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Can the Carbon Emissions Trading Pilot Policy Improve the Ecological Well-Being Performance of Cities in China?

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Abstract: Adhering to ecological priorities and promoting environmental regulations is essential for improving ecological well-being performance (EWP); conversely, EWP is a crucial measure of social and economic sustainability. From the perspective of high-quality development, we see China's cities' adoption of the carbon emissions trading pilot (CETP) policy as a quasi-natural experiment, and we use the difference-in-differences (DID) approach to analyze how market-based carbon credits affect the urban EWP and its action mechanism. The findings of the empirical study show that: (1) The implementation of CETP can effectively improve the quality of urban development, with an increase of 29.1% in the EWP value, effectively contributing to the realization of the goal of high-quality development; (2) the urban EWP levels in China are higher in the east, lower in the west and lowest in the middle, but they all show a fluctuating upward trend; (3) according to the heterogeneity study, the implementation of CETP has a scale effect and significant urban locational differences, and its impact on EWP of cities is greater in "advanced cities" and central region cities; (4) the implementation of CETP can advance industrial structure upgrading, thereby promoting the EWP level, but the mediating effect of technological innovation is not significant. The possible innovations in this paper are as follows: (1) It broadens the existing research system on the effectiveness of CETP policies. (2) It reconstructs the index system of EWP from the perspective of high-quality development so that its measurement results can reflect the quality of urban development more comprehensively. (3) The research samples of CETP and EWP are enriched by using prefectural-level data.

Keywords: carbon emission trading pilot policy; ecological well-being performance; high-quality urban development; difference-in-differences model; environmental regulation

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1. Introduction

In the past few years, China's total economic output has maintained a sustained and rapid growth trend. However, faster economic growth has also brought specific environmental pressures to China, such as overexploitation of coal and explosive growth in the chemical industry, leading to severe problems of atmospheric pollution [1], water pollution [2], and land pollution [3]. China has recognized the need to transition from its previous rapid industrialization model towards a more sustainable and environmentally friendly development path [4]. In the 19th National Congress, China put forward the concept of "high-quality development". Since then, high-quality development has become the basic requirement for China to enter a new stage of development and accelerate the construction of a new development pattern. The Fourteenth Five-Year Plan proposes to actively address climate change and anchor efforts to become carbon neutral by 2060. It responds to the new trend in global climate governance and reflects China's contribution to the world's climate change [5]. It also demonstrates China's determination and courage to transform its economic development model, which is significant for realizing high-quality economic development.

Building the carbon emissions trading market has emerged as a crucial strategy for advancing China's shift in the country's economic development model and high-quality economic development [6]. The carbon emissions trading policy (CETP), which utilizes market mechanisms to encourage the reduction of emissions and energy conservation and accelerate environmentally friendly and low-carbon transformation and development, has become a popular policy tool around the world as countries seek to reduce greenhouse gas emissions. The European Union Emissions Trading System (EU ETS) is currently the largest carbon market in the world, covering over 11,000 power plants and industrial sites in 31 countries [7]. With reference to the establishment of the EU-ETS, China identified seven trading pilot regions nationwide, covering 37 prefectural-level municipalities, and opened the markets one after another in June 2013, formally kicking off the prelude to the development of China's carbon emissions trading from scratch. The National Carbon Emission Trading Market (NCETM), which went live with online trading in July 2021, is now the most significant carbon trading market in the world, covering greenhouse gas emissions [8]. Through carbon emissions trading and the market mechanism, businesses can allocate their share of carbon emissions, internalizing the cost of carbon emissions, which has obvious advantages in promoting the realization of "dual control" of carbon emissions.

Numerous studies have demonstrated that the implementation of CETP leads to a substantial decrease in carbon emissions within pilot regions [9,10]. However, it is important to consider whether this reduction in emissions comes at the cost of a slowdown in economic activity or as a result of improved economic efficiency. Clearly, the latter scenario is essential for China's transition towards a green economy and the promotion of high-quality development. Therefore, have China's cities seen high-quality growth that is effectively promoted by the CETP? What is the impact mechanism, and does the effect of CETP implementation vary in different regions and types of cities? It has enormous theoretical significance as well as practical implications for constructing a unified national carbon emissions trading market, realizing the "double carbon" goal on time, and fostering the transformation of economic and social development into one that is high-quality.

From the existing research, the impact of the implementation of environmental regulation policies on economic development is very complicated. Different samples, different policies, and even different research methods produce different conclusions, or even completely opposite ones. Some scholars believe that the implementation of environmental regulation policies can stimulate enterprises to carry out technological innovation [11], optimize resource factor input [12], promote industrial transformation and upgrading [13], and thus achieve a win-win situation of environmental protection and economic growth [14]. However, some scholars hold the opposite view, arguing that environmental regulation will not necessarily stimulate enterprise innovation [15], but will bring additional costs to enterprises, squeeze production and research and development investment, reduce enterprise competitiveness, and inhibit high-quality economic development [16,17]. Some scholars believe that the implementation effect of environmental regulation will be uncertain due to various factors such as the fiscal decentralization system [18], environmental regulation intensity [19,20], and development stage [21]. In short, the existing literature has not reached a consensus on how environmental regulations affect economic development. Moreover, the content of environmental regulation is very extensive, and the Chinese government has issued a large number of environmental regulation policies, which makes it difficult for us to accurately quantify and build measurement models. In the context of China's continuous emphasis on high-quality economic development, CETP is a major institutional innovation in using market mechanisms to control and reduce greenhouse gas emissions, promote green and low-carbon development, and provide an important means to achieve the goal of "double carbon". Therefore, this paper takes CETP as a research object and analyzes its impact on the quality of urban economic development, which is not only of important theoretical significance but also provides an important decision-making basis for the construction and improvement of the national carbon trading market in the future.

The concept of high-quality development emphasizes the importance of balancing economic growth with environmental protection and social well-being [22], which is highly consistent with the connotation of ecological well-being performance (EWP). The EWP is the conversion efficiency between the consumption of ecological resources and the level of social welfare, aiming to reflect the relationship between the local ecological environment and human well-being [23]. As China enters the stage of "high-quality" development, the mode of development has changed from "high-speed" to "high-quality". The use of EWP to measure the degree of sustainability of a region and its potential for sustainable development avoids pure GDPism (GDPism places a strong emphasis on the importance of increasing GDP as a primary goal for a country's economic policies) and is more in line with the inherent requirements of high-quality development.

Therefore, in order to empirically test the impact of CETP on high-quality urban development, based on the concept of high-quality development, this paper constructs an EWP evaluation framework and measures the EWP of 253 cities at the prefecture level and above in China from 2010 to 2021. The implementation of CETP is regarded as a quasi-natural experiment, and a difference-difference (DID) model is constructed to study the impact of this market-oriented environmental regulation policy on the quality of economic development represented by urban EWP and its mechanisms. The possible innovations in this paper include: First, exploring the impact of CETP on urban EWP broadens the research perspective of the body of knowledge currently available on carbon emissions trading, and the enhancement of EWP is the subject of high-quality economic development and thus, to some degree, also fills the research gap in promoting the level of economic and social development. Secondly, the concept of EWP is essentially an extension of high-quality development, which provides a new research perspective and analytical tool for the study of high-quality development. With the proposal of high-quality development, the construction of the index system should consider the concept of high-quality development and practical needs. Therefore, in this study, the EWP measuring methodology is innovated by including non-resource-based inputs such as capital stock, labor, and wastewater and exhaust emissions as non-desired outputs so that the results of EWP measurement can reflect the quality of economic development more comprehensively. Third, the panel data of cities at the prefecture level are the focused research area of this work. Cities hold a significant position in social and economic activities, and evaluating the quality of urban development is vital for rational management of human activities in cities. Lastly, the research explores the heterogeneity of city type and location and conducts an empirical analysis of the CETP implementation mechanism.

2. Theoretical Analysis and Hypothesis Formulation

CETP is an environmental policy that reduces carbon emissions by using market mechanisms to regulate company output and business practices [24]. With the implementation of the CETP, carbon credits have become a publicly traded commodity in the market, and pilot companies need to bear higher production costs to purchase a share of carbon emissions [25]. Following the principle of profit maximization, implementing the CETP prompts enterprises to reduce carbon emissions by improving production technology [26], increasing energy efficiency [27], or choosing to use cleaner energy, thereby reducing production costs [28]. Simultaneously, the CETP can hasten the transition to a low-carbon and environmentally friendly economy by promoting industrial restructuring [29] and realizing overall regional carbon emission reduction [30]. As for the impact on economic development, most studies show that the CETP does not inhibit regional economic development while exerting carbon emission reduction effects [31]. CETP can achieve optimization of resource allocation through the market mechanism, reduce the abatement cost of the economic system as a whole [32], expand the scale of employment [33], and eventually achieve a win-win situation between environmental protection and economic growth. Therefore, this paper argues that CETP can curb environmental pollution and greenhouse gas emissions while encouraging businesses to implement green technological innovation, boost productivity, and encourage industries to switch from high-pollution, high-energy production to a green, environmentally friendly mode, which will enhance the quality of urban development and encourage the city to follow the path of high-quality development. At the same time, economic growth will prompt the government to increase investment in public infrastructure, popularize basic education [34], improve primary medical care [35], build a social security system to continuously enhance the people's sense of well-being and belonging [36], and promote the general improvement of the EWP level. In light of this, we propose Hypothesis 1:

Hypothesis 1 (H1). *The CETP can significantly promote China's degree of urban EWP.*

How, then, can CETPs realize their contribution to EWP? Firstly, the implementation of good environmental regulations allows enterprises that innovate in low-carbon technologies to benefit [37]. These regulations are crucial for achieving green economic growth [38]. According to Porter's hypothesis, environmental regulation does not hinder productivity growth. Instead, it stimulates firms to engage in technological innovation, and the resulting benefits partially or even fully offset compliance costs [39]. At the firm level, regulatory pressure compels companies to adjust their existing production methods or make technological innovations. This enables them to lower energy usage and greenhouse gas emissions while still ensuring output, thereby improving energy use efficiency [40]. Innovation in low-carbon technologies not only reduces pollution control expenditures but also decreases the overall energy demand of the enterprise [41]. From the government's point of view, the implementation of environmental regulation is often accompanied by a range of supporting policies. These policies aim to incentivize emission-control enterprises to carry out technological innovation in green technology [42]. Examples of such policies include tax cuts, fee reductions, and subsidies for enterprises that innovate with green technology or exhibit innovative behavior. By reducing the costs and risks associated with technological innovation, these supporting policies enhance the motivation of enterprises to innovate [43]. Consequently, they promote the accomplishment of businesses' green transformation. Based on these arguments, we propose the second hypothesis that CETP can enhance EWP by promoting corporate innovation in green technology.

Hypothesis 2 (H2). *The CETP can enhance EWP by promoting corporate green technology innovation*.

The transformation from an industrial structure that produces pollutants to one that is economical and environmentally friendly is an inevitable requirement for upgrading the quality of urban development [44]. Traditional industrial production processes have had a significant negative impact on the environment, often resulting in high levels of pollution and energy consumption. By transitioning towards a more sustainable and eco-friendly approach to industrial production, we can protect our environment while also promoting people's sense of well-being. On the one hand, implementing the CETP shifted corporate resources from their traditional productive use to reducing pollution [45]. At the same time, implementing the CETP will drive capital away from firms that cannot make effective carbon emission reductions, leading to the shrinkage of high-polluting and energy-consuming industries [46]. Therefore, the CETP may accelerate the restructuring of the industry and promote the industry to realize a green and low-carbon transformation. On the other hand, the CETP will change the energy use preference of enterprises, favoring the choice of green and clean energy [47], thus changing the investment structure of enterprises, guiding the overall production process to green and energy-saving transformation, and realizing the transformation and upgrading within enterprises. As a result, the joint efforts between enterprises and those outside the industry have led to the flow of production factors to more efficient industries, enhancing the overall output level of society and promoting economic development. In summary, we propose the third hypothesis that CETP can enhance EWP by promoting the modernization of industrial structures.

Hypothesis 3 (H3). *The CETP can enhance EWP by promoting the upgrading of industrial structures.*

The overall impact mechanism is shown in Figure 1.

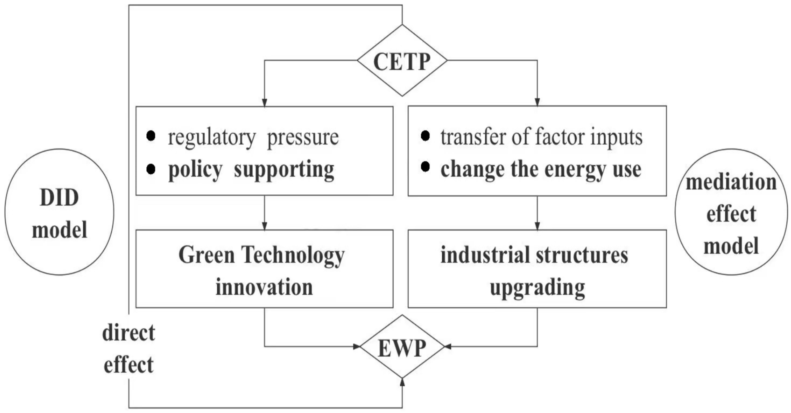

Figure 1. The overall impact mechanism.

3. Models, Variables, and Data

3.1. DID Model

This article aims to determine how the CETP affects EWP in regards to the establishment of the pilot and the launch of the market as a quasi-natural experiment, taking 2014 as the time point of policy occurrence, 34 pilot cities and municipalities as the group under experimentation, and the control group, which consists of the remaining 219 non-pilot cities and municipalities. A single time-point double-difference model was chosen to empirically test the differences in changes in the EWP of municipalities before and after the pilot. The specific model settings are as follows:

$$EWP_{i,t} = \beta_0 + \beta_1 CETP_{i,t} + \beta_2 X_{i,t} + u_i + v_t + \varepsilon_{i,t} \quad (1)$$

where $EWP_{i,t}$ denotes the level of EWP of the city in the year; $CETP_{i,t}$ denotes whether the city i was launched the carbon trading market in the year t. Its coefficient, β_1, evaluates the pilot policy's overall treatment impact; $X_{i,t}$ is a collection of city-level control variables; u_i and v_t are the effects that are fixed by the year and by the city. $\varepsilon_{i,t}$ is the random error term, which obeys an independent homoskedasticity distribution. The overview of the study area and the location of the pilot and non-pilot cities are shown in Figure 2.

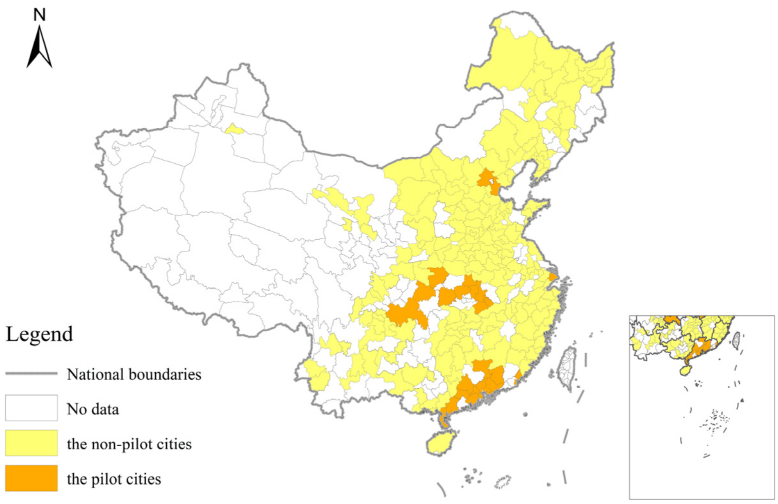

Figure 2. Overview of the study area.

3.2. Measuring EWP

This study attempts to evaluate how the CETP has enhanced the quality of urban development in China. Single-factor efficiency indicators, such as economic growth rate and carbon emissions efficiency, cannot comprehensively characterize the degree of urban economic development and environmental improvement, and it is necessary to integrate economic, environmental, and human welfare into the same production framework and efficiency evaluation system and to construct a comprehensive efficiency index.

3.2.1. Super-SBM Model

The Super-SBM model is a powerful tool that addresses the challenge of simultaneously validating multiple decision-making units. It also effectively resolves the issue of slackness in input and output variables, thereby enhancing its applicability in studying ecological well-being performance [48]. Therefore, the paper adopts the Super-SBM model to measure the performance level of urban ecological welfare; the specific model construction is shown in Equation (2).

$$\min \text{EWP} = \frac{1 + \frac{1}{n}\sum_{i=1}^{n} \frac{m_i^x}{x_{io}}}{1 - \frac{1}{m_1+m_2}\left(\sum_{k=1}^{m_1} \frac{m_k^y}{y_{k0}} + \sum_{l=1}^{m_2} \frac{m_l^z}{z_{l0}}\right)} \tag{2}$$

$$\text{s.t.} \begin{cases} x_{i0} \geqslant \sum_{j=1,\neq 0}^{s} \lambda_j x_j - m_i^x, (i = 1, \cdots n) \\ y_{k0} \leqslant \sum_{j=1,\neq 0}^{s} \lambda_j y_j + m_k^y, (k = 1, \cdots m_1) \\ z_{l0} \geqslant \sum_{j=1,\neq 0}^{s} \lambda_j z_j - m_l^z, (l = 1, \cdots m_2) \\ m_i^x \geqslant 0, m_k^y \geqslant 0, m_l^z \geqslant 0, \lambda_j \geqslant 0 (j = 1, \cdots s, j \neq 0) \\ 1 - \frac{1}{m_1+m_2}\left(\sum_{k=1}^{m_1} \frac{m_k^y}{y_{k0}} + \sum_{l=1}^{m_2} \frac{m_l^z}{z_{l0}}\right) > 0 \end{cases}$$

The efficiency value is denoted by EWP, and the number of inputs, desired output, and non-desired output indications are represented by the variables n, m_1, and m_2, respectively. $\sum_{j=1,\neq 0}^{s} x_{io}$, $\sum_{j=1,\neq 0}^{s} y_{ko}$, $\sum_{j=1,\neq 0}^{s} z_{lo}$ denotes the matrix of inputs, desired outputs, and non-desired outputs, respectively, λ is the weighting variable, and the input, desired output, and non-desired output slack variables are indicated by m_i^x, m_k^y, m_l^z. The above model is based on the premise of constant returns to scale.

Referring to Bian et al. [49] and Long and Wang [50], both resource and non-resource inputs should be included in the input indicators. Labor force and capital stock are examples of non-resource inputs; energy, water, and land usage are examples of resource inputs. Both acceptable and undesirable outputs should be shown on the output indicators. Human well-being is measured by the Human Development Index (HDI), which is a composite of three dimensions: economics, education, and health [51]. A particular indicator measures each dimension, and these measurements are utilized to choose indications for desired outputs. The data available indicate that the emissions of industrial wastewater, industrial sulfur dioxide, and soot are undesirable outputs. The main variables and their specific measures are shown in Table 1.

Table 1. Indicator variables of ecological welfare performance.

Dimension	Variable	Indicator
Input indicators	Energy	Per capita energy consumption
	Land	Per capita built-up area consumption
	Water	Per capita water consumption
	Labor	Labor force per 10^4 persons
	Capital	capital stock

Table 1. *Cont.*

Dimension	Variable	Indicator
Output indicators	Economy	Per capita GDP
	Education	Number of college students per 10^4 persons
	Health	Number of doctors per 10^4 persons
	wastewater	Per capita industrial wastewater
	Waste gases	Per capita SO_2 emission
		Per capita soot/dust emission

3.2.2. Malmquist Index

Sten Malmquist first proposed the Malmquist index, and then Caves and other scholars applied the index to measure dynamic efficiency changes. The Total Factor Productivity (TFP) index was established based on the model constructed by Fare et al. [52] The model is shown in Equation (3).

$$M^{t+1}\left(I^{t+1},O^{t+1},I^{t},O^{t}\right)=\left[\frac{E^{t}\left(I^{t+1},O^{t+1}\right)}{E^{t}\left(I^{t},O^{t}\right)}\times\frac{E^{t+1}\left(I^{t+1},O^{t+1}\right)}{E^{t+1}\left(I^{t},O^{t}\right)}\right] \tag{3}$$

where M^{t+1} denotes the value of M-efficiency with constant returns to scale, inputs and outputs for period t are indicated by $\left(I^{t},O^{t}\right)$, and those for period t + 1 by $\left(I^{t+1},O^{t+1}\right)$; $E^{t}\left(I^{t},O^{t}\right)$ and $E^{t}\left(I^{t+1},O^{t+1}\right)$ denote the distance function in period t and period $t+1$, respectively. In the event that $M^{t+1}\left(I^{t+1},O^{t+1},I^{t},O^{t}\right)>1$, it indicates that EWP improves from period t to $t+1$; in the event that $M^{t+1}\left(I^{t+1},O^{t+1},I^{t},O^{t}\right)<1$, EWP is considered to have deteriorated.

The Malmquist index can be decomposed into the technical efficiency change index (EC) and the technical progress change index (TC), which are decomposed as follows:

$$M^{t+1}\left(I^{t+1},O^{t+1},I^{t},O^{t}\right)=\mathrm{EC}\times\mathrm{TC} \tag{4}$$

$$\mathrm{EC}=\frac{E^{t+1}\left(I^{t+1},O^{t+1}\right)}{E^{t}\left(I^{t},O^{t}\right)} \tag{5}$$

$$\mathrm{TC}=\left[\frac{E^{t}\left(I^{t+1},O^{t+1}\right)}{E^{t+1}\left(I^{t+1},O^{t+1}\right)}\cdot\frac{E^{t}\left(I^{t},O^{t}\right)}{E^{t+1}\left(I^{t},O^{t}\right)}\right]^{\frac{1}{2}} \tag{6}$$

In the formula, TC indicates the technical progress; if TC > 1, then technology is changing in a way that is more advantageous, and vice versa, the technology changes in a negative direction; EC shows the shift in technical efficiency over two time periods; in the event that EC > 1, it indicates an improvement in technical efficiency, while a decrease in technical efficiency is indicated by the opposite.

3.3. Variables and Data

The explained variable is urban EWP. In this paper, the Super-SBM model is used to measure urban EWP values each year. However, the urban EWP values for different years are not comparable because of the different production frontiers chosen by the Super-SBM model to measure EWP in different years. Based on this limitation, this paper uses the ML index to measure the dynamic change of the urban EWP value between different years. In order to obtain a continuous EWP value that can be analyzed dynamically, this paper takes 2010 as the base period, while the urban EWP in the years 2011–2021 is obtained by multiplying the ML index of the corresponding years by the chain method. We use these continuity data that were substituted into the DID model to analyze the impact of CETP implementation on urban EWP changes.

Control variables: (1) economic development (lnpgdp): real GDP per capita converted from 2010; (2) opening up (lnopen): urban foreign direct investment; (3) urban greening (green): the built-up area's rate of greening coverage; (4) industry structure (sec): the secondary industry output value/urban GDP; (5) government intervention (lngov): the fiscal expenditure/urban GDP; (6) population density (lnpd): the population of the administrative territory divided into one unit of area. The China City Statistics Yearbook is where the variables are taken from.

Intermediate variables: As intermediate factors, this study takes into account changes in industrial structure [53] and innovation in green technology [54]. The industrial structure change is captured by the "industrial structure index" proposed by Xu [55], and the specific algorithm is as follows:

$$\text{industry} = \sum_{n=1}^{3} nI_n = I_1 + 2I_2 + 3I_3 \tag{7}$$

where I_n is the GDP's proportion of primary, secondary, and tertiary industries. The green technology innovation (lninnov) is represented in this article by the quantity of green patent applications submitted by publicly traded companies.

The data for the indicators were collected from the majority of municipalities or prefecture-level cities. Because some cities' relevant data could not be collected, only 253 cities were selected as sample cities. In this paper, the relevant data of 253 cities during 2010–2021 were collected from the China City Statistics Yearbook and the China City Construction Statistical Yearbook, except a few numbers need to be filled in through interpolation. All level variables (non-ratio variables) are logarithmically treated in order to narrow the magnitude gap between the data and facilitate the calculation of the subsequent regression as well as the presentation of the regression coefficients (Table 2).

Table 2. Descriptive statistics of relevant variables.

Variable	Total Sample					Experimental Group					Control Group				
	N	Mean	Sd	Min	Max	N	Mean	Sd	Min	Max	N	Mean	Sd	Min	Max
EWP	3036	1.46	1.05	0.06	14.46	408	1.62	1.39	0.58	14.46	2628	1.43	0.98	0.06	13.41
lnpgdp	3036	10.64	0.70	8.79	13.02	408	10.90	0.91	8.79	13.02	2628	10.60	0.65	8.80	12.70
lnopen	3036	11.98	1.82	4.88	16.83	408	12.65	1.90	9.27	16.83	2628	11.88	1.79	4.88	16.02
Green	3036	0.40	0.12	0.01	3.86	408	0.43	0.27	0.10	3.86	2628	0.40	0.06	0.01	0.95
Sec	3036	0.48	0.10	0.02	0.82	408	0.47	0.09	1.16	0.64	2628	0.48	0.10	0.02	0.82
lngov	3036	0.22	0.23	0.04	2.37	408	0.18	0.15	0.06	2.03	2628	0.23	0.23	0.04	2.37
lnPd	3036	5.82	0.88	2.28	7.88	408	6.33	0.70	4.97	7.88	2628	5.74	0.87	2.28	7.30
Indust	3036	2.30	0.22	1.80	3.22	408	2.39	0.44	2.04	3.22	2628	2.28	0.15	1.80	2.77
lninnov	3036	5.17	1.67	0.69	10.51	408	5.80	2.03	1.95	10.51	2628	5.07	1.59	0.69	9.67

4. Empirical Results and Analysis

4.1. Characterization of EWP Evolutionarily

4.1.1. Analysis of Spatial Variation

The overall level of EWP in China's cities could be higher, with an average value of 0.715, not realizing the relative effectiveness of DEA, implying that the cities are not achieving maximal output with minimal input. Among the 253 sample cities, only 45 cities and municipalities realized the relative effectiveness of DEA, accounting for 17.8% of the total sample size. In comparison, the remaining 207 cities failed to realize the effectiveness of DEA, accounting for 81.8% of the total sample size, which indicates that most of China's cities are less efficient at improving ecological welfare. Regarding city rankings, Haikou, Shenzhen, and Fuyang were ranked in the top three in that order, while Fangchenggang, Shizuishan, and Qitaihe were ranked in the bottom three (Table 3).

To classify the 253 sample cities based on their EWP values, six groups were formed using equal intervals. These groups include the following: excellent (EWP $\geq$ 1), good (0.8 $\leq$ EWP < 1), average (0.6 $\leq$ EWP < 0.8), poor (0.4 $\leq$ EWP < 0.6), and very poor (0.2 $\leq$ EWP < 0.4). With this classification, a map was created to illustrate the spatial distribution of urban EWP in Figure 3.

Table 3. Calculation results of average ecological welfare performance values and rankings of selected cities in China.

City	EWP	Rank	City	EWP	Rank	City	EWP	Rank
Haikou	1.705	1	Shijiazhuang	0.984	50	Xiamen	0.821	98
Shenzhen	1.422	2	Xi'an	0.980	52	Nanning	0.802	106
Fuyang	1.294	3	Changchun	0.965	55	Hangzhou	0.753	112
Changsha	1.169	7	Kuming	0.959	57	Ningbo	0.747	115
Peking	1.154	9	Wuhan	0.955	58	Fuzhou	0.713	127
Canton	1.121	13	Shanghai	0.928	66	Hefei	0.686	134
Hohhot	1.097	16	Lanzhou	0.910	69	shenyang	0.680	137
Taiyuan	1.069	24	Zhengzhou	0.886	72	Xining	0.497	186
Jinan	1.060	27	Tianjin	0.861	79	Chongqing	0.376	232
Qingdao	1.054	28	Nanjing	0.855	81	Fangchenggang	0.244	251
Hechi	1.003	45	Dalian	0.853	83	Shizuishan	0.242	252
Nanchang	0.989	46	Chengdu	0.849	86	Qitaihe	0.202	253
Harbin	0.988	47	Urumqi	0.836	89	National	0.715	—

Note: Due to the space limitations of the article, only the EWP values of the key cities are shown.

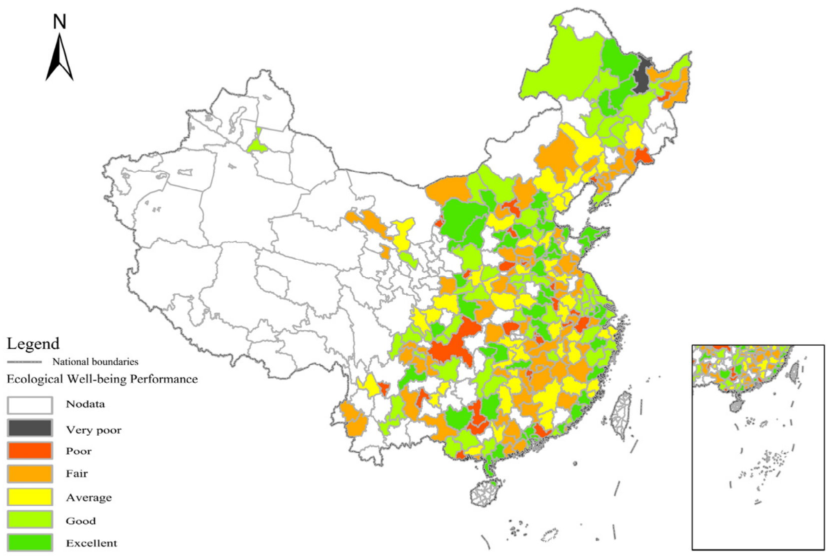

Figure 3. Spatial distribution of urban ecological welfare performance in China.

According to the overall spatial distribution in China, the EWP is highest in the east, low in the west, and lowest in the center. The cities in the east, such as Haikou, Shenzhen, and Beijing, mainly belong to the excellent group. Being pioneers in China's economic development, the eastern cities have attracted abundant factor inputs from foreign investment and the promotion of government macro-policies, which have contributed to advancing the eastern region's industrial structure and economic development. However, as the industry of the eastern area is upgraded, high-energy-consuming and high-polluting businesses are slowly moving to the central and western areas, which creates new environmental challenges for the western and central cities. At the same time, many cities in the west need assistance to obtain resources, technology, and talents. Hence, the catch-up process of central and western China in narrowing their economic gap with the east is prone to creating a vicious cycle of economic growth marked by excessive pollution and inefficient use of resources.

4.1.2. Characteristics of Time Evolution

When considering the entire nation, with a few exceptions, China's EWP shows a fluctuating upward trend. This is primarily due to China's consistent emphasis on the value and necessity of ecological priorities and green development, the introduction of numerous environmental regulations, stringent pollution emission controls, and the active support of green technological innovations by businesses. These measures make it easier for Chinese cities and towns to transition away from the GDP-only development model and have improved the EWP of Chinese cities. The ML index's decomposition shows that during the sample period, China's resource allocation efficiency (EC) shows a trend of initial growth followed by decline. Meanwhile, the technological progress index (TC) has been rising, exceeding the EC value since 2015 and consistently remaining above 1. It suggests that the level of technological innovation in Chinese cities has been rising annually and has progressively supplanted the advancement of technological efficiency as the primary factor propelling the development of EWP.

In terms of spatial distribution, the growth pattern of EWP is similar to the overall evolution pattern, but there is some regional heterogeneity. Although EWP is rising in all regions, the growth rate in the eastern and central regions is faster, which can be attributed to their strong economic foundation and infrastructural development. The average TC value of the eastern cities is 1.13, which is considerably higher than the national average, indicating a rapid growth trend in technological progress. The TC of central cities is slightly lower than that of the eastern region but still higher than its own EC level, which dominates the rise of EWP. The TC in the western cities, however, is marginally lower than the EC, indicating that the dominant force driving the western cities' EWP is the ever-increasing efficiency of technology utilization rather than technological innovation (Table 4).

Table 4. The ML index of ecological welfare performance as well as its decomposition term.

Year	Eastern			Central			Western			National		
	ML	EC	TC	ML	EC	TC	ML	EC	TC	ML	EC	TC
2011	1.03	1.05	0.99	1.01	1.09	0.94	1.05	1.19	0.88	1.03	1.10	0.95
2012	1.12	1.05	1.07	1.11	1.07	1.04	1.15	1.16	0.99	1.12	1.08	1.05
2013	1.27	1.01	1.28	1.36	0.92	1.48	1.27	0.95	1.33	1.33	0.96	1.40
2014	0.94	1.06	0.90	0.89	1.17	0.76	0.92	1.24	0.74	0.92	1.14	0.81
2015	1.15	1.03	1.13	1.15	1.08	1.07	1.06	0.96	1.10	1.13	1.03	1.10
2016	1.20	0.98	1.25	1.37	1.07	1.27	1.12	0.99	1.13	1.27	1.02	1.27
2017	1.04	1.08	0.99	0.91	1.08	0.86	0.87	1.02	0.85	0.95	1.07	0.90
2018	1.16	1.06	1.11	1.16	1.09	1.10	1.10	1.04	1.06	1.15	1.07	1.10
2019	1.13	0.95	1.20	1.12	0.98	1.18	1.06	0.93	1.14	1.11	0.95	1.18
2020	1.14	0.92	1.24	1.13	0.96	1.17	1.09	0.98	1.11	1.12	0.95	1.17
2021	1.13	0.90	1.26	1.12	0.89	1.25	1.11	0.95	1.16	1.12	0.91	1.22
Mean	1.13	1.01	1.13	1.12	1.04	1.09	1.07	1.04	1.03	1.11	1.03	1.10

Among the 253 cities, we randomly selected three pilot cities and three non-pilot cities and created a line graph to represent the time trends of EWP, as shown in Figure 4. Prior to 2013, there was no significant gap between the EWP levels of the pilot and non-pilot cities, suggesting that the six selected cities had similar levels of comprehensive development quality and ecological environment at that time. However, a marked change occurred in 2014, which marked a turning point in the development trajectories of the cities.

From 2014 onwards, the three pilot cities experienced a remarkable and noteworthy upswing in their EWP levels. This substantial improvement indicated a significant leap forward in their ecological performance, highlighting a concerted effort to prioritize environmental conservation and sustainability.

On the other hand, the non-pilot cities exhibited a different pattern. While they experienced fluctuations in their EWP levels during this period, these variations were relatively minor, and the overall trend remained stable. The non-pilot cities were unable to achieve the same level of consistent progress seen in the pilot cities, resulting in a widening gap between their respective EWP levels.

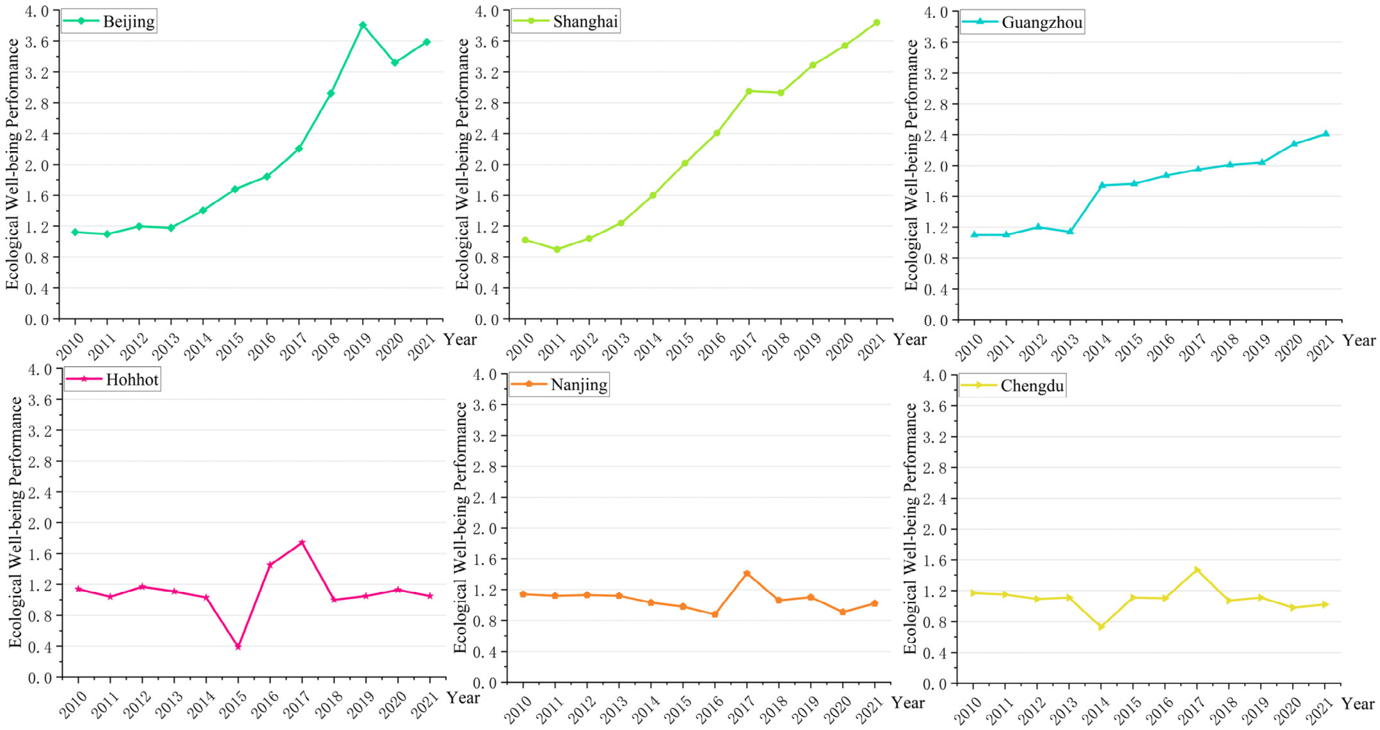

Figure 4. Time trends of ecological welfare performance in three pilot and three non-pilot cities from 2010 to 2021.

The reasons behind these differences between pilot and non-pilot cities were multi-faceted. It could be attributed to a series of targeted policies and initiatives implemented by local governments aimed at enhancing environmental protection, promoting renewable energy sources, implementing stricter pollution control measures, and encouraging sustainable urban development. Therefore, it is reasonable to speculate that the implementation of CETP can effectively contribute to the improvement of urban EWP.

4.2. Benchmark Regression and Heterogeneity Test

This research estimates a regression Equation (1) to examine the impact of CETP on urban EWP. Meanwhile, taking into account the variations in each city's industrial structure, economic base, and natural conditions, there are bound to be differences in the roles and status of cities in China in achieving the "double carbon" target and the process of high-quality development, which will lead to some heterogeneity in how the CETP affects the EWP of various city types in various places. This paper therefore establishes a dummy variable for city type and the area based on the administrative level of the city and the geographic location in the East, Central, and West, respectively, which are multiplied by $CETP_{i,t}$ for regression. The results are shown in Table 5.

From Column 1, there is a noticeable positive coefficient of $CETP_{i,t}$. It shows that implementing the pilot policy promotes the EWP of the pilot cities, which improves by 29.1% relative to the cities that have not yet carried out carbon trading pilots. It indicates that the performance of the CETP is evident and can greatly enhance the urban area's economic growth quality, supporting Hypothesis 1 (H_1). However, the results in Columns 2–5 show that the effect of CETP on the EWP of cities with varying types and locations is typically heterogeneous.

Table 5. Benchmark regression results and heterogeneity analysis.

Variable	Total Sample (1)	City Level (2)	City Area Eastern Cities (3)	Central Cities (4)	Western Cities (5)
$CETP_{i,t}$	0.291 ***				
	(3.14)				
City × $CETP_{i,t}$		0.455 **			
		(2.38)			
Area × $CETP_{i,t}$			0.237 **	0.375 **	−0.165
			(2.09)	(2.45)	(−0.33)
Control	Controlled	Controlled	Controlled	Controlled	Controlled
Urban	Controlled	Controlled	Controlled	Controlled	Controlled
Year	Controlled	Controlled	Controlled	Controlled	Controlled
N	3036	3036	3036	3036	3036
R^2	0.114	0.112	0.112	0.113	0.110
F value	37.109 ***	36.782 ***	36.678 ***	36.807 ***	36.34 ***

Note: *** $p < 0.01$, ** $p < 0.05$; the parenthesis are the robust standard error values.

In this paper, the pilots are divided into advanced and ordinary cities according to the administrative level. The analysis revealed that implementing the CETP has a more significant impact on the EWP in advanced cities, as indicated by the coefficient of City × $CETP_{i,t}$ (Column 2). The reason behind this finding can be attributed to several factors. Firstly, advanced cities tend to possess more developed infrastructure compared to ordinary cities. This advanced infrastructure enables them to better support and facilitate the implementation of carbon trading policies. It provides the necessary framework for establishing a carbon trading market, allowing for the efficient allocation of resources and the promotion of sustainable economic growth. Secondly, advanced cities often have a more developed and mature service sector, which forms a substantial part of their overall economy. The tertiary industry, including sectors such as finance, technology, consulting, and other service-oriented businesses, tends to have lower carbon emissions compared to heavy industries or manufacturing sectors. Due to the dominance of the tertiary industry, advanced cities have a natural advantage in transitioning towards low-carbon practices. Additionally, advanced cities typically exhibit a higher level of technological innovation. They have a greater capacity for research and development, which allows them to explore and implement innovative solutions to reduce carbon emissions. These technological advancements not only contribute to the success of the CETP but also enhance the overall economic growth and quality of life in these cities. Overall, the combination of well-developed infrastructure, rational industrial structures, and technological innovation in advanced cities creates an environment that is more conducive to the successful implementation of the CETP. As a result, the impact of the CETP on EWP is more pronounced in these cities compared to ordinary cities.

The results of Columns 3–5 show that the implementation of the CETP has been the most significant catalyst for EWP in central cities, followed by eastern cities, with a less pronounced impact on the western region. In the case of eastern cities, they have experienced a series of policy supports in the early stages, leading to mature overall economic development. The industrial structure in these cities has gradually shifted from resource-consuming industries to more technology-saving sectors. As a result, their economic strength is already at a high level. Implementing the CETP in these cities may bring smaller policy dividends and have a minimal impact on further encouraging economic growth, as they have already made significant progress in terms of energy efficiency and environmental sustainability.

On the other hand, central cities benefit from their factor endowment and location advantages. They often undertake mature industries transferred from the eastern region and absorb the development experiences of more developed areas. This allows them to raise the standard of EWP and make better use of the policy dividends provided by the CETP. The implementation of carbon trading policies can significantly contribute to their economic growth and development by leveraging the resources and experiences gained in the eastern region. In the case of western cities, it is true that their economic foundation may be relatively weaker compared to the eastern and central regions. The industrial structure in these cities may also be less efficient and unbalanced, with a larger proportion of heavy industries. As a result, they face challenges in achieving sustainable and low-carbon development.

4.3. Robustness Testing

4.3.1. Parallel Trend Testing

As a quasi-natural experimental method, the vital premise for establishing the results of the DID method is satisfying the parallel trend assumption. We have taken the policy implementation year 2014 as the benchmark, selected the data samples of the first three years and the last four years, and conducted a parallel trend test on EWP. As seen in Table 6, the regression coefficient of EWP is not significant in the years before the pilot policy, which is consistent with the assumption of a common trend.

Table 6. Parallel trend test results. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

EWP	Regression Coefficient	t Value	P > |t|
2011	0.158	0.92	0.357
2012	0.153	0.89	0.373
2013	0.148	0.86	0.389
2014	0.470 **	2.74	0.006
2015	0.559 **	3.27	0.001
2016	0.410 *	2.39	0.017
2017	0.589 **	3.41	0.001
2018	0.656 ***	3.83	0.000
cons	9.100 *	2.59	0.010

4.3.2. Placebo Test

The purpose of conducting a placebo test in this paper is indeed to rule out the possibility of other exogenous variables influencing the experimental results and potentially causing an overestimation or underestimation of the impact of the CETP implementation.

As shown in Table 7, Column 6, by advancing the implementation of the policy by 1 year and 2 years, we can examine whether there are any significant effects from these other exogenous factors during the experimental period. If such effects exist, the $CETP_{i,t}$ coefficient should be significant. However, as indicated in Column 6 of the analysis, the $CETP_{i,t}$ coefficient remains insignificant regardless of whether the policy implementation is advanced by 1 or 2 years. This suggests that the observed change in urban EWP can be attributed to the implementation of the CETP itself rather than other external factors.

Table 7. Other robustness tests' results.

Variable	Placebo Test		Substitution of Explanatory Variables	Consideration of Other Policy Implications
	Front_1	Front_2	GTFP	LCCP
	(6)		(7)	(8)
$CETP_{i,t}$	0.175	0.176	0.026 ***	0.281 **
	(1.57)	(1.19)	(2.77)	(2.28)
Control	Controlled	Controlled	Controlled	Controlled
Urban	Controlled	Controlled	Controlled	Controlled
Year	Controlled	Controlled	Controlled	Controlled
N	3036	3036	3036	1032
R^2	0.211	0.210	0.116	0.101
F value	46.452 ***	45.303 ***	37.454 ***	12.375 ***

Note: Front_1 and Front_2 represent the assumption that the CETP is implemented one and two years ahead of the scheduled timeline, respectively. *** $p < 0.01$, ** $p < 0.05$.

4.3.3. Substitution of Explanatory Variables

EWP, which integrates the evaluation indicators of "economy, environment, and human well-being," is an extension of the concept of quality development. This research replaces the original explanatory variable EWP for the robustness test with the green total factor productivity (GTFP). This indicator is frequently used in the literature to quantify regional development quality [56]. As shown in Table 7, Column 7, the result further validates H1 by demonstrating that when GTFP is used to represent the development quality level of the city.

4.3.4. Consideration of Other Policy Implications

If the country introduces other relevant policies on carbon emission reduction during the observation period, it may also impact the experimental results. In 2010, the low-carbon city policy (LCCP) was implemented, and up to now, there have been three batches of provinces and municipalities to carry out pilot work, including five provinces and eight municipalities in 2010, one province and 28 municipalities in 2012, as well as 45 localities and municipalities in 2017. Implementing LCCP can enhance GTFP and successfully cut carbon emissions in pilot cities [57]. Therefore, the cities that participated in the LCCP in the previous two batches (86 prefectural cities) were the new overall sample. This paper re-conducts the DID experiment using the prefectures that participated in both policies (a total of 34 prefectural cities) as the group under experimentation and the cities that took part in the LCCP only (a total of 52 prefectural cities) as the control group, in order to exclude the role of the LCCP on the EWP of cities. The robustness of the conclusions of this article is further confirmed in Table 7, Column 8, showing that the EWP of the cities implementing CETP is still significantly enhanced among all the cities participating in the LCCP.

4.4. Validation of Impact Mechanisms

After DID experiments and several robustness tests, evidence has shown that the CETP can effectively improve the urban EWP. In order to explore the CETP's intrinsic impact mechanism within the EWP, the following section selects the mediator variables regarding the capacity for green innovation and the shift in industrial structure, as shown in Table 8.

Table 8. Mechanism test results. *** $p < 0.01$, ** $p < 0.05$.

Variable	Indust (9)	EWP (10)	lninnov (11)	EWP (12)
$CETP_{i,t}$	0.076 ***	0.272 ***	0.019	0.294 ***
	(4.17)	(2.92)	(0.44)	(3.16)
Indust		0.261 **		
		(2.43)		
lninnov				−0.114 ***
				(−2.47)
Control	Controlled	Controlled	Controlled	Controlled
Urban	Controlled	Controlled	Controlled	Controlled
Year	Controlled	Controlled	Controlled	Controlled
N	3036	3036	3036	3036
R^2	0.146	0.116	0.116	0.116
F value	43.877 ***	35.350 ***	35.362 ***	33.483 ***

From Columns 9–10, it can be seen that the transmission effect from CETP to industry is remarkably positive. The transmission coefficients between industry and EWP and the core variable are also significant, indicating that improving the industrial structure is a crucial approach for CETP to enhance the city's EWP. H_3 is verified.

The results of Column 11 show that CETP did not promote EWP by promoting the technological innovation of firms. In other words, the mediating effect is invalid, and hypothesis H_2 is rejected. The CETP has not led to a significant increase in the level of green technology innovation in the pilot areas, which may be attributed to the fact that, according to the theory of the pollution paradise hypothesis, within carbon quota restrictions, highly polluting and energy-intensive businesses may choose to move directly to other regions that have not yet implemented a carbon trading system [58]. The remaining enterprises inevitably increased their production costs, squeezed their R&D investments, and expanded their financing constraints to achieve their emission reduction targets [59]. Whether relocating or conducting in-situ abatement, excessive costs can cause a company's earnings to drop or even go out of business. In addition, China is now in the pilot program for trading carbon emissions; the overall allocation of carbon trading credits is relatively loose, and the corresponding laws and regulations must be revised. The seven pilot markets' combined level of maturity could be low due to significant price volatility, a tiny market size, and poor market efficacy and activity [60]. The prospect of carbon emissions trading must be clarified and provide long-term practical policy guidance for market participants. As a result, enterprises tend to adopt a passive or even antagonistic stance toward green innovation, and enthusiasm for green innovation is low [61].

5. Conclusions

In advocating high-quality economic development, this paper, based on the intrinsic requirements of high-quality development, improves the measurement index system of EWP. The Super-SBM model was used to calculate the EWP of 253 cities in China from 2010 to 2021 and measure the quality of urban development with it. The results show that the spatial distribution of EWP in Chinese cities shows a distribution pattern of high in the east, low in the west, and lowest in the center. However, the overall urban EWP oscillated upward during the study period. After 2015, technological advancements were more critical to advancing EWP than technological efficiency improvements. Raising the nation's technological innovation level is necessary for advancing the quality of economic development.

On this basis, the impact of CETP on EWP in the pilot cities was examined using the DID method. The results indicate that the implementation of CETP can significantly improve the EWP of the pilot cities, and this result passes a series of robustness tests such as the parallel trend test, substitution of explanatory variables, the placebo test, and the consideration of the impact of other similar environmental regulation policies in the same period. The mediator variables are selected to analyze the influence mechanism of CETP on EWP, and it is found that CETP can further promote urban EWP by optimizing the city's industrial structure and then enhancing the quality of urban development. However, the mediating effect of technological innovation is not significant. Heterogeneity analysis found that the pilot policy for advanced cities' EWP enhancement role is significantly better than that of ordinary cities. On the other hand, CETP also has regional variability that can significantly improve the energy and environmental efficiency of the central and eastern regions, especially the central region, and the role of the western region for the city is not apparent.

Overall, the level of China's EWP is steadily increasing, which indicates that we are making significant progress towards achieving high-quality development. This is a promising trend for our society and the environment. When it comes to the spatial distribution of EWP, it has been observed that the central cities of China have the lowest level of EWP. Meanwhile, the implementation of the CETP has played a crucial role in elevating the level of EWP in the central region. This suggests that CETP has proven to be effective and targeted in improving environmental well-being in these areas. This finding aligns with the conclusions drawn in previous studies on the topic.

However, it is important to recognize that CETP is not without its shortcomings. In recent years, technological innovation has emerged as a dominant factor in enhancing the overall level of urban EWP. Unfortunately, the implementation of CETP has not fully utilized the potential of technological innovation to improve urban EWP. As a result, this paper takes a pessimistic view of the long-term effectiveness of CETP in promoting urban EWP.

Nevertheless, some scholars argue that CETP can indeed encourage enterprises to engage in green technological innovation. The difference in research conclusions may arise from variances in the selection of indicators for green technological innovation. Most proponents of CETP use the number of patent applications [62] or R&D expenditures [63] as indicators of green innovation, but these may not truly represent the innovation ability of enterprises. This paper proposes the number of green patents granted as a better indicator of green innovation. There are several reasons for this choice: Firstly, green patents are a concentrated manifestation of enterprises' innovation activities in green environmental protection, which has clearer value connotations compared to enterprises' R&D investments. Secondly, the approval time for patent applications is longer, and using the number of patents granted instead of the number of patent applications has more timeliness in measuring the impact of the implementation of the carbon emissions trading policy on technological innovation. Moreover, the study that also used the number of patents granted as a representative indicator obtained results consistent with this paper [64].

In summary, while the overall level of EWP is on the rise, indicating positive progress, there is room for improvement in the implementation of CETP to better harness the power of technological innovation. Further research and analysis are needed to optimize the effectiveness of CETP and ensure sustainable and high-quality development in urban areas.

6. Policy Implications

The study suggests the following policy implications in light of the results mentioned above:

Firstly, the establishment of a national carbon trading market is an important step towards achieving China's ambitious targets for promoting high-quality development. To realize this goal, the government should draw on the experience gained from the carbon trading pilot projects and develop a comprehensive strategy for establishing a national carbon trading market as soon as possible. One key aspect of this strategy is the improvement of relevant rules and regulations to guide the behavior of enterprises. Clear and well-defined regulations can incentivize companies to participate in the carbon trading market and ensure that carbon emissions are effectively reduced. This, in turn, can drive the adoption of cleaner technologies, improve the production efficiency of enterprises, and stimulate economic growth.

Additionally, it is important to recognize that carbon trading policies should not be one-size-fits-all but rather tailored to local conditions. This means that policies should be designed in consideration of regional economic and environmental characteristics, as well as local industrial structures and energy consumption patterns. To facilitate policy spillover from advanced cities to neighboring cities, the government should also encourage intercity cooperation and collaboration. This could involve sharing best practices, providing technical assistance, and promoting knowledge exchange between cities. By leveraging the strengths of more advanced cities, less developed regions can benefit from their experience and expertise and accelerate the adoption of low-carbon technologies and practices. Meanwhile, attention should be paid to cities in the central region, which are the cities with the most room for EWP progress. The government should increase support for these regions, both in terms of financial resources and technical assistance. This could include providing financial incentives for enterprises in these regions to participate in the carbon trading market, as well as providing training and capacity-building programs to help them understand the benefits and requirements of carbon trading.

Finally, the government should provide support for research and development of low-carbon technologies to accelerate the transition to a greener and more sustainable economy. This could involve providing tax incentives or subsidies for companies that invest in research and development of low-carbon technologies, as well as promoting collaboration between industry and research institutions to accelerate the development and adoption of new technologies.

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