each prefecture-level city puts forward a specific low-carbon development plan, combining its implementation plan, low-carbon construction foundation and pilot city layout, with NDRS and provincial development and reform commissions determining the preliminary list, and then carrying out on-site appraisals of the preliminary list, organising expert reviews and finally determining the list of pilots. From the practical meaning of this policy, the low-carbon pilot policy integrates the development concept of "innovation, coordination, greenness, openness and sharing" into urban construction, which not only becomes a "testing ground" for testing climate change policies, but also injects new vitality into the innovative development of cities. Currently, China's economy is in a critical period of transforming its kinetic energy and realising green development, and the implementation of low-carbon pilot policies is an important result of pollution reduction and emission reduction. However, waste reduction and carbon reduction measures to reduce emissions of three wastes is only a superficial goal, and its deeper goal is to optimise the ecological environment, so that China's economy can step into a new era of sustainable green development, and to achieve innovation-driven development.

This paper intends to use the data of 212 prefecture-level cities in China from 2007 to 2017 to comprehensively analyse the impact of low-carbon pilot policies on carbon emissions, and air pollution prevention. Scholars have studied low-carbon pilot policies from multiple perspectives, such as eco-efficiency, foreign direct investment, and corporate science and technology innovation, which provide methodological reference and ideological guidance for this study. However, domestic and international studies have rarely analysed the environmental quality benefits of low-carbon pilot city policies, such as reducing carbon emissions, dust reduction and water pollution. As the first batch of pilot cities started earlier, the first batch of pilot cities were removed, and also two cities with missing data were removed, a total of 22 pilot cities were retained, and the rest of the 190 control sample cities with more complete sample size data values were used as the research object of this paper. Therefore, this paper carries out an empirical study on the second batch of low-carbon pilot cities by double-difference method to analyse the relationship between low-carbon pilot city policies and urban waste reduction and carbon reduction so that this study has more theoretical value and practical significance. Achieving low-carbon urban development is the leading direction of future urban development. The essence of urban low-carbonisation is not only to reduce carbon dioxide emissions and improve the neutralisation capacity of urban carbon sequestration, but also to reduce pollutant emissions and develop a green economy.

2. Literature review

The document of NDRC indicates that the fundamental purpose of the pilot low-carbon city policy is to control greenhouse gas emissions, and the primary goal of the low-carbon policy is to reduce carbon, in fact, the carbon-reducing effect of the low-carbon policy has been

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researched and confirmed by many scholars[1]. Sholpanet [3] based on the study of the local energy consumption structure and the consumption of water resources in Kazakhstan, found that the local government based on the low-carbon policy of Water resource planning and utilization is important for resource managers and policy makers to design lower carbon ecosystem management plans and strategies in the face of climate change. The maintenance of the ecological environment relies on human green low-carbon lifestyle and production methods, and existing foreign studies are more consistent that urban decarbonization development has a significant positive effect on reducing the level of environmental pollution and improving the level of urban health. Among them, Sun and Wang researched that the low-carbon city policy has a significant air pollution effect in the center city of transportation hub [4]. Deng et al. (2022) constructed an eco-efficiency model using a spatial Durbin double difference model to explain that the low-carbon pilot policy has a positive local effect on the pilot eco-efficiency and a positive spillover effect on the eco-efficiency of neighboring cities错误!未找到引用源。. Song et al. (2019) utilized panel data from 119 prefecture-level cities and with the help of the double difference method, found that the construction of low-carbon cities significantly reduces PM10 and API pollution indices and improves urban air quality. Zhang(2020) found that low-carbon city pilot policies help reduce regional carbon emissions[6]. Similarly, Wang and Shi (2019) found that low-carbon city construction significantly reduced PM2.5 concentration. Tian et al. likewise utilized the second batch of low-carbon city pilots to empirically analyze the panel data of 202 Chinese cities from 2012 to 2016 using the propensity score matching-double difference method, and found that the construction of low-carbon cities significantly improves the performance of carbon emissions[9]. In fact, not limited to the ecological field, the economic spillover effect of low-carbon pilot policies is also significant[11]. Chen et al. (2019) use the second batch of low-carbon city pilots and find that low-carbon city construction significantly enhances green total factor productivity[12]. Gong et al. (2019) take foreign direct investment as the research object, using panel data of 197 Chinese cities from 2004 to 2015, and find that low-carbon city construction significantly promotes foreign direct investment[13]. Closely related to this study is the literature on the assessment of the policy effects of low-carbon city building[14]. Most of the existing literature focuses on carbon emissions, air pollution or other economic and technological dimensions, such as foreign direct investment, science and technology technological progress, the literature on the assessment of the policy effects of low-carbon city construction provides important ideas and deep insights for this study, which provides ideas for this study's research[17].

At the same time, this study also focuses on the problem of estimation bias caused by the non-random selection of low-carbon pilot cities. In a practical sense, it provides empirical evidence for further expanding the pilot scope of low-carbon cities, as well as a scientific basis for the state to improve the environmental policy of carbon emission reduction[20]. The findings of this study show that the construction of low-carbon cities has achieved the expected effect of pollution reduction and emission reduction, thus responding to this skepticism, and the future environmental policy should pay more attention to the sustainability of the policy effect[23]. Realizing the decarbonization of urban development is the leading direction of future urban development[26]. The essence of urban decarbonization is not only to reduce carbon dioxide emissions and improve the city's ability to neutralize carbon sequestration, but also to reduce pollutant emissions and develop a green economy[27],[28].

3. Policy context and research hypotheses

3.1. Policy context for low-carbon pilot city development

In July 2010, the NDRC issued the Notice on the Pilot Work of Low-Carbon Provinces, Regions and Cities ("Notice"), identifying eight cities in five provinces in China as the first batch of low-

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carbon pilot provinces and cities. In April 2012, in order to further promote the construction of low-carbon pilot cities, the NDRC expanded the scope of the pilot cities and identified the second batch of provinces and cities. According to the requirements of the Notice, the creation of low-carbon pilot cities includes the following five aspects: preparation of low-carbon development plans, formulation of relevant supporting policies for low-carbon development, construction of low-carbon emission industrial systems, establishment of greenhouse gas emission statistics and management systems, and promotion of low-carbon green lifestyles and consumption. Combined with the tasks of creation, it can be seen that the construction of low-carbon pilot cities will be combined with the adjustment of industrial structure, quality and efficiency improvement, energy saving and consumption reduction, and a series of work will be carried out so as to improve the level of carbon emission performance.

3.2. Mechanism analysis

Based on the general background and policy context of low-carbon city pilot construction, it is argued that low-carbon pilot city construction integrates the application of planning, engineering, technology and legal and other administrative means. As a development mode of low-carbon pilot city construction, the pilot city may reduce the level of pollutant emissions through the innovation and application of clean technology, the transformation and upgrading of industries to low-pollution and low-energy consumption, and policy constraints. Through the above analyses, the mechanism of the impact of pilot low-carbon city construction on the reduction of pollutant emissions will follow below logic.

3.2.1. Low-carbon pilot, industrial structure, air pollution

The low-carbon pilot policy affects the industrial structure of the city, and the upgrading of the industrial structure is one of the priorities in the creation of pilot cities. The Notice explicitly states that it is necessary to "establish an industrial system characterized by low carbon and develop modern service industries". With the gradual deepening of the pilot policy, high-energy-consuming, high-polluting industries bear higher environmental costs, these industries are forced to withdraw or relocate, to the new manufacturing and service industries will be based on the new industry will get a huge space for growth. Low-carbon city construction can improve air quality by improving the structure of industrial industries and promoting the upgrading of industrial structure. Low-carbon pilot policies enhance the operational efficiency of industries and reduce various costs in industrial production activities by formulating and improving relevant supporting facilities for low-carbon development, such as improving the construction of corresponding infrastructure. The essence of resource allocation is the efficient transfer of factors of production between different sectors, and good urban infrastructure will enhance the operational efficiency of industries and avoid the waste of resources, thus effectively reducing the level of pollutant emissions.

3.2.2. Low-carbon pilot, municipal waste treatment, air pollution

Low-carbon pilot policies have affected the way and efficiency of urban waste disposal, with a direct impact on urban air. Northern cities have a longer heating period because of the lower temperatures after winter, which requires the use of large amounts of coal resources during the heating period, while the ratio of organic matter to combustible matter remaining in southern cities is substantially higher than in northern cities. Currently, there are three main ways of treating municipal waste, namely landfilling, incineration and resource utilization. Among them, direct landfilling has the lowest eco-efficiency and causes the most serious pollution to the atmosphere, which not only causes waste of resources and greenhouse gas emissions, but also increases the economic cost of the whole recycling process. Therefore, landfill and incineration are the most uneconomical and environmentally harmful disposal methods for society as a whole. The treatment of domestic waste in the city is still dominated by incineration, which also produces a large amount of harmful gases, especially the

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incineration of plastic products will produce highly toxic gases, which contain certain carcinogenic gases that have already polluted the atmosphere, such as the ozone layer appeared in the hole, the ultraviolet rays directly to the human skin and infected with skin epidemics. Winter heating in the northern region to coal as the main fuel, but since the implementation of the low-carbon pilot policy, the development of heating technology and equipment heating mode of diversification, heating energy structure has also seen some changes. At present, gas, oil, potential for heating energy heating area in the year-on-year increase in coal, gas, oil, electricity, etc. constructed heating energy structure is becoming more reasonable, to a certain extent, to alleviate the combustion of carbon dioxide and the formation of harmful gases. It can be seen that the implementation of low-carbon policy can effectively carry out the industrial transformation, and the traditional way of municipal waste disposal has been greatly improved, making municipal waste disposal more low-carbon, more reasonable and more in line with the policy requirements.

Synthesizing the above discussion and analysis, from the perspective of low-carbon pilot policy, this study puts forward three basic research hypotheses.

Research hypothesis 1: Low-carbon city construction can reduce the level of environmental pollution in the city and realize pollution reduction and emission reduction.

Research hypothesis 2: Low-carbon city construction can reduce the level of environmental pollution in the city through industrial structure upgrading.

Research hypothesis 3: Low-carbon city construction can reduce the level of environmental pollution in the city by optimizing the way of urban waste disposal and improving the waste disposal rate.

4. Research models and data

4.1. Samples and data

The NDRC announced eight cities and five provinces as low-carbon pilot areas in 2010; the first pilot areas were province-based, and the impact of the pilot policy on cities within the province was uneven. The second low-carbon pilot policy is city-based, and in the process of pilot city selection, the layout planning of the pilot cities is fully considered, and the study is better represented. Secondly, because the research period of this paper is 2007-2017, the policy implementation effect of the third batch of low-carbon pilot cities in 2017 is not considered, so this paper mainly examines the effect of the second batch of low-carbon pilot policies in 2012. Accordingly, this paper excludes the eight cities and the prefecture-level cities under the jurisdiction of five provinces, and excludes the two experimental groups of Da Xinganling District and Ji Yuan City due to the incomplete sample size, and finally, we select the panel data of 212 prefectural-level and above cities from 2007-2017 in this paper. The economic data in this paper comes from China Urban Statistical Yearbook, China Environmental Statistical Yearbook and the statistical yearbook of each city.

5. Modeling

The purpose of this study is to assess the impact of the low-carbon city pilot policy on urban pollution reduction and abatement. Since the first low-carbon pilot was mainly for the provincial level and the third low-carbon pilot was implemented later and was not put into the experimental group, the second low-carbon city pilot policy in 2012 was used as a quasi-natural experiment. By comparing the differences in urban environmental pollution between the experimental group (pilot area) and the control group (non-pilot area) before and after the low-carbon pilot policy, factors that do not change over time and are unobservable are eliminated, so as to reasonably assess the disposal effect of the low-carbon pilot policy. This study intends

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to adopt the double difference method, which is more maturely applied in the field of policy evaluation, for the design of the benchmark model. The multi-period DID model is set as:

$$pollution = \beta_0 + \beta_1 treat_i * post_t + \beta_2 X_{it} + u_i + v_t + \varepsilon_{it} \quad (1)$$

In Eq. (1), i and t denote the city and year respectively; pollution represents the level of environmental pollution; treat is a grouping dummy variable, which takes the value of "1" if the city is a low-carbon pilot city and "0" otherwise; post is a time dummy variable, which takes the value of "1" in the year after the promulgation of the low-carbon pilot policy, and "0" otherwise; treat*post is a DID term; X is a control variable; ε is the random error.

5.1. Air pollution levels.

This study draws on the way of constructing the environmental quality index in the Technical Specification for Evaluation of Ecological Environmental Conditions to construct the air pollution index. The environmental quality index refers to the load of pollutants in the evaluated area, which is used to reflect the pressure of environmental pollution on the evaluated area. With the process of industrialization and urbanization, a large amount of industrial "three wastes" and domestic and agricultural surface sources have caused the pollution of land and water resources, and the problem is becoming more and more serious. The ecosystems have retaliated against mankind in different ways in response to this coercion.

$$\text{Pollution} = (0.4*SO_2 + 0.4*\text{COD} + 0.2*\text{SOD})/\text{population} \quad (2)$$

Where SO_2 is the sulphur dioxide emissions, COD is the sewage discharges from the city, and SOD is the industrial soot emissions, they were assigned different weights to construct the air pollution variable pollution.

5.2. Low-carbon city pilots.

The core explanatory variable in this study is the double difference term treat * post, which is the interaction term between the grouping dummy and the time dummy.In December 2012, NDRS established 29 cities and provinces to become the second batch of low-carbon pilots, among which Wuhan, Guangzhou, Yan'an, and Kunming overlap with the first batch of low-carbon pilots, and removing the missing values of the Daxing'anling area and the city of Jiyuan, so that the 22 second batch of low-carbon cities constitute the experimental group, and other cities constitute the control group. The experimental group treat = 1 and the control group treat = 0. Given that the second batch of low-carbon pilot policies was enacted in December 2012, post = 1 for years 2013 and after; post = 0 for years prior to 2013. The official documents for the second batch of pilot cities were issued on November 26, 2012, and required that by December 31, 2012 to submit the revised pilot program to the NDRC again. The timing of the implementation of the second batch of pilot cities is disputed in the literature because it is close to the end of the year. Considering the possible lag in the implementation of the policy, the empirical test part of this study defines the implementation time as 2013, and uses 2012 as the robustness test.

5.3. Other variables.

This study controls for other variables that may affect air pollution in urban areas: (1) per capita gross domestic product (pgdp), expressed as the ratio of the city's real gross domestic product to the city's total population; (2) population (popu), expressed as the logarithm of the city's year-end population; (4) the level of openness to the outside world (fdi), calculated by using the unit of gdp for foreign direct investment; (5) the level of income (income) is expressed in logarithmic terms using per capita income; (6) consumption level (consumption) is expressed in terms of social retail income. Details are in Table 1 below:

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Table 1: Description of variables and results of descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max.
pollution	2331	35222.895	67797.805	0	2105978.2
did	2333	.047	.212	0	1
pgdp	2333	4.425	13.544	0	642.176
fdi	2333	.308	.421	0	11.476
Income	1476	9.741	.318	8.713	10.689
consume	2,333	9.272	.779	6.195	11.352
water	2326	8.706	8.779	0	131.15
elec	2284	6.851	12.141	0	252.008
meiqi	2,135	3.315	6.035	0	163.819
invest	2119	.742	.293	.028	3.618
green	2333	15.009	22.028	0	295.199

6. Empirical results and analysis

6.1. Benchmark regression

Low-carbon pilot city construction provides a good quasi-natural experiment for improving and managing environmental pollution, and this study examines and assesses the impact of low-carbon pilot policies on urban environmental pollution using the DID model. In Table 2, model (2) and model (3) reflect the regression with the addition of relevant control variables to examine the impact of low-carbon pilot city construction on exhaust emissions. The estimation results show that the construction of low-carbon pilot cities significantly reduces the city's exhaust emissions, regardless of whether the corresponding control variables are added or not, and whether the control variables of income category are added or not. Regarding the economic significance of the estimated coefficients for the pilot low carbon cities, given all other things being equal, the environmental pollution value of the pilot low carbon cities is reduced by an average of 1.7% compared to the non-pilot cities. According to the data statistics, the environmental pollution of the sample cities (taking the human mean) is 2.38%. Regarding the estimation results of the control variables, the paper is interpreted with the estimated values of the entire sample of cities in column (2) of Table 2. The estimated coefficient of the level of foreign openness is significantly less than 0, indicating that the level of foreign openness has an inhibitory effect on environmental pollution. Before the implementation of the low-carbon policy, the result of opening up characterized by low-end industrialization inevitably brought about environmental degradation and ecological damage; however, as the level of opening up to the outside world is further increased, its negative effect on the environment enters an inflection point, and the industrial structure adjustment effect and technological upgrade effect brought about by opening up to the outside world moderates and inhibits the further deterioration of the environment. Further expanding China's openness to the outside world, changing the mode of economic development, and adjusting the industrial structure are effective means to deal with the environmental pollution problem. The coefficient of economic development level is significantly negative, indicating that with the improvement of economic development level, environmental pollution is getting more and more attention from the government and the general public, and the implementation of necessary green economic policies can effectively reduce pollution and emission. The green space per capita measures the urban population urban green space system planning, from the low-carbon thinking, put forward to update the urban green space system planning concept, and on this basis, put

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forward the corresponding optimization strategy, in order to enhance the resilience of the urban green space system, and promote the sustainable renewal and development of the city.

Table 2 Benchmark regression

	(1)	(2)	(3)
	pollution	pollution	pollution
did	-0.0169*	-0.0238*	-0.2886*
	(-1.83)	(-1.82)	(-1.86)
fdi	-0.0930	-0.064**	-0.0180
	(-1.31)	(-2.32)	(0.55)
pgdp	-28.88	-23.053**	-19.377*
	(-1.09)	(-2.54)	(-1.80)
green	-0.0520	-0.0380	0.065**
	(-1.31)	(-1.57)	(2.28)
Income	286.598**	146.177*	1.154
	(1.98)	(1.79)	(0.01)
consume	-0.0370	0.061*	
	(-0.99)	(1.89)	
invest	0	0.000**	0.000***
	(-0.50)	(2.49)	(3.38)
Constant	-1400	-291.0	960.2
	(-1.03)	(-0.38)	(1.05)
Time fixed effect	be	be	be
Area fixed effect	be	be	be
Observed value	1298	1298	1298
R-squared	0.887	0.8330	0.7170

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6.2. Robustness tests

6.2.1. Replacement of the dependent variable

This study benchmark regression in the dependent variable for environmental pollution-related indicators, but environmental pollution in this study focuses on the object of atmospheric pollution pollution sources are more airborne sulfur dioxide content. Therefore, this study wants to unit economic sulfur dioxide emissions as another way of presenting atmospheric pollution. As can be seen from the model 1 in Table 3, treat * post coefficients are negative and significant at the 10% level, so the pilot policy of low-carbon cities is conducive to reducing environmental pollution, and its conclusions are reliable and robust.

6.2.2. counterfactual

To further test the robustness of the estimation results, this study adds low-carbon cities in 2013 and 2014 to the regression sample in order to test the robustness of low-carbon city construction affecting environmental pollution. The estimation results show that low-carbon city construction still significantly reduces the level of environmental pollution. All signs and significance are not significantly different from the previous paper, indicating that the conclusions of this study are relatively robust.

This study adopts the counterfactual test to confirm the robustness of the previous results, specifically, the policy implementation time is assumed to be one year ahead of time, and

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regression is carried out respectively, and the regression results are shown in Table 3, Model 2, which shows that the low-carbon pilot policy at the virtual point in time does not promote the improvement of urban eco-efficiency, proving that the previous regression results are reliable.

6.2.3. Shrinkage treatment

In order to exclude the interference of outliers, the highest and lowest 5% samples of the explanatory and control variables are subjected to the reduced-tail method in this study, and the results are shown in Table 3.

Table 3 Robustness test

	(1)	(2)	(3)
	pso2	pollution	ppollution
did	-0.0288*	0.0144**	-0.0194
	(1.553)	(1.7033)	(1.851)
fdi	0.0183	-0.0638**	0.0339
	(0.0329)	(0.0279)	(0.0334)
green	0.0649**	-0.0387	0.0511*
	(0.0284)	(0.0240)	(0.0292)
elec	-6.89e-05*	0.000160***	-0.000114**
	(4.11e-05)	(3.48e-05)	(4.55e-05)
water	-0.000770	-0.00512***	-0.00567**
	(0.00190)	(0.00160)	(0.00243)
Income	1.154	135.9	0.00255
	(98.40)	(83.38)	(0.00352)
consume	0.0612*	0.0276	-83.51
	(0.0323)	(0.0274)	(105.0)
meiqi	0.00504*	-0.00394	0.0457
	(0.00295)	(0.00249)	(0.0339)
pgdp	-19.38*	-23.18**	-20.25*
	(10.77)	(9.103)	(11.52)
invest	1.16e-05***	7.40e-06**	2.35e-05***
	(3.44e-06)	(2.90e-06)	(4.07e-06)
constant	960.2	-221.1	1,771*
	(918.1)	(778.0)	(980.7)
Time fixed effect	YES	YES	YES
Area fixed effect	YES	YES	YES
Observed value	1,298	1,298	1,197
R-squared	0.025	0.041	0.042

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6.3. Mechanism testing

The above empirical results show that the low-carbon pilot policy significantly reduces the environmental pollution of the pilot city, and how its specific mechanism is yet to be analyzed. According to the previous analysis, the low-carbon pilot policy mainly affects the urban ecology through the industrial structure effect and the urban waste disposal rate, in order to examine

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the mechanism of the low-carbon city pilot policy on carbon emissions, this study refers to Song et al. (2019), and sets the following econometric model.

$$M_{it} = \alpha_0 + \alpha_1 treat_i * post_t + \alpha_2 X_{it} + u_i + v_t + \varepsilon_{it} \quad (3)$$

Where i and t denote the city and year respectively; M denotes the mechanism variables, i.e., the low-carbon city pilot policy affects carbon emission through these variables, and X denotes a set of control variables, including per capita income, per capita consumption, regional economic development level, FDI, unit economic fixed asset investment level, per capita green space area, unit economic resource consumption, etc. Regarding the selection of mechanism variables, this study, based on the analysis of the theoretical mechanism in the previous section, selects two types of variables to measure the mechanism variables M. These two types of variables are as follows: ①structural effects, this study will be structural effects measured by industry, i.e., the proportion of the secondary industry in the total output value of gdp. (ii) Municipal waste treatment is measured by the rate of harmless treatment of domestic waste. The harmless treatment rate of domestic garbage, data from China Urban Statistical Yearbook and China Environmental Yearbook. The regression results of the impact mechanism of the pilot policy on environmental pollution in low-carbon cities are presented in Table 4. Among them, it can be seen from columns (3) and (4) that the impact of low-carbon city pilot policy on per capita electricity consumption and total electricity consumption is negative and passes the 1% significance level test, which indicates that low-carbon city pilot policy can significantly reduce environmental pollution. The essence of modern industrial structure upgrading brought by low carbon policy is to change the economic growth mode and economic growth power, capital-intensive and knowledge-intensive gradually replace the labor-intensive economic growth mode, and investment-driven and innovation-driven become the power of modern economic growth. In the past decade, the gradual development of technology-intensive industries with high-tech as the core has significantly reduced the intensity of environmental pollution. The optimization and upgrading of economic structure has eased the pressure of environmental pollution, and started to control and eliminate pollution-intensive secondary industries, and the focus of development has shifted to tertiary industries centered on modern service industry and high-tech, and the industrial structure has evolved towards rationalization and advancement. The scale ratio of different industries determines the output volume and types of various pollutant emissions, and the generation of environmental pollution is closely related to the change of industrial structure, the adjustment of industrial scale and the change of industrial development rate.

From columns (1) and (2), it can be seen that cities with low-carbon policy pilots are 1.2% more efficient in urban waste disposal than cities without low-carbon pilots, indicating that the better the implementation of low-carbon policies, the more conducive it is to promoting the efficiency of urban waste disposal, and the more it can reduce the emission of urban pollutants, which verifies hypothesis three.

Table 4 Mechanism tests

	(1)	(2)	(3)	(4)
	hjgz	pollution	Cyjg	Pollution
did	0.0117*	-0.0240*	-0.0766***	-0.0224*
	(0.64)	(13.12)	(0.21)	(12.88)
hjgz		-0.0745		
		(1.18)		
Cyjg				0.0205***
				(2.60)
Control variable	YES	YES	YES	YES

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Time fixed effect	YES	YES	YES	YES
Area fixed effect	YES	YES	YES	YES
Observed value	1296	1295	1298	1299
R-squared	0.143	0.155	0.187	0.266

t statistics in parentheses

* p<0.1, ** p<0.05, *** p<0.01

6.4. Heterogeneity test

Since different locations of cities have large differences in economic development, this study is divided into three sub-samples based on geographic location in the east, center, and west for the heterogeneity test. The results, as shown in columns (1)-(9) in Table 5, show that the effect of urban low-carbon governance is relatively significant in eastern cities, cities with relatively high levels of economic development, and cities with relatively high population concentration. The reason for this is that most of the eastern cities are in the middle and late stages of industrial transformation and upgrading, with rapid development of high-tech industries, and the ecological and environmental protection governance has already achieved a certain degree of success, so they tend to increase low-carbon transformation and energy-saving and emission reduction under the low-carbon constraints to promote the high-quality development of the economy. Secondly, the earliest implementer of the garbage classification policy, Shanghai Municipality, the scientific classification of garbage is the basis of garbage reduction, harmlessness and resource treatment. Garbage classification is a part of the circular economy, and scientific garbage classification and treatment can effectively reduce land occupation, reduce environmental pollution, and improve the efficiency of resource utilization. Meanwhile, from the perspective of economic development level and population, it is found that the policy effect is more obvious in areas with high economic development level and population concentration. Western cities generally have a lower level of green economic development, and thus respond more sensitively and quickly to low-carbon governance policies, and the marginal effect of low-carbon governance policies on western cities is stronger. On the other hand, most of the cities in central China are dominated by high-pollution heavy industry development mode, which results in a long-term "carbon lock-in" effect and makes it difficult to transform and upgrade the industrial structure, thus leading to the insignificant effect of low-carbon governance policies. Secondly, because of the small sample size of western cities, the findings may not be representative.

Table 5 Heterogeneity test

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	eastern	central	western	developed	moderate	less developed	agglomeration of populations	moderate	thinly populated
did	-0.0471***	0.0491	0.0411	-0.0649***	0.0153	0.0701	-0.0253**	-0.0171	0.0324
	(-2.77)	(0.19)	(1.24)	(-2.89)	(0.58)	(0.11)	(-2.13)	(-0.80)	(0.25)
cons	733.1	483.9	-995.6	-900.0	3090	720.6	1028.160***	932.150***	935.557***
	(0.50)	(0.30)	(-0.56)	(1.42)	(0.44)		(8.27)	(8.53)	(8.76)
control variable	YES	YES	YES	YES	YES	YES	YES	YES	YES
area fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES

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Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES	YES
N	388	552	356	310	432	552	673	645	564
r2 a	0.6501	0.9402	0.6507	0.1847	0.5143	0.2670	0.8130	0.6370	0.7612

t statistics in parentheses

* p<0.1, ** p<0.05, *** p<0.01

7. Conclusions and insights

Using the panel data of 212 prefecture-level cities from 2007 to 2017, this study measures the effect of low-carbon pilot policies on environmental pollution using a multi-period DID model with low-carbon pilot policies as the policy shock, and analyzes the path of its impact with the help of the mediation effect test model. The findings of the study include the following four main points: 1. The low-carbon pilot policy has a positive promotion effect on pollution reduction and emission reduction in the pilot cities. This suggests that the low-carbon pilot policy not only promotes the reduction of pollutants in low-carbon cities, but also promotes economic growth and improves eco-efficiency through the "industrial upgrading effect". 2. The low-carbon pilot policy reduces pollutant emissions and improves eco-efficiency through the industrial structure effect and the municipal waste treatment effect. This further indicates that the low-carbon pilot policy forces the transformation and upgrading of industries, especially the transformation and upgrading of high-pollution and high-energy-consumption industries, which reduces pollutant emissions; in terms of industrial structure, the low-carbon cities optimize the industrial structure through the development of the service industry and guiding the transfer of polluting enterprises, which improves the eco-efficiency.3 The results of the heterogeneity analysis indicate that the pollutant emissions reduction and mitigation effects of the low-carbon pilot policy, in descending order, are as follows: Eastern region>Central region>Western region, which is determined by the size of the economy and population, the larger the economy and population size of the region, the stronger the dependence on resources, the weaker the marginal effect of the low-carbon pilot policy; the low-carbon pilot policy only in the eastern region has produced a significant spillover effect, and the regional integration process in the eastern region is faster than in other regions, which suggests that the higher the level of urban agglomeration, the more This indicates that the higher the level of urban agglomeration, the more favorable to play the role of low-carbon pilot policy in reducing pollution and emission.

The findings of this study have important implications for the management of environmental pollution in China. First, promote the construction of low-carbon cities. The results of the study show that there is a more significant inhibition effect of low-carbon policies on the pollution problems of pilot cities, indicating that low-carbon pilot policies should continue to be promoted as an important means of achieving energy conservation and emission reduction, transforming the mode of growth, and promoting the construction of ecological civilization in China, and that in the context of the increasingly close regional economic ties, the overall layout and planning of low-carbon pilots should be taken into account to give full play to the spatial "pollution halo effect", contributing to the realization of China's commitment to carbon emission reduction. Second, industrial structure upgrading is crucial to environmental pollution reduction. Accelerate industrial transformation and upgrading, and realize the replacement and transformation of traditional manufacturing industries and the development of high-tech industries. The central and western regions are gradually eliminating backward production capacity and accelerating the transformation and upgrading of high-pollution and high-energy-consuming industries; the eastern regions need to further develop high-tech

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industries and strive to promote the industrial chain to the middle and high end, so as to reduce environmental pollution through the upgrading of industrial structure. Thirdly, it is important to pay attention to urban garbage pollution, and improving the garbage disposal rate is of great significance to the discharge of environmental pollutants, which is an inevitable choice for achieving significant results in the prevention and control of environmental pollution and realizing efficient and high-quality economic development.

References

[1] C.J. Liu, Z.B. Zhou, Q. Liu, et al. Can a low-carbon development path achieve win-win development: evidence from China Can a low-carbon development path achieve win-win development: evidence from China's low-carbon pilot policy, Mitigation and Adaptation Strategies for Global Change, vol. 25 (2019), 1199-1219.

[2] T. Feng, Z.G. Lin, H.B. Du, et al.Does low-carbon pilot city program reduce carbon intensity? Evidence from Chinese cities, Research in International Business and Finance, vol.58(2021), 101450.

[3] S. Saimova, G. Makenova, A. Skakova, et al. Towards a low-carbon economic sustainable development: scenarios and policies for kazakhstan, International Journal of Energy Economics and Policy,vol.10(2020), 638-646.

[4] X.T. Sun, Z.H. Wang. Can Chinese families achieve a low-carbon lifestyle? An empirical test of china's low-carbon pilot policy, Frontiers in Energy Research,vol.9(2021),655733.

[5] Q. Sun, Q.S. Wu, J.H. Cheng, et al. How Industrialization Stage Moderates the Impact of China's Low-Carbon Pilot Policy, Sustainability, vol.12(2020),10577.

[6] R.R. Deng, A.X. Zhang, M. Chen. The impact and spillover effects of low-carbon pilot policies on ecological efficiency: an empirical analysis based on spatial double difference, Research World, vol.1(2022), 38-47.

[7] H. Song, Y.J. Sun, D.K. Chen. Evaluation of the Effect of Government Air Pollution Control: An Empirical Study from the Construction of "Low Carbon Cities" in China, Management World, vol.35(2019), 95-108+195.

[8] H. Zhang. Can pilot low-carbon city policies reduce carbon emissions? --Evidence from a quasi-natural experiment, Economic Management, vol.42(2020), 25-41.

[9] H.X. Wang,D.Q. Shi. Does new urbanization help alleviate haze pollution - empirical evidence from low-carbon city construction, Journal of Shanxi University of Finance and Economics, vol.41(2019), 15-27

[10] Y.P. Tian, W.J. Song, M. Liu. An assessment of how environmental policy affects urban innovation: Evidence from China's low-carbon pilot cities program, Carbon Pilot Cities Program, Economic Analysis and Policy, vol.71(2021),41-56.

[11] Q.Q. Wei. Explaining the emergence of low carbon forerunner cities based on the interaction effects of different governance processes: a case study of China's low carbon pilot, Carbon Management, vol.12(2021), 81-92.

[12] N. Chen, G.Y. Zhuang. Assessment of the effectiveness of low-carbon pilot cities in China, Urban Development Research, vol.25(2018), 88-95+156.

[13] M.Q. Gong, H.Y. Liu, X. Jiang. A study on the impact of China's low-carbon pilot policy on foreign direct investment, China Population-Resources and Environment, vol.29(2019), 50-57.

[14] Z.Y. Chen, G. Yang, X.W. Bow. Analysis of the impact of carbon trading price on closed-loop supply chain decision-making under low-carbon policy, Practice and Understanding of Mathematics, vol.51(2021),1-9.

[15] Y.L. Yao, X.Y. Shen. Environmental protection and economic efficiency of low-carbon pilot cities in China, Environment, Development and Sustainability,vol.1(2021), 1-24.

[16] M.M. Hu, J.B. Wu, S.Y. Shi, et al. Research on eco-efficiency of municipal construction waste treatment - A case study of Chongqing, Construction Economy,vol.37(2016),82-87.

ISSN: 2710-0170

[17] X.C. Hu, Z.H. Zhen. Resourceful treatment of municipal waste in environmental protection, Resource Conservation and Environmental Protection, vol.38(2022), 38-40+44.

[18] C.C. Liu, J.Z. Wu. Toward Carbon Neutral Low Carbon Policy Development of UK Government and Enterprises, International Petroleum Economics, vol.29(2021), 83-91.

[19] J. Lu, X.F. Wang. The impact of low-carbon pilot policy on technological innovation in Chinese cities-a quasi-natural experimental study based on low-carbon city pilots, Journal of China University of Geosciences (Social Science Edition), vol.19(2019), 128-141.

[20] J. Xu, J.B. Cui. Low-carbon city and enterprise green technology innovation, China Industrial Economy, vol.12(2020), 178-196.

[21] J. Peng, J. Li, Y. Ding. Analysis of the impact and mechanism of low-carbon city pilot policy on environmental pollution, Urban Issues,vol.10(2020), 88-97.

[22] J. Qian, Q. Zhang. Systematic analysis of low-carbon economic transition and low-carbon policy planning in China, China Soft Science, vol.04(2011), 22-28+21.

[23] Provincial Department of Housing and Urban-Rural Development. Accelerating the construction of waste incineration power generation facilities to improve the efficiency of harmless treatment of domestic waste. (Jilin Daily), 2013-07-30 (015).

[24] W.G. Wang, X.L. Wang. Analysis of energy saving and emission reduction policy of China's high energy consumption enterprises based on evolutionary game, Research on Financial Issues, vol.04(2012), 75-82.

[25] D.Z. Zhao,C.G. Wang. Research on supply chain enterprises' emission reduction decision-making considering low-carbon policy, Industrial Engineering, vol.17(2014), 105-111.

[26] C.B. Zhong, D.M. Hu, Y.Z. Huang. Assessment of green innovation effects of low-carbon pilot policies - An empirical study from data of Chinese listed companies, Science and Technology Progress and Countermeasures, vol.37(2020), 113-122.

[27] G.F. Zhuang. The logic of policy design for pilot low carbon cities in China, China Population-Resources and Environment, vol.30(2020), 19-28.

[28] D. Zhou, F.N. Zhou, X.Q. Wang . Impact assessment and mechanism analysis of low-carbon pilot policies on urban carbon emission performance, Resource Science, vol.41(2019), 546-556.