The Effect of Low Carbon on Urban Economy: Romer Model and Empirical Evidence

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Abstract:

We investigate the relationship between carbon emissions and the economy, focusing on the environmental and economic conditions of cities in China. The research is conducted within the framework of low-carbon city pilot policies, aiming to determine whether city economies in China are growing, declining, or exhibiting a "U-shape" pattern under low-carbon circumstances. A sample of 29 cities, including municipalities and provincial capitals, was selected from the period between 2011 and 2016. Using regression analysis, we examine the negative correlation between GDP and carbon emissions and total industrial sulfur dioxide emissions. Additionally, we find a positive association between GDP and park green area. The robustness of our findings is confirmed through Budget Revenue tests. Furthermore, Difference-in-Differences (DID) testing reveals the positive impact of control variables on the two main variables under investigation.

Keywords: Low-carbon pilot programs•Urban economy•Romer model•Empirical evidence

Introduction

The relationship between carbon reduction and its impact on the economy has been a topic of considerable research interest. Prior studies have demonstrated the effectiveness of environmental innovation in reducing emissions. (Zhang et al., 2017) Moreover, a quasi-natural experiment analyzing a low-carbon city pilot policy using "difference-in-differences" analysis has revealed that low-carbon governance can stimulate economic growth. (Wei & Gu, 2021) Against the backdrop of the growing low-carbon economy, our research aims to investigate the connection between low-carbon measures and the economic landscape through various tests. While previous studies have predominantly focused on the influence of digital and low carbon-related factors on the economy, it is important to recognize that economic growth and environmental governance outcomes may differ for cities pursuing low-carbon goals. Thus, conducting a comparative analysis between pre- and post-policy implementation periods will offer valuable insights into the relationship between low-carbon policies and the economy.

As global emissions to the atmosphere rise to approximately 51 billion tons of greenhouse gases, leading to global warming, low carbon has been considered a crucial factor for better human living conditions worldwide. On June 22, 2016, 175 countries participated in the high-level signing rite of the Paris Agreement. The agreement would be ratified on November 4, 2016, which determined the promise of controlling the temperature increase within two ˚C.

China, as the second largest economy in the world, announced the goal of controlling greenhouse gas emissions to impetus a community of shared destiny for mankind. On June 6, 2013, the conference was held to announce the first "National Low Carbon Day," with the slogan "Practice energy conservation and low carbon and construct our beautiful homelands." The establishment of this festival helped to popularize the knowledge of climate change as well as low-carbon ideas and policies. At the same time, Shenzhen initiated and became the first carbon trading market in China, along with the assignment as the low-carbon pilot city, further demonstrating the importance of the low-carbon goal.

Carbon-related factors have been studied to discover the extent of the environmental impact. Alam and Murad focus on the use of renewable energy resources in developing countries around the world in terms of cooperation to test for the impact on economic growth, trade, and technical advancement, which helps to find out that international trade can boost the use of renewable resources in the long run, which accordingly decrease the consumption of carbon. (Alam & Murad, 2020)trade openness and technological progress on renewable energy use in Organization for Economic Co-operation and Development (OECD Focusing on the second patch of pilot cities in China explores the internal relations between the low-carbon policy and the level of environmental pollution. (Wang, 2022) Besides, Sun explores the intensity of carbon emission, which turns out to be the level of economic development, industrial structure, urbanization, and government intervention.

These factors contribute to the decline of carbon emission intensity, which may appear to alleviate the situation of global warming. (Sun & Huang, 2022)
At the same time, plenty of related studies include the economic outcomes in the discussion of carbon perspectives. The digital economy positively influences carbon emission performance but is further found to undergo a "U" curve development. (Yang et al., 2022) The dualistic effect of the digital economy on the urban economy is also proved from the perspectives of technological advancement and structural transformation. (Gao et al., 2023) At the same time, Lin Shen (2014) chose Wuhan city to study the connections between carbon emission and GDP per capita to the Kuznets Curve respectively, explaining the sustainable growth of a low-carbon city is a process of an "inverted U shape" curve. (Lin, 2014) However, previous documentary research has neither put comparatively more attention on the factor and the new goal of low carbon nor has combined Romer theory (1986) for derivation and experimentation, leading to fewer field-related studies.
Our paper focuses on the study of the environmental and economic conditions of cities in China in the context of related low-carbon city pilot policies. This research has innovated in several sections, which brings greater significance to in-depth acknowledgment and research of low carbon along with the research methods.
Our contribution is demonstrated in a renewed perspective: Firstly, our paper provides a new theoretical interpretation or perspective for Romer's theory by modifying the environmental factors in the equations to low carbon factor, which can better help to establish the link between low carbon and economic growth in the research. Secondly, our paper uses models to build up the relationship between the variables. Integrating low carbon as an important part of Romer's endogenous growth model can help explore the specific relationship between the factor of low carbon and economic advance. Lastly, our paper expands the contribution of exploring the low-carbon economy using empirical linear or non-linear regression testing. Studies in the past have concentrated on or merely used linear regression test models to figure out related conclusions. Still, this paper considers both linear regression and non-linear regression while determining the relationship between low carbon and the economy.

Theoretical Model

Production Function

Introducing environmental quality into the production function and assuming that environmental quality ρ(t) is a necessary condition for output, the production function Y(t) in the economy depends on the stock of knowledge used in the productive sector A(t)LM, the capital stock k(t) and the environmental quality ρ (t), assuming that the total amount of labor is equal to the total population and is constant. The production function is of Cobb-Douglas form, considering the time-continuous case and omitting the subscript t: $Y = F(k, AL_M, \rho) = Bk^{\alpha}\left(AL_M\right)^{\beta}\rho^{1-\alpha-\beta}$
where B, α, and β are positive constants, and α and β respectively denote the shares of k an ALM contributions to output growth.

Capital Accumulation

Investment can be divided into two types: one directly increases the capital stock, and the other is used to improve the quality of the environment. Thus, expenditure consists of three components: consumption c, capital accumulation, and environmental investment E. There is a relationship between environmental investment and capital stock: E=ak, where a ∈ (0,1), is the share of environmental investment in the capital stock, and without considering depreciation, capital accumulation is as follows:
$\dot{k} = Y - c - E$

Knowledge Accumulation

Romer (1986) argues that the R&D sector generates new product designs, and the increase in new capital goods can become new production requirements. Hence, the number of new designs created by the R&D sector reflects the level of technology, and its inputs include human capital and existing knowledge accumulation. Thus, the knowledge production function is as follows:

$$\dot{A}(t) = \delta A(t)L_A = \delta A(t)(1-\theta_M)L$$

In the formula, A(t)represents the level of knowledge accumulation at time t, and A(t)is the rate of change of knowledge stock. LA is the labor input in the R&D sector, δ is the normal number representing the productivity parameter; θM = LM/L is the proportion of labor input in the production sector, where LA + LM = L.
Environmental Quality
Assuming that the quality of the environment is affected by only two factors, the ability of the environment to purify itself and human production activities, the environmental constraint equation can be defined as:

$$\dot{p} = \theta_p - ZY$$

where θ ∈ (0,1) denotes the self-cleaning ability of the environment, and ZY denotes the pollution of the environment.
Environmental protection investment and technological

progress can reduce the pollution of the environment by production, and it can be seen that Z is determined by E (= ak) and A. We may assume that Z = a0m(a,k, A), which, by the above analysis, requires m(•) to be a decreasing function, where a0∈(0,1). For ease of calculation, assume that:

$$m(a,k,A)=\alpha^{-\alpha_1}A^{-\alpha_2}k^{-\alpha_3},\alpha_1,\alpha_2,\alpha_3\in(0,1)$$

Thus, the environmental constraint equation is:

$$\dot{p}=\theta_p-ZY=p-a_0\alpha^{-\alpha_1}A^{-\alpha_2}k^{-\alpha_3}Y$$

Maximizing Consumer Utility

Suppose the consumer's utility function is $U(c)=(c^{1-\sigma}-1)/(1-\sigma),\sigma\in(0,1)$, then the representative infinite-life consumer utility function can be defined as:

$$\int_0^\infty U(c)e^{-\rho t}dt=\int_0^\infty[(c^{1-\sigma}/(1-\sigma)]e^{-\rho t}dt$$

Where ρ is the discount factor. Under the above assumptions, there is the following dynamic optimization problem:

$$\begin{cases} Max\int_0^\infty U(c)e^{-\rho t}dt \\ s\cdot t\cdot\dot{k}=Y-c-ak \\ A(t)=\delta\dot{A}(t)(1-\theta_M)L \end{cases}$$

We construct the Hamiltonian function as follows:

$$H=U(c)+\lambda_1(Y-c-ak)+\lambda_2(\delta A(1-\theta_M))+\lambda_3(\theta_p-ZY)$$

Where k, A, and p are state variables, c, θM, and a are control variables, and λ1, λ2, and λ3 are shadow prices of physical capital, knowledge accumulation, and environmental quality, respectively. According to the optimization first order condition:

$$\begin{cases} \frac{\partial H}{\partial c}=c^{-\sigma}-\lambda_1=0 \\ \frac{\partial H}{\partial c}=\lambda_1\frac{\partial H}{\partial\theta_M}-\lambda_2\delta LA-\lambda_3 Z\frac{\partial Y}{\partial\theta_M}=0 \\ \frac{\partial H}{\partial c}=-\lambda_1 k-\lambda_3 Y\frac{\partial Z}{\partial a}=0 \\ \rho\lambda_1-\dot{\lambda}_1=\lambda_1\left(\frac{\partial Y}{\partial k}-a\right)-\lambda_3(Y\frac{\partial Z}{\partial k}+Z\frac{\partial Y}{\partial k}) \\ \rho\lambda_2-\dot{\lambda}_2=\lambda_1\frac{\partial Y}{\partial A}+\lambda_2\left(\delta(1-\theta_M)L\right)-\lambda_3(Y\frac{\partial Z}{\partial A}+Z\frac{\partial Y}{\partial A}) \\ \rho\lambda_3-\dot{\lambda}_3=\lambda_1\frac{\partial Y}{\partial p}+\lambda_3(\theta_M-Z\frac{\partial Y}{\partial p}) \end{cases}$$

We use g_x to represent the growth rate of some variable x, i.e., $g_x=\frac{\Delta x}{x}$. Assuming steady-state growth in consumption, physical capital, human capital, and environmental quality, the equilibrium can be solved for with $g_c, g_k, g_A, and g_p$ as constants:

$$g_k=g_c=g_Y=\frac{[\beta-(1-\alpha-\beta)\alpha_2]}{(1-\alpha-\beta)\alpha_3+\beta}\delta LA(1)$$

$$g_p=\frac{[\beta-(1-\alpha_3)-\alpha_2(1-\alpha)]}{(1-\alpha-\beta)\alpha_3+\beta}\delta LA(2)$$

Two conditions must be met to maintain sustainable economic growth: (1) the rate of economic growth, g_Y, must be positive, and (2) the quality of the environment cannot decline indefinitely as the size of the economy increases. Since the economy has a minimum requirement for environmental quality, the growth rate of environmental quality, g_p, cannot be negative. Assume that $\delta LA>0$ according to equation (1):

$$g_Y=\frac{[\beta-(1-\alpha-\beta)\alpha_2]}{(1-\alpha-\beta)\alpha_3+\beta}\delta LA>0\rightarrow\alpha_2<\frac{\beta}{1-\alpha-\beta}(3)$$

Equation (3) shows that if the contribution of technology in environmental governance, α_2, is less than the relative contribution of technology to environmental quality in material production, $\frac{\beta}{1-\alpha-\beta}$, then the national economy can achieve sustained growth.

Assuming that $\delta LA>0$, the condition for sustainable economic growth can be deduced from equation (2):

$$g_p=\frac{\beta-(1-\alpha_3)-\alpha_2(1-\alpha)}{(1-\alpha-\beta)\alpha_3+\beta}\delta LA\geq 0$$

To reach a more concise conclusion, we can assume that environmental investment, capital stock, and the contribution of technology to environmental quality improvement are scale-invariant, i.e., with $\alpha_1+\alpha_2+\alpha_3=1$, the condition for sustainable economic growth is:

$$\frac{\alpha_1}{\alpha_2}=\frac{1-\alpha-\beta}{\beta}(4)$$

Equation (4) indicates that if the relative contribution of environmental investment to technology in environmental governance, $\frac{\alpha_1}{\alpha_2}$, exceeds the relative contribution of environmental quality to technology in material production, $\frac{1-\alpha-\beta}{\beta}$, then the national economy can achieve sustained growth.

Since the production function and equation $Z = a_0 m(a,k,A) = a_0 a^{\alpha_1} A^{\alpha_2} k^{\alpha_3}$ are scale-invariant, Eqs. (3) and (4) show that realizing sustainable economic growth under environmental constraints consists of two paths: first, increasing the efficiency of environmental protection investment and improving the contribution of environmental protection investment to the improvement of environmental quality; second, promoting the accumulation of knowledge stock to improve the role of science and technology in production.

Research Design

Data sources

Our research includes 29 cities consisting of municipalities and provincial capitals. The time interval of the sample is between 2011 and 2016. The reasons are that: firstly, the data integrality started in 2011; secondly, setting the first release of National Low Carbon Day in 2013 as the event for the DID experiment helps to determine the time intervals of 2011-2016. As the low-carbon pilot policies were released in the middle of the year 2013, we consider the start of the policy in 2014. Data sources are from the cities' statistical yearbooks, the National Bureau of Statistics website, China Emission Accounts and Datasets (CEADs), and Peking University Open Research Data.

Variable definitions

I. Dependent variables

There are two urban economic indicators used as dependent variables in this passage, which are GDP and general public budget revenue, which help to reflect the general economic condition of the cities considered in our research.

GDP, known as gross domestic product, is the total value of goods and services produced in a country in a given period, usually one year. (Chen, 2013)climate change and other global environmental issues have attracted wide attention from governments and academic circles. Numerical simulation and attribution techniques prove that the increase in global mean temperature in recent years is likely to be caused by excessive anthropogenic increase in greenhouse gas concentration, and the reliability of the conclusion is above. Therefore, the most direct means to mitigate climate change is to control greenhouse gas emissions. Among the six greenhouse gases, carbon dioxide has the greatest effect on the greenhouse effect, and carbon dioxide has a high contribution rate to the greenhouse effect. Studying the influencing factors of carbon dioxide emissions is of great practical significance for how to develop low-carbon economy, formulate reasonable and feasible emission reduction policies and strategies, and cope with climate change.\n\nThis paper attempts to study the relationship between technological progress, carbon emission and energy consumption. Using the annual panel data of China's provinces, cities and autonomous regions, the panel threshold model is constructed with energy consumption as the threshold variable to explore the nonlinear relationship between technological progress, carbon emissions and energy consumption in China. The study found that economic growth, economic structure and energy consumption lead to the increase of carbon emissions; independent research and development had no significant impact on carbon emissions; the introduction of foreign technology reduced carbon emissions; and there was a threshold effect among technological progress, carbon emissions and energy consumption; the positive effect of technological progress on carbon emissions gradually decreased with the increase of energy consumption. In addition, this paper also uses the Kuznets curve theory to study the form of China's carbon dioxide Kuznets curve, and analyzes the deep relationship between China's carbon dioxide emissions and economic growth in the short and long term. The results show that China's carbon dioxide Kuznets curve is \"\" curve, the inflection point value is trillion yuan, China is still in the rising stage of the Kuznets curve, and there is a trend of accelerated growth of carbon dioxide emissions. In the short term, when the gross regional product of each province or autonomous region is less than 100 million yuan, the carbon dioxide emission will increase with the increase of economic level. When the regional GDP exceeds 100 million yuan, it increases with the economic level.\nIn addition, the increase rate of carbon dioxide emissions has further accelerated; However, in the long run, when the total regional product of provinces and autonomous regions reaches one trillion yuan, carbon dioxide emissions may gradually decrease and the environment can be improved.\n\nFinally, the paper gives corresponding policy suggestions: (actively develop modern service industry, gradually change from industry to service, constantly reduce the energy consumption level of economic development, and effectively promote the development of low-carbon economy.

General public budget revenue is part of the revenue retained after allocating central and provincial fiscal revenues. (Li, 2022)and steady urbanization is a key way to achieve balanced development between urban and rural areas and among different regions, and a strong support for accelerating socialist modernization. The opportunities and challenges of urbanization construction in our country, our country's realistic problem is based on the huge population urbanization, there is no precedent for reference, not copying of foreign modes, must be in accordance with the requirements of the \"much starker choices-and graver consequences-in\” and \”difference\”, based on basic national conditions in China, respect the law, to control the direction, actively promote the human-centered new urbanization. Xi jinping comrades in the party’s 19 big report that \”the future of the coordinated development of big and medium cities and small towns and urban landscape in urban agglomeration as the main body\”, the main body of urban agglomeration has become a new urbanization pattern, healthy development of urban agglomeration is the powerful guarantee to improve the bearing capacity of regional resources and environment, the pearl river delta urban agglomeration is currently one of the highest level of urbanization in our country, Its urbanization rate has reached nearly 86% (by the end of 2020

II. Independent variables

There are three urban low-carbon indicators used as independent variables in the article, which are also known as ecological and environmental factors and can be divided into two categories: ecological environmental endowment and ecological, environmental pressure. The indicator of ecological environmental endowment is the park green area; the indicators of ecological environmental pressure include carbon emission and total industrial sulfur dioxide emissions.

Carbon emission is the amount of greenhouse gas emissions during the stages of production, transportation, use, and recycling of the product. Park green area means the urban park green area. (Li, 2022)and steady urbanization is a key way to achieve balanced development between urban and rural areas and among different regions, and a strong support for accelerating socialist modernization. The opportunities and challenges of urbanization construction in our country, our country’s realistic problem is based on the huge population urbanization, there is no precedent for reference, not copying of foreign modes, must be in accordance with the requirements of the \”much starker choices-and graver consequences-in\” and \”difference\”, based on basic national conditions in China, respect the law, to control the direction, actively promote the human-centered new urbanization. Xi jinping comrades in the party’s 19 big report that \”the future of the coordinated development of big and medium cities and small towns and urban landscape in urban agglomeration as the main body\”, the main body of urban agglomeration has become a new urbanization pattern, healthy development of urban agglomeration is the powerful guarantee to improve the bearing capacity of regional resources and environment, the pearl river delta urban agglomeration is currently one of the highest level of urbanization in our country, Its urbanization rate has reached nearly 86% (by the end of 2020

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Total industrial sulfur dioxide emissions mean the amount of sulfur dioxide that is released into the atmosphere by enterprises during the processes of fuel combustion and production. (Gao et al., 2023)

III. Control variables

The total output value of foreign-invested enterprises is the total market value of all the products and services created by an enterprise within a specific time of period. (Li, 2022)and steady urbanization is a key way to achieve balanced development between urban and rural areas and among different regions, and a strong support for accelerating socialist modernization. The opportunities and challenges of urbanization construction in our country, our country’s realistic problem is based on the huge population urbanization, there is no precedent for reference, not copying of foreign modes, must be in accordance with the requirements of the \”much starker choices-and graver consequences-in\” and \”difference\”, based on basic national conditions in China, respect the law, to control the direction, actively promote the human-centered new urbanization. Xi jinping comrades in the party’s 19 big report that \”the future of the coordinated development of big and medium cities and small towns and urban landscape in urban agglomeration as the main body\”, the main body of urban agglomeration has become a new urbanization pattern, healthy development of urban agglomeration is the powerful guarantee to improve the bearing capacity of regional resources and environment, the pearl river delta urban agglomeration is currently one of the highest level of urbanization in our country, Its urbanization rate has reached nearly 86% (by the end of 2020

The number of students enrolled in ordinary universities is the number of students who attend universities in the region with ordinary full-time student status. (Wang, 2022)

The total amount of imports and exports of goods is the total monetary amount of actual exported and imported commodities in a country or a region during a specific period of time, which is also presented as the sum of exports and imports of goods in the same period. (Zhu, 2023)as the world’s largest foreign trade exporter and carbon emitter, China is facing an increasingly severe and complex foreign trade environment, especially green barriers may weaken China’s trade competitiveness. At present, China’s foreign trade development is facing greater internal and external pressure and constraints, we should pay close attention to foreign policy trends and its short-term and long-term impact. In fact, the green and low carbon transformation of China’s foreign trade is an inevitable requirement, but it is not accomplished overnight, and it is necessary to guard against improper \”transformation risks\”. A country’s foreign trade competitiveness depends on a country’s overall industrial system, especially the green and low-carbon development strength of foreign trade exports, which is increasingly subject to the formulation of international rules. At present, it is urgent to accelerate the establishment of a comprehensive and high-quality green trade system. On the one hand, we should base on the long-term and current reality, improve the incentive and compatible policy system and supporting measures for green trade, actively, steadily and orderly promote green production, green trade, green consumption and technical cooperation, and continue to optimize the foreign trade structure and target market. On the other hand, it is necessary to participate in global climate governance, strengthen global cooperation, deeply participate in the formulation of global norms and technical standards for green trade, and strive for favorable development space.”,”container-title”:”Economic Management”,”DOI”:”10.15891/j.cnki.cn62-1093/c.20230309.003”,”language”:”Chinese”,”page”:”216-224”,”title”:”Exploring the path of green and low-carbon transformation of China’s foreign trade”,”author”:[{“family”:”Zhu”,”given”:”Dan”}],”issued”:{“date-parts”:[[“2023”,3,13]]}}}],”schema”:”https://github.com/citation-style-language/schema/raw/master/csl-citation.json”}

TABLE 1: VARIABLE DEFINITIONS

Variable name	English shortend form	Definition
GDP	GDP	The total value of goods and services produced in a country in a given period of time, usually one year.
General public budget revenue	Budget_Rev	The part of the revenue retained after the allocation of central and provincial fiscal revenues.
Carbon emission	Carbon	The amount of greenhouse gas emissions during the stages of production, transportation, use and recycling of the products.
Park green area	Green_Area	The urban park green area.
Total industrial sulfur dioxide emissions	SO2	The amount of sulfur dioxide that is released into the atmosphere by enterprises during the processes of fuel combustion and production.
Total output value of foreign-invested enterprises	FIE_Outcome	The total market value of all the products and services created by an enterprise within a specific period of time.
Number of studnets enrolled in ordinary universities	Univ_Student	The amount of students who attend in universities in the region with ordinary full-time student status.
Total amount of imports and exports of goods	Total_Im_Ex	The total monetary amount of actual exported and imported commodities in a country or a region during a specific period of time, which is also presented as the sum of exports and imports of goods in the same period.

Model Setup

I. Linear regression mode

In order to focus on the impact of low-carbon policies and measures on economic development, our research sets up the linear regression model as shown below: $Y_{it} = \alpha_0 + \alpha_1 Carbon_{it} + \Sigma_k \alpha_k Controls_{kit} + \mu_i + \delta_t + \epsilon_{it}$ (1)

In equation (1), Y_{it} is the explained variable of our research, including GDP and general public budget revenue. (Budget_Rev) $Carbon_{it}$ represents the carbon-related indicators, including carbon emission, park green area, and total industrial sulfur dioxide emissions, which are the explained variables in our essay. α_1 helps to measure the extent of the effect of low-carbon policy measures on the cities on an environmental and economic level. If α_1 is negative at 1% significance, it shows that the carbon-related factors exert a negative impact on economic growth and vice versa. $Controls_{kit}$ is a series of control variables that demonstrate the city features, including the total output value of foreign-invested enterprises, the number of students enrolled in ordinary universities, and the total amount of imports and exports of goods; α_0 is the intercept; α_1 and α_k are the estimated coefficients of the variables; μ_i is the city-fixed effect; δ_t is the time-fixed effect, and ϵ_{it} is the random error term.

II. DID model

DID, known as Difference-in-Differences, is a statistical technique and quasi-experimental design that analyses the data from the treated and control groups with a provision of causal inference about a specific intervention or treatment. (Columbia University Mailman School of Public Health, 2016) It works by finding the constant difference in outcome between the intervention group and the control group to reveal the corresponsive effect of the variable assigned.

In our research, we set up DID testing for the purpose of finding out the impact of control variables on the dependent variables. The equation is shown below:

$$Y_{it} = \alpha_1 + \beta_1 D_{it} + \gamma_1 Controls_{kit} + \mu_i + \delta_t + \epsilon_{it} \quad (2)$$

In equation (2), I represent the city; t represents the year; Y_{it} represents the explained variables of our research, including GDP and general public budget revenue ;(Budget_Rev) D_{it} indicates the state of pilot cities in China; $Controls_{kit}$ is a series of control variables that demonstrate the city features, including the total output value of foreign-invested enterprises, number of students enrolled in ordinary universities, and the total amount of imports and exports of goods; β_1 is the estimated impact of low-carbon policies towards carbon emission and other sources of pollution; μ_i is the city-fixed effect, δ_t is the time-fixed effect, and ϵ_{it} is the stochastic disturbance term.

Empirical Results

Descriptive statistics

For independent variables, the mean and median of carbon emission are 71.543 and 58.624, respectively. The mean and median of the park green area are 87618.545 and 3914.000, respectively. The mean and the median of total industrial sulfur dioxide emissions are 87168.545 and 67923.500, respectively. For dependent variables, the mean and median of GDP in billion are 0.685 and 0.521, respectively. The mean and median of general public budget revenue are 845.969 and 444.688, respectively.

For control variables, the mean and median of the total output of foreign-invested enterprises are 1957.240 and 575.548, respectively. The mean and median of the number of students enrolled in ordinary universities are 487614.244 and 465144.000, respectively. The mean and median of the total amount of imports and exports of goods are 526.918 and 140.403, respectively. These figures are all displayed in TABLE 2.

TABLE 2: DESCRIPTIVE STATISTICS

Variable	N	Mean	SD	P10	Median	P90
GDP	180	0.685	0.573	0.071	0.521	2.818
Budget_Rev	180	845.969	1083.938	45.247	444.688	6406.130
Carbon	180	71.543	47.141	4.095	58.624	207.634
SO2	180	87168.545	86194.643	593.000	67923.500	531340.000
Green_Area	180	6520.348	6359.814	853.000	3914.000	30069.000
FIE_Outcome	180	1957.240	3127.709	16.609	575.548	15114.352
Univ_Student	180	487614.244	236688.014	58661.000	465144.000	1057281.000
TOL_Im_Ex	180	526.918	1017.000	8.156	140.403	4666.223

Note: This table summarizes the statistics of the variables in the time span from 2011 to 2016, which constructs a sample of data of 180 observations due to the appearance of a specific low-carbon event released in 2013. All variables are defined in TABLE 1.

Baseline Regression

I. GDP

TABLE 3 indicates the result of the regression of GDP as the dependent variable, in which the city and year are controlled to explore the effect. Panel A presents the relationship between GDP, as the dependent variable, and carbon, as the independent variable, which has a negative coefficient near zero, as well as a T value between -0.4 and 0.8. R-squared are all greater than 0.6. Panel B chooses GDP and Park Green Area as the dependent variable and independent variable, respectively, to indicate the implication, which has all results of coefficients in low positive figures at approximately 0.5. The R-squared values are all greater than 0.78. Panel C chose GDP and total industrial sulfur dioxide emissions as the dependent variable and independent variable, respectively, to indicate the implication, which turns out to have a relatively small coefficient of around -0.00070 with a T-value of approximately ten as well. The R-squared numbers are all greater than 0.78. The results in Panel B and Panel C are all at a 1% significance. In conclusion, GDP is negatively proportionate to the carbon emission and total industrial sulfur dioxide emissions, respectively, indicating that worse environmental management will lead to a decrease in the GDP; GDP is positively correlated with the park green area, showing a positive effect of a greener environment on GDP.

TABLE 3: BASELINE REGRESSION RESULTS

Panel A: Carbon Emission				
Variables	Dependent Variable: GDP			
	(1)	(2)	(3)	(4)
Carbon	-0.0003	-0.0003	0.0007	0.0008
	(-0.2637)	(-0.3366)	(0.6177)	(0.7278)
FIE_Outcome	0.0002***	0.0002***		
	(7.4195)	(6.7935)		
Univ_Student	0.0000		-0.0000	
	(0.0539)		(-0.1214)	
TOL_Im_Ex	-0.0002***			-0.0002***
	(-3.8915)			(-2.8112)
Constant	0.3456***	0.2681***	0.4930***	0.5571***
	(2.9951)	(3.3611)	(3.6288)	(6.4295)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	180	180	180	180
Adj_R2	0.717	0.686	0.585	0.606

Panel B: Park Green Area				
Variables	Dependent Variable: GDP			
	(1)	(2)	(3)	(4)
Green_Area	0.4642***	0.4733***	0.5494***	0.5612***
	(9.0960)	(10.3492)	(11.4394)	(10.8265)
FIE_Outcome	1.0383***	1.0048***		
	(5.5041)	(5.5024)		
Univ_Student	-15.4794		-8.3186	

	(-0.8595)		(-0.4323)	
TOL_Im_Ex	-0.2016			0.3192
	(-0.4198)			(0.6381)
Constant	1,675.3449**	899.6751**	2,672.1660***	2,082.0214***
	(1.9802)	(2.4381)	(2.9828)	(4.5544)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	180	180	180	180
Adj_R2	0.822	0.820	0.783	0.783

Panel C: Total Industrial SO2 Emissions				
Variables	Dependent Variable: GDP			
	(1)	(2)	(3)	(4)
SO2	-0.0067***	-0.0066***	-0.0078***	-0.0079***
	(-3.4510)	(-3.2786)	(-3.3757)	(-3.4993)
FIE_Outcome	1.5917***	1.5080***		
	(7.4461)	(6.7615)		
Univ_Student	-1.4656		-3.4052	
	(-0.0676)		(-0.1329)	
TOL_Im_Ex	-2.1086***			-1.7552***
	(-4.0385)			(-2.9292)
Constant	4,309.7612***	3,366.4623***	6,388.5259***	7,098.9437***
	(4.1458)	(6.5859)	(5.3490)	(16.3776)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	180	180	180	180
Adj_R2	0.739	0.708	0.614	0.636

Note: All reported t-statistics are based on the robust standard errors adjusted following White (1980). All the variables are defined in Table 1. This table represents the result of GDP with the three independent variables. Nearly all results in the table are shown to be significant as $p<0.01$.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

DID Test

The test indicates the DID result, in which the city is controlled. The table represents the relationship between the urban economy and the DID variable. For the test of GDP and DID variable, the results are shown with a large positive coefficient of about 1335 and a positive T-value of 5.6. The R-squared value is 0.476, while for the test of budget revenue and DID variable, the coefficient is about 150, the T-value is about 2.7, and the R-squared is 0.278.

TABLE 4: DID REGRESSION RESULTS

Variables	Dependent Variable: GDP	Dependent Variable: Budget_Rev
	(1)	(2)
POST	1,335.2846***	150.3941***
	(5.6016)	(2.6624)
DID	928.1444***	222.3632***
	(2.8435)	(2.8748)
Constant	5,932.6273***	711.4754***
	(51.5222)	(26.0747)
City FE	YES	YES
Observations	180	180
Adj_R2	0.476	0.278

Note: All reported t-statistics are based on the robust standard errors adjusted following White (1980). All the variables are defined in Table 1.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Heterogeneity Test

I. Heterogeneity testing of Resource and Environment

The test in our essay chooses Chongqing, Guangzhou, Haikou, Chengdu, Nanjing, Xian, Harbin, Fuzhou, and Xining as resource-based cities.

The test indicates the result of heterogeneity testing of resources and environment by comparing the results of resource-based cities to those of resource-based cities where the city and year are controlled. (1) in all panels indicate the results of the resource-based cities, while (2) in all panels indicate the results of the non-resource-based cities. Table 5 represents the relationship between GDP and the three independent variables. In Panel A, the results of GDP with carbon emission are shown: the coefficients are 63 and 91, and the T values of the panel are about 6 and 11, respectively. R-squared digits are about 0.467. In Panel B, the coefficients are about 0.58 and 1.0, respectively, and the T-values are greater than zero at about 17 and 25. R-squared values are all greater than 0.82. In Panel C, the coefficients are near 0.02, and the T-values are about 2.5 and 2.0, respectively. R-squared digits are both greater than 0.02. All the data reveals the environmental impacts of the resources on economic development in terms of the difference in coefficients with these two categories of cities.

TABLE 5: HETEROGENEITY REGRESSION RESULTS

Panel A: Carbon Emission		
Variables	Dependent Variable: GDP	
	(1)	(2)
Carbon	62.7994***	91.4320***
	(5.9202)	(10.9412)
Constant	3,149.9356***	165.8156
	(2.9694)	(0.2458)
resource FE	YES	YES
Observations	42	138
Adj_R2	0.467	0.468

Panel B: Park Green Area		
Variables	Dependent Variable: GDP	
	(1)	(2)
Green_Area	0.5774***	1.0103***
	(16.8679)	(25.3007)
Constant	2,697.7219***	813.3301***
	(6.1337)	(2.6820)
resource FE	YES	YES
Observations	42	138
Adj_R2	0.877	0.825
Panel C: Total Industrial SO2 Emissions		
Variables	Dependent Variable: GDP	
	(1)	(2)
SO2	0.0131**	0.0176**
	(2.5290)	(1.9921)
Constant	6,949.4119***	4,965.6469***
	(7.4164)	(5.7420)
resource FE	YES	YES
Observations	180	180
Adj_R2	0.739	0.708

Note: All reported t-statistics are based on the robust standard errors adjusted following White (1980). All the variables are defined in Table 1.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Robustness Test

The test indicates the result of the robustness test of Budget Revenue with the same several independent variables as the regression test, in which the city and year are controlled to explore the effect. Panel A presents the relationship between budget revenue, as the dependent variable, and carbon emission, as the independent variable, which has a negative coefficient of around -1.4 and a T value of around -0.483. The figures of R-squared are all greater than 0.3 and smaller than 0.5. Panel B represents the result of the robustness test of budget revenue and park green area, with GDP as the explained variable and park green area as the explaining variable, which has all results of coefficients in low positive figures at approximately 0.0856. The R-squared values are all greater than 0.46. Panel C chooses budget revenue and total industrial sulfur dioxide emissions as the dependent variable and independent variable, respectively, to indicate the implication, which turns out to have a low negative coefficient of around -0.0017 with a T-value of approximately -2.8 as well. The R-squared numbers are all greater than 0.3. In conclusion, it also presents the positive relationship between Budget Revenue and park green area as well as the negative relationship between Budget Revenue and carbon emission, total industrial sulfur dioxide emissions, showing the same effect as the GDP in previous tests and illustrating the positive effect of a greener environment on Budget Revenue.

TABLE 6: ROBUSTNESS REGRESSION RESULTS

Panel A: Carbon Emission				
Variables	Dependent Variable: Budget_Rev			
	(1)	(2)	(3)	(4)
Carbon	-1.696	-2.516	-0.489	-0.899
	(-0.602)	(-0.851)	(-0.163)	(-0.315)

FIE_Outcome	0.211***	0.181***		
	(3.299)	(2.689)		
Univ_Student	-0.001		-0.001*	
	(-1.313)		(-1.728)	
TOL_Im_Ex	-0.617***			-0.610***
	(-3.977)			(-3.880)
Constant	1,033.393***	464.280**	1,176.273***	974.701***
	(3.140)	(2.012)	(3.393)	(4.466)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	180	180	180	180
Adj_R2	0.435	0.355	0.336	0.387

Panel B: Park Green Area

Variables	Dependent Variable: Budget_Rev			
	(1)	(2)	(3)	(4)
Green_Area	0.0754	0.0894***	0.0955***	0.0821***
	(4.3800)	(5.6362)	(6.3918)	(5.0695)
FIE_Outcome	0.1054	0.0657		
	(1.6568)	(1.0370)		
Univ_Student	-11.6846		-13.3855	
	(-1.9229)		(-2.2362)	
TOL_Im_Ex	-0.3054			-0.3108
	(-1.8849)			(-1.9889)
Constant	679.7864	6.9716	687.7819	317.1500
	(2.3815)	(0.0545)	(2.4683)	(2.2209)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	180	180	180	180
Adj_R2	0.502	0.469	0.484	0.480

Panel C: Total Industrial SO2 Emissions

Variables	Dependent Variable: Budget_Rev			
	(1)	(2)	(3)	(4)
SO2	-0.0016	-0.0016	-0.0017	-0.0017
	(-2.8337)	(-2.6166)	(-2.8744)	(-2.9697)
FIE_Outcome	0.1907	0.1579		
	(3.0857)	(2.4102)		
Univ_Student	-9.5446		-12.6580	
	(-1.5217)		(-1.9182)	
TOL_Im_Ex	-0.6147			-0.6156

	(-4.0714)			(-4.0389)
Constant	1,181.6134	514.1623	1,381.8313	1,117.1911
	(3.9308)	(3.4255)	(4.4935)	(10.1335)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	180	180	180	180
Adj_R2	0.465	0.381	0.372	0.422

Note: All reported t-statistics are based on the robust standard errors adjusted following White (1980). All the variables are defined in Table 1. This table represents the result of Budget_Rev with the three independent variables. Nearly all results in the table are shown to be significant as $p<0.01$.
*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Conclusion

Research Finding

Using linear regression analysis, we examine the negative correlation between GDP and carbon emissions, as well as total industrial sulfur dioxide emissions. Additionally, we find a positive association between GDP and park green area. The robustness of our findings is confirmed through Budget Revenue tests with the same independent variables and controlled variables. Furthermore, Difference-in-Differences (DID) testing reveals the positive impact of control variables on the two main variables under investigation.

Research Limitations

Our research sets our data sources over the range of megapolis in the provinces in China, which actually ignores the cities on a county level or on a prefecture-level, which may leave the result inconclusive or incomprehensive for all the cities when it comes to the relations between low-carbon and economy.

We use carbon emissions, park green areas, and total industrial sulfur dioxide emissions as indicators for carbon consumption in the research. However, there may be innovative indicators that can be utilized.

In the model we use in the research, there will be confusion on whether the factor carbon will be included in the equation in Romer theory as an index or a constant, which might lead to different impacts on the research results.

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