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Can the construction of ecological civilization pilot demonstration areas improve urban green total factor productivity? Evidence from China

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Improved urban green total factor productivity contributes to the enhancement of the global ecological environment and the promotion of sustainable development. This paper constructs a multiperiod double-difference model using a quasi-natural experiment and investigates the impact of constructing ecological civilization pilot demonstration areas on urban green total factor productivity based on data from 261 cities in China from 2007 to 2020. The results indicate that building ecological civilization pilot demonstration areas can elevate urban green total factor productivity, particularly in nonresource-based cities and medium-sized to large cities. The mechanism operates through two main channels: Enhancing government environmental concern and promoting the development of high-tech industries in the region. The findings of this study can offer Chinese insights for the global assessment of green city policies.

KEYWORDS

ecological civilization pilot demonstration areas, urban green total factor productivity, multiperiod double-difference model, quasi-natural experiment, green city policy evaluation

1 Introduction

Against the backdrop of increasingly severe ecological challenges worldwide such as natural disasters and climate change, achieving sustainable and coordinated development across economic, environmental, and social dimensions has become an inevitable choice for all countries across the globe. The United Nations General Assembly adopted the 2030 Agenda for Sustainable Development in 2015, and the exploration of a sustainable development model has been advocated worldwide (Zhao et al., 2022). Over the past few decades, China's economy has developed rapidly, and it has become the second largest economy in the world. However, rapid economic development has also led to ecological and environmental problems, such as the depletion of some resources and the degradation of the ecological environment in some areas (Wu et al., 2014). Based on relevant data from the Statistical Review of World Energy (2024) and the International Energy Agency (IEA), in 2023, China's primary energy consumption reached 171.64 EJ, far exceeding the combined total of major energy-consuming countries (the United States, Russia, and India). Moreover, in 2023, China's total carbon dioxide emissions hit a new record high of

12.6 billion tons, with its increment representing the largest global increase to date. Against this backdrop, promoting the transition to green development and achieving sustainable development goals hold crucial strategic significance for enhancing human wellbeing and fostering sustainable economic growth.

China has been persistently exploring an indigenous eco-governance policy framework tailored to its unique national context, with the dual objectives of intensifying environmental conservation efforts and accelerating the transformation of ecological reform. This endeavor seeks to achieve paradigm-shifting advancements in the realm of ecological management, propelling the formation of a modernized development trajectory characterized by harmonious coexistence between humanity and nature. A seminal milestone in this journey was the 2013 promulgation by the Ministry of Environmental Protection of the "National Eco-Civilization Construction Pilot Demonstration Zone Indicators (Provisional)," which systematically delineated the foundational prerequisites and specific performance benchmarks for designating model zones. This pivotal initiative marked China's transition from conceptual advocacy to regional implementation in its eco-civilization development endeavors. The 20th National Congress of the Communist Party of China (CPC) issued pivotal directives concerning the proposition that "Chinese-style modernization is the modernization of harmonious coexistence between man and nature."

The Chinese government has successively introduced the construction of Ecological Civilization Pilot Demonstration Areas (ECPDA), Provincial Ecological Civilization Pilot Demonstration Areas, low-carbon city pilot policies, and carbon emissions trading pilot policies. These integrated measures aim to build a green, low-carbon and circular development model, and fully leverage the demonstration and leading effects of specific regions in sustainable development practices. The construction of ECPDA is an important measure for the Chinese government to explore sustainable development. This type of area is a quasi-natural at the urban level, and its experimental results are an important reference for the green transformation of cities in developing countries. The effectiveness of such regional policies is further exemplified by studies like Yuan et al. (2024), who analyzed trans-jurisdictional cooperation mechanisms in water pollution management, demonstrating how coordinated governance frameworks can address cross-boundary environmental challenges, a critical dimension of eco-civilization pilot programs.

Many scholars are committed to exploring the impact of the construction of ECPDA on urban sustainable development, but there is still no consensus (Chai et al., 2022). Some scholars have also conducted research on whether this policy can help improve the level of green total factor productivity in cities (Jiang L Y, 2022), but they focus more on the treatment effect of this policy on some regions or provincial regions, leaving unresolved the broader question of whether this policy instrument universally contributes to elevated urban green total factor productivity (UGTFP). The 20th CPC National Congress Report proposes a strategic framework that synergizes "pollution reduction, green expansion, and economic growth," leveraging green total factor productivity enhancement as the endogenous driver to construct a green development paradigm for Chinese modernization.

UGTFP serves not only as a vital indicator for measuring the sustainable development of cities, but also as a critical benchmark for evaluating the coordination between resource utilization efficiency and environmental impact during economic development. At its core, GTFP aims to achieve economic growth while minimizing the adverse impacts on resources and the environment, striving to attain maximum economic, social, and ecological benefits with minimal resource consumption (Zhao, 2023). This concept aligns profoundly with the core objectives of the Eco-Civilization Demonstration Zone Program, wherein institutional innovation and technological advancement are harnessed to drive green transitions—essentially representing a practical exploration of GTFP theory in policy implementation. This concept transcends the limitations of traditional productivity metrics, which primarily focus on factor inputs such as capital and labor, by integrating environmental factors like energy consumption, pollutant emissions, and ecological degradation into its analytical framework. This approach embodies the core tenets of sustainable development. Unlike traditional total factor productivity, UGTFP incorporates undesirable outputs such as carbon emissions into the measurement system, including sustainable development, thus allowing for a more comprehensive assessment of economic performance (Lin and Chen, 2018). This approach aligns with empirical studies such as Yuan et al. (2023), who demonstrated the feasibility of decoupling economic growth from resource-environmental pressures in the Yangtze River Economic Belt, highlighting the critical role of integrating ecological costs into productivity evaluations. At present, the literature mainly studies the impact of financial technology (Hu and Li, 2023; Lee and Lee, 2022), digitalization (Lyu et al., 2023; Liu et al., 2024) and other factors on the level of UGTFP. However, few studies have explored the impact of ECPDA on the level of UGTFP.

Based on the above discussion, three questions arouse our interest: Can the construction of ECPDA improve the level of UGTFP? What is its realization path and mechanism? Does such promotion have a heterogeneous effect due to the city's own characteristics? Therefore, taking 261 prefecture-level cities in China from 2007 to 2020 as the research object, this paper constructs a multiperiod double-difference model (DID) to explore the impact of the construction of ECPDA on UGTFP and analyses its mechanism and heterogeneity effects to provide a reference for urban green transformation in developing countries. This study bridges empirical analysis with three theoretical pillars: First, Porter's Hypothesis (Porter and Linde, 1995) elucidates how ECPDA's institutional pressure catalyzes innovation compensation—transforming environmental constraints into productivity gains through high-tech industry clustering. Second, the Attention-Based View (Ocasio, 1997) explains governmental prioritization shifts, where demonstration zones redirect fiscal and regulatory focus toward ecological modernization. Third, we integrate these into a Chinese institutional transition paradigm, wherein top-down policy signals interact with localized market responses to drive green total factor productivity—a mechanism empirically examined through our dual-channel design. This framework positions China's ecological civilization experimentation as a critical testbed for sustainability transition theories.

Compared with the literature, the main contributions of this paper are as follows: First, in terms of perspective innovation, this study transcends conventional single-policy impact evaluation frameworks by adopting GTFP as the focal observation point. It integrates the policy shock effects of the Eco-Civilization First-Mover Demonstration Zone Program into a dual-dimensional "policy-efficiency" analytical model, thereby offering a novel paradigm for dissecting the intrinsic linkages between environmental regulations and urban sustainable development capacity. Second, in terms of research content, the investigation delves into the potential transmission mechanisms through which the Eco-Civilization First-Mover Demonstration Zone Program drives urban GTFP, specifically examining two pathways: government environmental attention and regional high-tech industry development. This analysis provides data-driven insights to assist local governments in formulating targeted strategies for enhancing urban GTFP. Third, in terms of practical significance, the study constructs an "urban heterogeneity-policy response" analytical framework, revealing that the Eco-Civilization Demonstration Zone Program significantly elevates GTFP across both resource-based and non-resource-based cities, as well as cities of varying scales, *via* differentiated transmission mechanisms. This finding offers theoretical underpinnings for city-specific green transition strategies. Diverging from prior research, this study delivers three pivotal advances (Chai et al., 2022). First, it establishes urban green total factor productivity as a comprehensive metric integrating economic-environmental synergies. Second, it reveals dual transmission channels—specifically governmental prioritization of ecological concerns and high-technology industry clustering—through which ECPDA achieve impact. Third, it identifies critical heterogeneity thresholds contingent upon urban resource endowments and scale parameters, dimensions consistently overlooked in policy transfer scholarship. These contributions collectively enable precise policy design for developing nations' urban sustainability transitions while remedying theoretical deficiencies in productivity measurement frameworks and policy adaptation mechanisms.

The rest of the paper is organized as follows. The second part establishes the theoretical framework and hypothesis development, the third part details the research design, the fourth part presents empirical analysis, the fifth part delves into the operational mechanisms and heterogeneous effects, the sixth part concludes with a summary of key findings and proposes corresponding policy recommendations.

2 Theoretical framework and hypothesis development

2.1 Institutional background

In recent years, the Chinese government has been emphasizing the construction of an ecological civilization, which is a concept focused on environmental sustainability and ecological balance in economic and social development. The core of ecological civilization is to pursue the coordination and balance between economic growth and ecological environmental protection. To realize the concept of ecological civilization, the Chinese government has adopted a series of policies and institutional measures. For example, in 2011, to strengthen the construction of an ecological civilization in the western region, the National Development and Reform Commission of China, together with the Ministry of Finance and the State Forestry Administration, promulgated the Notice on the Pilot Opinions on the Demonstration Project of Ecological Civilization in the western region. To further emphasize the status and role of the construction of an ecological civilization, the report of the 18th National Congress of the Chinese Government puts the construction of an ecological civilization in a prominent position and incorporates it into the overall layout of socialist modernization. Based on this, the National Ecological Civilization Construction Pilot Demonstration Zone Indicators (Trial) was released in May 2013. In August 2013, the State Council issued the Opinions on Accelerating the Development of Energy-saving and Environmental Protection Industries. The document explicitly proposes the establishment of 100 Ecological Civilization Pilot Demonstration Areas in China to encourage local governments to actively explore and innovate in ecological protection and sustainable development. After the release of the document, the National Development and Reform Commission, together with six other departments, jointly issued the Notice on the Issuance of the Construction Plan for the National Ecological Civilization Pilot Demonstration Area (Trial Implementation) and included 102 areas, such as Miyun County in Beijing, in 2014 and 2015. The establishment of ECPDA aims to help demonstration zones explore environmentally friendly development paths by providing policy support, capital investment and related supporting measures. These demonstration zones are expected to become a model for the construction of ecological civilizations and provide experience and reference for other regions.

2.2 Literature review

2.2.1 Evaluation of the policy effect of the ECPDA

There are two main types of literature on the policy effects of the construction of ECPDA. The first kind of literature is mainly from a qualitative point of view. These scholars demonstrate the rationality and necessity of constructing ECPDA through theoretical analysis. The authors summarize the experience and lessons in the process of ecological civilization construction in pilot cities to construct and improve the evaluation index system for the construction of ECPDA. Specifically, Meng et al. (2021) analyze the theoretical basis and development context of the construction of ECPDA and suggest that we should adhere to the concept of green development and transform "green water and green hills" into "golden mountains and silver mountains." The second kind of literature is mainly from a quantitative point of view. On the one hand, scholars test the effect of green development on the construction of ECPDA on enterprise innovation transformation at the micro level. Chen et al. (2022) construct a double difference model (DID) and a triple difference model (DDD) and find that the construction of ECPDA promote investment in the science and technology of growth-oriented enterprises in demonstration zones. Bai et al. (2023) construct a new SC-DID model and report that the number of green utility model (GUP) patents in pilot provinces

increase by 38.1% on average after the construction of ECPDA, while the number of green invention patents (GIPs) increase by only 23.1%. On the other hand, scholars study the impact of the construction of ECPDA on the ecological and social benefits of pilot cities at the macro level. Chai et al. (2022) report that the construction of ECPDA can reduce the carbon emission intensity of pilot cities and promote their ecological efficiency. Li et al. (2022) suggest that the construction of ECPDA could promote the balance between the economic benefits and green efficiency of pilot cities. In addition, the effect of the construction of ECPDA on the improvement of carbon emission efficiency in different types of cities is also heterogeneous (Li and Han, 2023).

2.2.2 Influencing factors of UGTFP

There are abundant studies on the influencing factors of UGTFP, mostly focusing on financial science and technology, environmental regulation and the digital economy.

First, green finance promotes the improvement of UGTFP. Lee and Lee (2022) conduct an empirical study using panel data from 30 provinces in China and find that the development of green finance can significantly improve the UGTFP. They also find that the effect tends to be stronger in provinces with better economic and social conditions, lower public participation in environmental protection and higher pollution levels. Hu and Li (2023) find that the level of urban financial science and technology has a significant role in promoting UGTFP, and the upgrading of the industrial structure and technological innovation are the intermediary mechanisms of this path.

Second, there is a close relationship between environmental regulation and UGTFP. Some scholars believe that environmental regulation has a negative impact on UGTFP by increasing the extra cost of normal production and operation. Greenstone et al. (2012) prove that environmental regulation leads to a substantial increase in the cost of corporate compliance, inhibits productive investment and green innovation activities, and has a negative impact on the level of UGTFP. Other scholars believe that reasonable environmental regulation can produce an innovative compensation effect. Specifically, command-and-control environmental regulation can improve urban total factor productivity by inducing technological innovation, optimizing industrial structure, improving scale efficiency, and promoting coordinated regional development (Tian and Feng, 2022). In addition, environmental regulation not only has a significant positive impact on local total factor productivity but also makes a significant contribution to green total factor productivity in neighboring areas (Fan et al., 2022).

Finally, the rapid development of the digital economy will promote the UGTFP. Lyu et al. (2023) suggest that the digital economy can improve the level of UGTFP by promoting technological innovation, saving energy and reducing emissions, and increasing market uncertainty. In addition, the rapid development of the Internet has a nonlinear impact on UGTFP (Li et al., 2020).

In summary, the literature mostly focuses on a single level of policy effect evaluation of the construction of ECPDA, such as carbon emissions, air quality in terms of environmental benefits, or residents' health level in terms of social benefits. This will lead to the separation of the potential relationships between UGTFP and social and economic development. Moreover, most of the related studies on the influencing factors of UGTFP concentrate on the fields of financial science and technology, environmental regulation and the digital economy, and few involve in-depth studies on how government ecological environment policies affect UGTFP.

2.3 Hypothesis development

As a policy innovation, the construction of ECPDA actively guides China's regions to promote regional green development while pursuing the organic combination of economic development and environmental protection. The construction of ECPDA play an important role in eliminating barriers to environmental regulation policies.

First, the construction of ECPDA can increase the attention of local governments on ecological environment protection through guidance and demonstration to increase local financial expenditure on environmental protection and promote the level of UGTFP. To support the construction of an ecological civilization, the government usually gradually improves upon the relevant laws and regulations. These regulations help to improve the management of environmental protection affairs and make environmental protection work valued within the government system (Hafezi and Zolfagharinia, 2018). Additionally, these measures incentivize businesses to adopt sustainable production practices and invest in green technologies, thus boosting UGTFP. The government's emphasis on environmental protection not only supports sustainable development but also encourages technological innovation, particularly in environmentally friendly production methods (Rothwell, 1992; Liu et al., 2020). This, in turn, stimulates market demand for green products and services, further enhancing UGTFP.

Second, ECPDA attracts high-tech talent and enterprises to demonstration zones, fostering the growth of regional high-tech industries. On the one hand, the focus on green technology and environmental innovation within ECPDA appeals to professionals engaged in advanced research, leading to technological breakthroughs and the development of green industries (Weng and McElroy, 2010). On the other hand, government support in these areas, including financial and tax incentives, further attracts businesses and reduces operational costs. High-tech industries, which often employ clean energy and energy-saving technologies, contribute to reducing resource consumption and emissions, thereby promoting sustainable urban development and improving UGTFP.

In summary, the construction of ECPDA may enhance the level of UGTFP by enhancing the government's environmental attention and promoting the development of regional high-tech industries. Therefore, Hypothesis 1 is proposed in this paper.

Hypothesis 1: The construction of ECPDA can significantly improve the level of UGTFP.

Given the heterogeneity of urban resources and scale, the impact of ECPDA on UGTFP may differ significantly across cities with distinct characteristics.

On the one hand, in terms of city type, resource-based cities usually face the problem of overexploitation of natural resources. To

obtain short-term economic benefits, some cities may suffer from overlogging and overexploitation, resulting in environmental deterioration, resource depletion and "resource curse," which is not conducive to improving UGTFP (Cheng et al., 2021). In addition, these cities tend to lag in technological innovation, limiting their capacity for green production (Fan and Zhang, 2021). Therefore, the effect of the construction of ECPDA on the improvement of UGTFP in resource-based cities may be very limited.

On the other hand, in terms of urban area, smaller cities have relatively limited natural resources and land. This may make it difficult for cities to carry out large-scale green infrastructure construction, such as green energy projects and ecological parks, which may limit the development of UGTFP. In addition, Moreover, the lack of economies of scale in smaller cities can result in higher production costs and lower efficiency in green industries (Frick and Rodríguez-Pose, 2018). Therefore, it may be more difficult to improve the level of UGTFP in smaller cities. Therefore, Hypothesis 2 is proposed in this paper.

Hypothesis 2: *The construction of ECPDA has a more significant effect on the improvement of UGTFP in nonresource-based cities and medium-sized and large cities.*

3 Research design

3.1 Models and variables

3.1.1 Model

Ashenfelter (1978) was the first to introduce the Difference-in-Differences (DID) model into the field of economics for evaluating the net effect of training programs on participants' earnings. Subsequently, Zhou and Chen (2005) pioneered the application of the DID methodology in Chinese policy evaluation by examining the tax-for-fee reform. They treated pilot cities as natural experimental groups and quantified the reform's impact on farmers' income through the DID model, thereby establishing the foundational framework for DID methodology in Chinese empirical research. This seminal work not only achieved the localization of DID models in China but also constructed the methodological cornerstone for empirical economic research in the country. It opened new avenues for subsequent large-scale policy effect studies by demonstrating the feasibility and effectiveness of DID methodology in Chinese contexts. Generalized DID serves as an extension of the conventional DID methodology, primarily employed to evaluate the causal effects of policies or interventions in scenarios characterized by phased implementation and time-varying treatment statuses.

This paper utilizes the Generalized DID method to examine the impact of the construction of ecological civilization pilot zones on GTFP. By comparing changes in GTFP between cities within the pilot zones (treatment group) and those outside the zones (control group) before and after policy implementation, the Generalized DID method effectively eliminates the interference of confounding factors such as macroeconomic fluctuations and inherent urban characteristics. This approach provides "purified" evidence for assessing the true effectiveness of the pilot zone policies. First, according to the basic principles of the Generalized DID model, we set up two dummy variables. One is the individual dummy variable (Treat). If the city is a construction city of ECPDA, the value of the dummy variable (Treat) is 1; otherwise, the value is 0. This dummy variable is used to describe the difference between the experimental and control groups. The second is the time dummy variable (Post). In this paper, the time dummy variable (Post) for the year after a city is selected as the ECPDA is defined as 1, and the year before the city is selected is defined as 0. Post is used to distinguish differences before and after the construction of the ECPDA. The interaction term of two dummy variables (Treat × Post) is denoted by DID. DID is the core explanatory variable for the construction of ECPDA. Considering the temporal differences among different cities in the construction of ECPDA, this paper sets up a progressive double-difference model based on Beck et al. (2010). The details are as follows.

$$GTFP_{it} = \alpha + \beta_1 DID_{it} + \gamma X_{it} + \delta_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Specifically, i and t represent the city and year, respectively; GTFP is the explained variable representing UGTFP; DID is the policy variable for the construction of ECPDA; X is a series of control variables; δ_i And λ_t represent the urban fixed effect and the time fixed effect, respectively; and ε_{it} represents the random error term.

3.1.2 Variables

The explained variable is the level of UGTFP (GML). Referring to Li and Shi (2014), this paper constructs a super efficient SBM model with undesirable outputs to solve the problems of variable relaxation and effective DMU. The input indicators include labor input, capital input and energy input. Labor input is expressed as the sum of the number of employees in units and the number of private and individual employees in each city at the end of the year. The capital stock is estimated by the perpetual inventory method and expressed by the total investment in fixed assets of the whole city. The energy input uses social electricity consumption as a proxy indicator. The expected output is expressed by the actual GDP of the whole city, and the unexpected output is expressed by the industrial SO_2 emissions, industrial wastewater emissions and industrial soot emissions of the whole city.

The explanatory variable is the policy variable (DID) for the construction of the ECPDA. This variable is the interaction of an individual dummy variable (Treat) and a time dummy variable (Post), and its regression coefficient represents the net impact of the construction of ECPDA on UGTFP.

To overcome the endogeneity problem caused by the omission of variables in policy evaluation related to the construction of ECPDA, this paper controls for a series of factors that may affect urban total factor productivity on the basis of existing research. Specifically, the following control variables are included. The variables are defined in Table 1.

(1) Scale of the city: Expressed by the logarithm of the number of employees at the end of the period in the city;
(2) Population density: Expressed by the logarithm of the ratio of the urban permanent population to the administrative area;
(3) Economic development level: Expressed by the logarithm of urban *per capita* GDP;
(4) Public budget expenditure (Fiscal): Expressed as the logarithm of local general public budget expenditure;

TABLE 1 Definition of each variable.

Category	Variables	Symbol	Definition
Explained variable	Green total factor productivity	*GML*	Constructing a Super-Efficiency SBM Model with Undesired Output
Explanatory variable	Establishment of ECPDA	*DID*	The interaction item Treat × Post between the dummy variable of policy implementation time and the dummy variable of implementation area
Control variable	City size	*Scale*	Log (number of employees in the city at the end of the period)
	Population density	*Density*	Log (number of permanent urban residents/number of square kilometers of administrative area)
	Level of economic development	*Economic*	Log (urban GDP *per capita*)
	Public budget expenditure	*Fiscal*	Log (local general public budget expenditure)
	Level of urbanization	*Urban*	Log (urban building area/total area)
	Financial Development	*Finance*	Log (total loan balance of financial institutions at the end of the year/nominal GDP)
Mediating variable	Environmental concern	*Rul*	Total number of employees in water conservancy, environment and public facilities management industry/annual average number of employees
	Development of high-tech industries	*Tec*	Total number of employees in scientific research, technical services and geological exploration/annual average number of employees

Table provides the results of the definition of each variable.

(5) Urbanization level (Urban): Expressed by the logarithm of the ratio of urban building area to total area;
(6) Financial development level (Finance): This variable is expressed by the logarithm of the ratio of the total loan balance of financial institutions to the nominal GDP at the end of the year.

3.2 Samples and data

By 2015, two batches of 100 cities (districts) in China are selected as the construction list of ECPDA. This fully ensures that the number of samples in the experimental group and the control group in this study is sufficient. The selected cities (districts) are widely distributed in different regions of China, so there are significant differences in population size, geographical area and economic development level among the samples, which can avoid sample selection bias. The detailed sample screening process is as follows: First, because the construction of ECPDA includes three levels of municipalities, prefecture-level cities and county-level cities, to ensure that the research samples can form a better contrast, this paper excludes the urban samples of municipalities and county-level cities and retains only the samples of prefecture-level cities. Second, given that the construction of pilot demonstration zones for ecological civilization advancement encompasses regions at three different administrative levels, namely, municipal districts under direct jurisdiction of central government, prefecture-level cities, and county-level cities, and considering that the impacts of this policy vary across different administrative divisions such as provinces, cities, and districts/counties, in order to ensure effective comparability, this paper excludes the samples of cities in the central municipalities and county-level cities, and this paper only retains the sample of prefecture-level cities as the object of the study. Finally, this paper excludes the city of Lhasa, which has a serious lack of data. The total sample includes 261 prefecture-level cities, 47 selected cities in the experimental group and 214 unselected cities in the control group. The data in this paper are from the China Urban Statistical Yearbook, China Environmental Statistical Yearbook and Statistical Yearbook of each city. For some missing data, this paper uses the linear interpolation method.

3.3 Descriptive statistics

The descriptive statistics of the full sample are shown in Table 2. The annual average UGTFP (GML) is 1.002, the standard deviation is 0.043, the minimum value is 0.488, and the maximum value is 1.438. This shows that the level of UGTFP among cities is quite different. The explanatory variable (DID) had a mean of 0.078 and a standard deviation of 0.269.

4 Empirical analysis

4.1 Benchmark regression

Table 3 shows the benchmark regression results. In Table 3, Model 1 gives the regression results without any control variables. In Model 1, the regression coefficient for DID is 0.00936 and is significant at the 5% level. This shows that the construction of ECPDA has promoted the improvement of UGTFP in pilot cities. This may be because the construction of ECPDA can enhance local governments' attention on the ecological environment, attract more ecological environment research talent to produce scale effects in the demonstration area, and achieve breakthroughs in advanced technology for ecological environment protection. Examples include renewable energy and carbon capture, utilization and storage technologies (Xu and Li, 2020; Yan et al., 2020; Zhao et al., 2022). This has led to the improvement of UGTFP in pilot cities. This result is consistent with that of Chai et al. (2022).

Model 2 adds the city scale (Scale) as a control variable on the basis of Model 1. In Model 2, the regression coefficient of the explanatory variable (DID) is positive and is significant at the 5%

TABLE 2 Descriptive statistics.

Variables	Mean	Sd	Min	Max	P50	N
GML	1.002	0.043	0.488	1.438	0.999	3,584.000
Treat	0.184	0.387	0.000	1.000	0.000	3,584.000
Post	0.078	0.269	0.000	1.000	0.000	3,584.000
DID	0.078	0.269	0.000	1.000	0.000	3,584.000
Scale	4.454	1.534	−17.016	7.728	4.521	3,584.000
Density	5.736	0.959	−1.368	7.882	5.941	3,584.000
Economic	10.529	0.677	4.595	13.056	10.527	3,584.000
Fiscal	14.564	0.842	11.271	17.643	14.590	3,584.000
Urban	1.644	1.088	−3.912	5.375	1.683	3,584.000
Finance	16.594	1.086	13.384	20.673	16.511	3,584.000

Table provides the results of the descriptive statistics. Table 1 shows the meaning of each variable. The basic data are from the China Urban Statistical Yearbook, China Environmental Statistical Yearbook and Statistical Yearbook of each city.

TABLE 3 Benchmark regression results.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	GML	GML	GML	GML	GML	GML	GML
DID	0.00936**	0.00930**	0.00905**	0.00905**	0.00914**	0.00908**	0.00879**
	(0.00423)	(0.00426)	(0.00426)	(0.00426)	(0.00424)	(0.00422)	(0.00419)
Scale		−0.000159	−0.000139	−0.000139	−0.000200	−0.000127	−0.000181
		(0.000726)	(0.000723)	(0.000723)	(0.000747)	(0.000730)	(0.000712)
Density			−0.00468*	−0.00467*	−0.00424	−0.00442	−0.00417
			(0.00278)	(0.00278)	(0.00274)	(0.00274)	(0.00267)
Economic				−0.000134	0.00193	0.00236	0.00406
				(0.00394)	(0.00408)	(0.00417)	(0.00444)
Fiscal					−0.00874*	−0.00888*	−0.00593
					(0.00517)	(0.00516)	(0.00520)
Urban						−0.00227	−0.00209
						(0.00375)	(0.00375)
Finance							−0.0135**
							(0.00667)
Constant	1.001***	1.002***	1.028***	1.030***	1.133***	1.135***	1.298***
	(0.000332)	(0.00329)	(0.0162)	(0.0432)	(0.0760)	(0.0753)	(0.110)
City FE	Y	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y	Y
Observations	3,584	3,584	3,584	3,584	3,584	3,584	3,584
Adjusted R^2	0.139	0.139	0.139	0.139	0.139	0.140	0.140

Table provides the results of the benchmark regression. Table 1 shows the meaning of each variable. "* * *" indicates significance at the level of 1%, "* *" indicates significance at the level of 5%, and "*" represents significance at the level of 10%. The standard error is given in parentheses. The basic data are from the China Urban Statistical Yearbook, China Environmental Statistical Yearbook and Statistical Yearbook of each city.

level, indicating that the results are robust. Moreover, the regression coefficient of the scale is −0.000159 but not significantly. An increase in the urban scale means the excessive agglomeration of population, economy and industry, which leads to an imbalance of factor allocation and congestion (Broersma and Oosterhaven, 2009). The congestion effect leads to the excessive agglomeration of similar industries and the formation of industrial isomorphism. Excessive industrial isomorphism will turn benign competition among enterprises into vicious competition, which is not conducive to urban economic development, and the level of UGTFP will decrease.

Model 3 adds a control variable, Density, to Model 2. In Model 3, the regression coefficient of the explanatory variable (DID) is 0.00905 and is significant at the 5% level. This shows that the construction of ECPDA has promoted the improvement of UGTFP in pilot cities. In addition, the regression coefficient of population density is −0.00468, which is significant at the 10% level, indicating that the level of UGTFP decreases by 0.468% when the population density increases by 1 unit. This is because an increase in urban population density usually means that the demand for fossil fuel energy combustion increases, and the scale of urban CO_2 emissions increases accordingly, which is not conducive to improving UGTFP.

Model 4 adds the control variable Economic development level to Model 3. In Model 4, the regression coefficient of the explanatory variable (DID) is 0.00905, and it is significant at the 5% level. In Model 5, we continue to add the control variable public budget expenditure (Fiscal), and the regression coefficient of the explanatory variable (DID) increases from 0.00905 to 0.00914, and all of them are significant at the 5% level. This shows that the construction of ECPDA has promoted the UGTFP. In addition, the regression coefficient of public budget expenditure (Fiscal) is −0.00874, which is significant at the 10% level. This shows that public budget expenditure inhibits UGTFP. This may be because the government has insufficient financial funds for green transformation and R&D. The government should pay more attention to investing the dividends brought about by economic development in the R&D of new green technologies (Godil et al., 2021). In particular, governments should focus on increasing public budget expenditures for energy research and sustainable development in the future (Ulucak, 2022).

Model 6 gives the regression results including the control variable Urbanization Level (Urban). In Model 6, the regression coefficient of the explanatory variable (DID) is 0.00908 and is significant at the 5% level. The regression coefficient of the urbanization level (Urban) is negatively correlated with the level of UGTFP, which indicates that the level of urbanization hinders the improvement of UGTFP. On the one hand, the spread of urbanization will emit more fine particulate matter and cause environmental pollution (Rahman and Alam, 2021). On the other hand, the spread of urbanization leads to the decentralization of urban industries and the low effect of economic agglomeration, which leads to high energy consumption and low efficiency in the production process; these conditions are not conducive to the pilot policy of pilot demonstration zones.

Model 7 gives regression results with all the control variables. In Model 7, the regression coefficient of the explanatory variable (DID) is 0.00879 and is significant at the 5% level. The regression coefficient of the level of financial development (Finance) is −0.0135, which is significant at the 5% level. The negative association between financial development and UGTFP in Model 7 reflects a critical developmental trade-off. In China's growth context, financial development initially prioritizes capital-intensive heavy industries (e.g., manufacturing, construction) that generate high pollution lock-in effects (Zhang et al., 2021). This mirrors the early-stage Environmental Kuznets Curve phenomenon, where financial expansion accelerates resource exploitation before environmental regulations mature (Sarkodie and Strezov, 2019). After controlling for individual effects, time effects and all control variables, the regression coefficient of the explanatory variable (DID) is still positive. This shows that the construction of ECPDA has steadily promoted the level of UGTFP. This result is consistent with that of Li et al. (2022).

In summary, the implementation of the ECPDA has improved the UGTFP of the pilot cities, and the results are robust. Hypothesis 1 is supported by this result.

4.2 Robustness test

Our research design inherently mitigates endogeneity concerns through three interconnected features of the ECPDA policy rollout: the phased implementation batches distinguishing 2014 and 2015 cohorts create quasi-randomized treatment timing that controls for time-invariant confounders *via* multi-period DID design; simultaneously, the documented geographic dispersion of demonstration cities enables spatial comparison groups validated through empirically verified pre-intervention parallel trends; furthermore, our inclusion of pre-treatment control variables captures time-varying confounders through strategic lagged specification. Collectively, these elements transform the policy's natural experimental properties into endogenous bias controls, complementing robustness checks with structural safeguards against selection bias.

4.2.1 Parallel trend test

The premise of using the progressive DID model is that the benchmark regression model meets the parallel trend assumption; that is, before the implementation of the policy of the ECPDA, there is no significant difference in the trend of UGTFP between the experimental group and the control group. Referring to Beck et al. (2010), this paper uses the event study method to test the parallel trend of the sample. The regression equation constructed in this paper is as follows:

$$GTFP_{it} = \alpha + \sum_{t=2007}^{2020} \beta \times Treat \times year_t + \gamma X_{it} + \delta_i + \lambda_t + \varepsilon_{it} \quad (2)$$

where $Year_t$ is a time dummy variable representing the year. If prefecture-level city i is listed in the policy list of ECPDA in year t, $Treat_{i,t} \times Year_t$ is assigned a value of 1; otherwise, it is 0. The control variables in Equation (2) are the same as those in Equation (1). To avoid multicollinearity, this paper takes the year 2013 before the implementation of the policy as the base period. Considering the problem of a sparse sample in some years, this paper uses the tail-shrinking processing strategy to regress the sample cities from

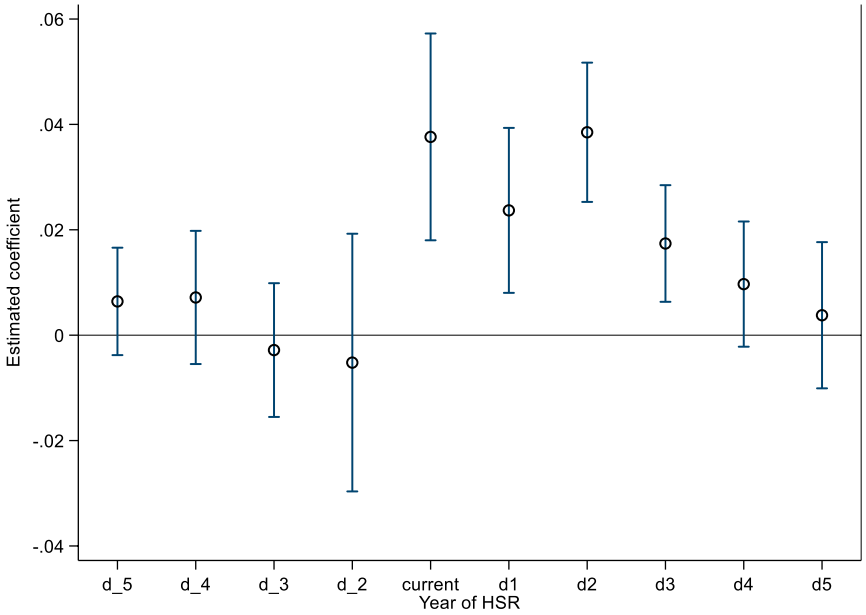

FIGURE 1
Parallel trend test.

2007 to 2008. Finally, for the parallel trend test, a symmetrical sample interval of 5 years before and after the implementation of the policy is obtained. If the regression coefficient of Treat $_{i,t}$ × Year $_t$ is not significant before the implementation of the policy, it indicates that there is no significant difference in the level of UGTFP between the experimental group and the control group; that is, through the parallel trend test.

Figure 1 shows the change trend and 95% confidence interval of the estimated parameter β_1 of the impact of the construction of an ECPDA on UGTFP. The coefficient of Treat $_{i,t}$ × Year $_t$ before the implementation of the pilot policy is always near the zero axis, and the confidence interval of the coefficient is always zero. This shows that there is no significant difference in the level of UGTFP between the experimental group and the control group before the implementation of the policy in the ECPDA, which meets the assumptions of parallel trends and that the progressive DID model is applicable. In the current period of policy implementation and the first three observation periods thereafter, the coefficients are significantly positive, with their confidence intervals excluding zero. This suggests that the construction of ecological civilization pilot zones indeed has a significant positive impact on urban GTFP levels. However, in the fourth year and beyond after policy implementation, the coefficients become insignificant again, indicating that the policy implementation exhibits temporal effectiveness. Its influence may be strongest in the initial stages but gradually weakens until it eventually diminishes. Market shocks and structural changes in the economy can both have an impact on the effectiveness of policies (Nain and Kamaiah, 2020), therefore, temporal factors must be fully considered in policy formulation and implementation to ensure that policies can exert timely and effective impacts.

While our results confirm the positive impact of ECPDA construction on UGTFP, we observe a diminishing marginal effect over time. This pattern aligns with the policy fatigue phenomenon observed in environmental governance (Kahn et al., 2015), where initial stringent enforcement gradually weakens due to regulatory capture or compliance costs. Additionally, as pilot cities achieve baseline environmental targets, further improvements require exponentially greater technological innovation and institutional restructuring (Wang and Shen, 2016). This implies that sustained UGTFP growth necessitates dynamic policy upgrades, including periodic tightening of environmental standards and incentives for continuous green innovation.

4.2.2 Placebo test

4.2.2.1 Time placebo test

The results in Table 3 show that the construction of ECPDA has a significant positive impact on the level of UGTFP, but this impact may be due to other random factors or regulatory policy differences.

Referring to Yang et al. (2021), this paper constructs a counterfactual model for the placebo test. In this paper, the implementation times of the ECPDA are artificially set to 3 years and 4 years before the first establishment. If the regression coefficient of the explanatory variable (DID) is not significant, the benchmark regression result is robust. Moreover, unobservable factors can affect the level of UGTFP, which interferes with the experimental results.

Table 4 shows the regression results. Model 1 shows that the policy implementation time in the ECPDA has advanced by 4 years, and the regression coefficient of the explanatory variable (DID-t_4) is not significant. This shows that the conclusion that the construction of ECPDA can increase the level of UGTFP is robust. This is because advancing the policy duration can exclude the influence of nonpolicy factors on the results of the study. Model 2 gives the regression results for advancing the implementation time of the policy in the ECPDA by 3 years, and the regression coefficient

TABLE 4 Time placebo test.

Variables	Model 1	Model 2
	GML	GML
DID-t_4	0.00538	
	(0.00365)	
DID-t_3		0.00470
		(0.00373)
Scale	−0.000257	−0.000259
	(0.000687)	(0.000687)
Density	−0.00444	−0.00443
	(0.00282)	(0.00281)
Economic	0.00381	0.00391
	(0.00436)	(0.00437)
Fiscal	−0.00565	−0.00574
	(0.00514)	(0.00514)
Urban	−0.00214	−0.00214
	(0.00374)	(0.00374)
Finance	−0.0139**	−0.0139**
	(0.00679)	(0.00682)
Constant	1.303***	1.305***
	(0.111)	(0.112)
City FE	Y	Y
Time FE	Y	Y
Observations	3,584	3,584
Adjusted R-squared	0.139	0.139

Table provides the results of the time placebo test. Table 1 shows the meaning of each variable. "* * *" indicates significance at the level of 1%, "* *" indicates significance at the level of 5%, and "*" represents significance at the level of 10%. The standard error is given in parentheses. The basic data are from the China Urban Statistical Yearbook, China Environmental Statistical Yearbook and Statistical Yearbook of each city.

of the explanatory variable (DID-t_3) is still not significant. This shows that the results are robust and will not be affected by other random factors. That is, the improvement in UGTFP in pilot cities is mainly due to policy dividends (Gao and Yuan, 2021). In summary, the construction of ECPDA can indeed increase the level of UGTFP. This result is consistent with that of Bai et al. (2023).

4.2.2.2 Individual placebo test

Referring to Zhao et al. (2023a), this paper sets up independent repeated experiments for individual placebo tests to further exclude the influence of other random factors on the benchmark regression results.

First, 47 cities are randomly selected from 256 prefecture-level cities as the pseudoexperimental group, and dummy variables are constructed and substituted into Equation (1) for double difference to obtain coefficient estimates. Second, the above random process is repeated 500 times for the placebo test. Figure 2 shows the P value scatter plot and kernel density plot of 500 regression estimation coefficients. The results show that the coefficient of the interaction term Treat × Post is concentrated at approximately 0, which is close to the normal distribution and significantly different from the benchmark regression coefficient 0.00879 in Table 3. The scatter points representing the P values are mostly located above 0.1 (horizontal dashed line), which indicates that a large number of regression coefficients are not significant. This suggests that other random factors or related policies have little impact on the empirical results. The construction of an ECPDA has a positive impact on UGTFP, and the empirical results are robust.

4.2.3 Other robustness tests

In order to check the robustness of the results, the robustness tests are carried out in this paper. Table 5 provides the results of the robustness tests.

4.2.3.1 The explained variable is treated with 1% upper and lower tail reductions

To eliminate the interference of outliers on the experimental results, all continuous variables are treated with a 1% tail reduction.

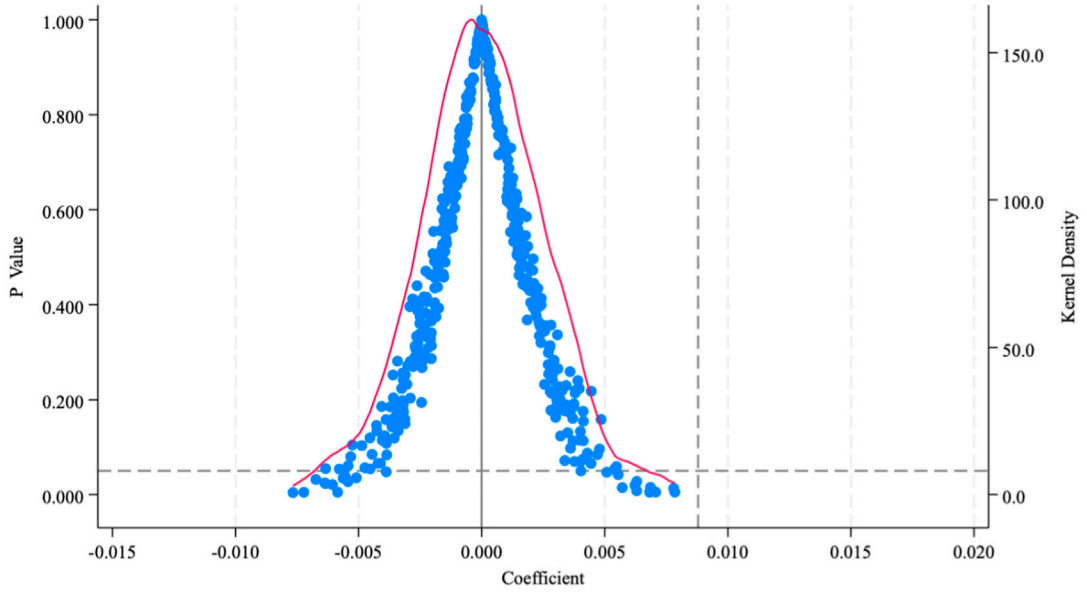

FIGURE 2
Individual placebo test.

The empirical results are shown in Model 1 of Table 5. In Model 1, the regression coefficient of the explanatory variable (DID) is 0.00677 and is significant at the 5% level. This shows that after excluding extreme samples, the construction of ECPDA still positively promoted the level of UGTFP. The empirical results are robust.

4.2.3.2 Another available measure of the explained variable

In the benchmark regression, the explained variable in this paper is the UGTFP measured by the SBM-GML model. To test the robustness of the empirical results, this paper uses the SBM-DDF model to measure the UGTFP of prefecture-level cities and carries out regression analysis. The regression results are shown in Table 5 for Model 2. In Model 2, the regression coefficient of the explanatory variable (DID) is 0.00290 and is significant at the 10% level. This shows that the construction of ECPDA can improve the level of UGTFP, and the empirical results are robust.

4.2.3.3 Endogeneity problem

To eliminate the endogeneity problem caused by the lag of the policy effect, this paper performs a regression analysis of the lag of the explanatory variables. Model 3 in Table 5 shows the empirical results. The regression coefficient of the explanatory variable (DID) is 0.0105 and is significant at the 5% level. Thus, after considering the endogeneity problem, there is still a positive correlation between the construction of an ECPDA and the level of UGTFP.

5 Further discussions

Compared with conventional analytical approaches, our methodology innovatively quantifies policy intensity dynamics inherent to ECPDA. We capture governmental environmental prioritization through longitudinal tracking of municipal ecological conservation expenditure growth rates—a direct fiscal commitment metric aligned with this study's theoretical framework. Simultaneously, high-tech industry clustering is measured by differential output value expansion in environmental technology sectors within demonstration zones relative to control regions. These core metrics integrate with our multi-period difference-in-differences specification *via* policy-intensity interaction terms, enabling robust assessment of how implementation rigor modulates transmission efficacy. Further elevating analytical depth, heterogeneity analysis incorporates unique demonstration zone attributes: policy innovation depth quantified by the presence of cross-departmental coordination systems, and resource transition intensity reflected by extractive industry GDP contraction in resource-based cities. This integrated approach transforms the research paradigm from verifying policy effects toward identifying design elements that optimize sustainable productivity outcomes.

5.1 Mechanism analysis

5.1.1 The government's environmental attention

The construction of ECPDA may play a role in UGTFP by enhancing the government's attention to the ecological environment. This paper uses the ratio of the total number of employees in the water conservancy, environment and public facility management industry to the annual average number of employees to measure the environmental concerns of local governments. The regression models are shown in Table 6 for Model 1 and Model 2. Model 1 shows the regression results for the impact of the construction of ECPDA on the government's environmental concern without any control variables. The results

TABLE 5 Robustness tests.

Variables	Model 1	Model 2	Model 3
	GML	GML2	GML
DID	0.00677**	0.00290*	0.0105**
	(0.00335)	(0.00153)	(0.00500)
LGML			−0.211***
			(0.0306)
Scale	8.97e-05	−6.75e-05	−0.000364
	(0.000734)	(0.000300)	(0.000807)
Density	−0.00432	−0.00190	−0.00905**
	(0.00275)	(0.00120)	(0.00364)
Economic	0.00309	0.00171	0.00450
	(0.00305)	(0.00193)	(0.00516)
Fiscal	−0.00549	−0.00194	−0.00720
	(0.00443)	(0.00207)	(0.00626)
Urban	−0.00287	−0.000657	−0.00338
	(0.00191)	(0.00164)	(0.00430)
Finance	−0.00941*	−0.00463*	−0.0131
	(0.00570)	(0.00276)	(0.00824)
Constant	1.234***	1.100***	1.549***
	(0.0984)	(0.0439)	(0.144)
City FE	Y	Y	Y
Time FE	Y	Y	Y
Observations	3,584	3,584	3,328
Adjusted R-squared	0.191	0.133	0.173

Table provides the results of the robustness tests. Table 1 shows the meaning of each variable. "* * *" indicates significance at the level of 1%, "* *" indicates significance at the level of 5%, and "*" represents significance at the level of 10%. The standard error is given in parentheses. The basic data are from the China Urban Statistical Yearbook, China Environmental Statistical Yearbook and Statistical Yearbook of each city.

show that the regression coefficient of the explanatory variable (DID) is 0.0386 and is significant at the 1% level. This shows that since the announcement of the list of ECPDA in 2014, the attention of local governments on the protection of the ecological environment has greatly increased. Model 2 gives the regression results with all control variables added, and the individual and year two-way fixed effects are carried out. In Model 2, the regression coefficient of the explanatory variable (DID) is 0.0416 and significant at the 1% level. This shows that the construction of an ECPDA has a significant effect on the government's environmental attention.

The possible reasons are as follows: First, the construction of ECPDA can result in a demonstration effect. The construction of ECPDA involves pilot exploration in a specific area, and successful pilot exploration has demonstrated its effectiveness in other areas. The government should pay attention to the achievements of demonstration areas and learn from and promote advanced environmental governance models, technologies and management experience to improve the overall level of environmental protection. Second, the construction of ECPDA has an economic driving role. The construction of ECPDA is closely related to the development of green industry. By promoting the construction of an ecological civilization, the government cultivates and develops green industries, promotes employment growth and achieves sustainable economic development. This economic driving effect on the environment can enhance the government's attention on the construction of ecological civilization.

After the government pays more attention to the environment, it usually further strengthens environmental management and supervision and standardizes the environmental protection behavior of enterprises. This will encourage enterprises to manage resources more carefully, control pollution, improve production efficiency and quality, and contribute to the improvement of UGTFP. In addition, increased attention on the environment is usually accompanied by increased attention on energy issues. The government may promote the development of clean energy and reduce dependence on traditional energy with high energy consumption and pollution to improve the UGTFP. The

TABLE 6 Mechanism analysis.

Variables	Model 1	Model 2	Model 3	Model 4
	rul_2	rul_2	tec_1	tec_1
DID	0.0386***	0.0416***	0.00834***	0.00773***
	(0.0104)	(0.0104)	(0.00264)	(0.00263)
Scale		0.00956***		0.00174***
		(0.00242)		(0.000614)
Density		−0.00846		0.000821
		(0.0104)		(0.00264)
Economic		−0.0424***		−0.0183***
		(0.0126)		(0.00320)
Fiscal		−0.0154		−0.00145
		(0.0167)		(0.00422)
Urban		−0.00262		−0.00537***
		(0.00526)		(0.00133)
Finance		0.0690***		−0.0107**
		(0.0216)		(0.00546)
Constant	0.0642***	−0.401	0.0256***	0.413***
	(0.00215)	(0.348)	(0.000548)	(0.0881)
Observations	3,584	3,584	3,584	3,584
Adjusted R-squared	0.675	0.678	0.656	0.664

Table provides the results of the mechanism analysis. Table 1 shows the meaning of each variable. "* * *" indicates significance at the level of 1%, "* *" indicates significance at the level of 5%, and "*" represents significance at the level of 10%. The standard error is given in parentheses. The basic data are from the China Urban Statistical Yearbook, China Environmental Statistical Yearbook and Statistical Yearbook of each city.

construction of ECPDA can effectively enhance the government's attention on the ecological environment, thus promoting the improvement of ECPDA. Therefore, enhancing the government's environmental concern may be the mechanism and path for the construction of ECPDA to promote UGTFP.

5.1.2 The development of regional high-tech industries

The construction of ECPDA may improve the level of UGTFP by promoting the development of regional high-tech industries. In this paper, the ratio of the total number of personnel engaged in scientific research, technical services and geological exploration to the annual average number of employees in the region is used as a proxy variable for the development level of high-tech industries in the region. The regression results are shown in Table 6 for Model 3 and Model 4. Model 3 gives regression results without control variables. In Model 3, the regression coefficient of the explanatory variable (DID) is 0.00834 and is significant at the 1% level. This shows that ECPDA can significantly promote the development of high-tech industries in the region. Model 4 gives regression results including all the control variables. In Model 4, the regression coefficient of the explanatory variable (DID) is 0.00773 and is significant at the 1% level. This shows that since the announcement of the list of ECPDA in 2014, high-tech industries in the pilot areas have developed rapidly.

The possible reasons are as follows: First, the construction of ECPDA is usually accompanied by government support policies, especially for high-tech industries. The government may encourage and support the development of high-tech industries in pilot areas by providing tax incentives and financial support. Second, the construction of ECPDA has usually led to the development of a platform for scientific and technological innovation, attracting high-tech enterprises and research institutions to establish R&D centers in the region. This approach will help to improve the level of science and technology in the pilot areas and promote R&D and innovation in high-tech industries. Finally, the demonstration zones of ecological civilizations tend to form industrial agglomerations, attracting a large number of related enterprises and R&D institutions to gather together. This will help to form an industrial chain, improve technology intensity, and promote the development of high-tech industries in the pilot areas.

The rapid development of high-tech industries can improve regional UGTFP. On the one hand, it is easier for high-tech industries to adopt cleaner production technologies, including the use of clean energy, the reduction of pollutant emissions, and the optimization of production processes, in the process of development. The application of these technologies will help to improve the environmental friendliness of urban production and enhance green total factor productivity. On the other hand, high-tech industries

TABLE 7 Heterogeneous regression.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
	GML	GML	GML	GML	GML
DID	0.00125	0.0136**	0.0166***	0.0135**	0.00763
	(0.00435)	(0.00622)	(0.00624)	(0.00668)	(0.0103)
Scale	−0.000315	−0.000283	−0.00178	0.000264	−0.000432
	(0.000830)	(0.00148)	(0.00244)	(0.00189)	(0.000633)
Density	−0.00399	−0.00651	−0.000575	−0.00338	−0.00479**
	(0.00332)	(0.00858)	(0.00951)	(0.00420)	(0.00188)
Economic	0.00324	0.00219	−0.00586	0.0107	0.0270***
	(0.00484)	(0.00805)	(0.00620)	(0.00838)	(0.00983)
Fiscal	0.00134	−0.0114	−0.0138	−0.00160	−0.0217**
	(0.00812)	(0.00735)	(0.0147)	(0.00760)	(0.0101)
Urban	0.00393	−0.00642**	0.0103	−0.00418	−0.00890***
	(0.00799)	(0.00251)	(0.0111)	(0.00286)	(0.00333)
Finance	−0.0163	−0.0111	0.00296	−0.0316***	−0.0114
	(0.00994)	(0.00854)	(0.0136)	(0.0104)	(0.0152)
Constant	1.230***	1.385***	1.211***	1.460***	1.264***
	(0.117)	(0.172)	(0.269)	(0.168)	(0.223)
Observations	1,428	2,156	949	1,560	1,072
Adjusted R-squared	0.109	0.163	0.104	0.158	0.149

Table provides the results of the heterogeneous regression. Table 1 shows the meaning of each variable. "* * *" indicates significance at the level of 1%, "* *" indicates significance at the level of 5%, and "*" represents significance at the level of 10%. The standard error is given in parentheses. The basic data are from the China Urban Statistical Yearbook, China Environmental Statistical Yearbook and Statistical Yearbook of each city.

usually rely on advanced technology and innovation, which helps to improve production efficiency. The introduction and innovation of new technologies can improve the production process, reduce the waste of resources, and thus enhance the UGTFP. The construction of ECPDA can promote the development of regional high-tech industries and improve the UGTFP. Therefore, promoting the development of regional high-tech industries may be the mechanism and path for the construction of ECPDA to promote UGTFP.

5.2 Heterogeneity analysis

The above analysis revealed that the construction of ECPDA can significantly improve the level of UGTFP. Based on this, is the impact of the construction of the first civilized demonstration area on different cities different? Is there a heterogeneous effect due to urban differences? To answer the above questions, this paper analyses heterogeneity from the aspects of urban resource endowment and urban scale. The regression results are shown in Table 7.

5.2.1 Types of cities

Considering the regional differences in resource endowments, this paper divides the sample cities into resource-based and nonresource-based cities for grouping regression according to the Sustainable Development Plan of Resource-based Cities in China (2013–2020). Model 1 and Model 2 in Table 7 report the heterogeneous impact of the construction of ECPDA on the GTFP of resource-based and nonresource-based cities, respectively. The regression results of Model 1 show that the regression coefficient of the explanatory variable DID in resource-based cities is 0.00125 but is not significant. This shows that the construction of ECPDA has not played a significant role in promoting resource-based cities. After a long period of extensive development, resource-based cities have developed the inherent characteristics of high energy consumption, high pollution and low ecological efficiency and have suffered from the "resource curse" for a long time, which has led them to fall into multiple shackles of "resource environment," "technological innovation" and "industrial structure." To be included in the list of ECPDA, the government of resource-based cities will certainly enhance environmental attention. In the case of certain financial expenditures, the government needs to give up part of the economic benefits and invest more in the construction of an ecological civilization. This may lead to the crowding out of investment in green emerging industries, hinder the transformation of traditional industrial structure and the development of high-tech industries, and thus inhibit the improvement of UGTFP.

Model 2 is the first demonstration area of ecological civilization and has an impact on the GTFP of nonresource-based cities. In Model 2, the regression coefficient of the explanatory variable DID is 0.0136 and is significant at the 5% level. This shows that the driving effect of UGTFP in nonresource-based cities will be significantly promoted after being selected for inclusion in the list of ECPDA. This is because the ECPDA implements an ecological compensation mechanism, which helps nonresource-based cities improve the ecological environment and share ecological dividends through the support of funds, technology and policies. This can bring more development opportunities and economic benefits to nonresource-based cities, stimulate their enthusiasm and creativity for green development, and thus increase the level of the UGTFP. This result is consistent with that of Li and Han (2023).

5.2.2 City size

Following Xu et al. (2022), we consider the land area of the urban administrative region. The sample cities are divided into large cities (with an area of more than 18,000 square kilometers), medium-sized cities (with an area between 8,000 and 18,000 square kilometers) and small cities (with an area less than 8,000 square kilometers). The regression results are shown in Table 7 for Model 3, Model 4, and Model 5.

Model 3 shows the impact of the construction of an ecological civilization pilot demonstration area on the level of green total factor productivity in cities with large administrative areas. The regression coefficient of the explanatory variable DID is 0.0166 and is significant at the 1% level. This shows that the construction of ECPDA has significantly promoted the improvement of green total factor productivity in large cities. Specifically, the larger the urban land area is, the stronger its comprehensive strength, the greater the efficiency of resource allocation, and the easier it is to form an agglomeration effect. As more innovative talent and resources are attracted, the level of green science and technological innovation will increase, which can significantly reduce the average cost of government infrastructure construction, environmental pollution control and other aspects.

Model 4 is the first demonstration area of ecological civilization and has an impact on the level of green total factor productivity of medium-sized cities with administrative areas. The regression coefficient of the explanatory variable DID is 0.0135 and is significant at the 5% level. This shows that the construction of ECPDA has significantly promoted the improvement of UGTFP in medium-sized cities. This is because the policy of developing an ECPDA encourages technological innovation and industrial upgrading and promotes the transformation of medium-sized cities to high-tech and high value-added industries. By introducing and cultivating advanced green technology and promoting clean energy, medium-sized cities can optimize their industrial structure, improve their industrial technology level and competitiveness, and thus enhance their level of UGTFP.

Model 5 shows the impact of the construction of an ECPDA on the level of green total factor productivity in cities with small administrative areas. The regression coefficient of the explanatory variable DID is positive and is not significant. This shows that the construction of ECPDA has not played a role in promoting the level of UGTFP with small administrative areas. The reason may be that when the urban area is too small, the establishment of ECPDA will lead to excessive agglomeration of the urban population and industry, resulting in inefficient allocation of factors and "crowding effects" (Dong et al., 2020). Moreover, the establishment of ECPDA in small cities easily leads to the formation of industrial isomorphism, which is not conducive to improving UGTFP.

6 Conclusion and policy recommendations

6.1 Conclusion

This paper regards the construction of ECPDA as an exogenous event, uses panel data from 271 cities in China from 2007 to 2020, and constructs a multiperiod double difference (DID) model to explore the impact of the construction of ECPDA on the level of UGTFP from the perspective of sustainable development. The results are as follows:

First, the construction of ECPDA has a significant role in improving the level of UGTFP, and the above conclusion is still valid after parallel trend tests and robustness tests. Second, the construction of ECPDA can not only increase the attention of local governments on ecological environment protection through guidance and demonstration but also attract a large number of high-tech talent and enterprises to gather in the demonstration zones. This will promote the development of regional high-tech industries and then optimize the level of UGTFP. Finally, the construction of ECPDA has different effects on the improvement of UGTFP in heterogeneous cities. Compared with those of resource-based cities and cities with smaller regional areas, the government's environmental protection policies can significantly improve the level of UGTFP in nonresource-based cities and cities with medium and large areas.

6.2 Policy recommendations

The conclusions of this study can guide the sustainable development of cities and the construction of ECPDA in developing countries and have certain policy implications for the improvement of UGTFP.

First, the construction of ECPDA emphasizes the concepts of green, low-carbon and circular development, which provides useful insights for the green development of cities in developing countries. By formulating and implementing green development policies, the government can promote enterprises and society to shift to a more environmentally friendly and sustainable development model. Moreover, the construction of ECPDA has led to innovative policy attempts, including the establishment of cross-sectoral collaborative governance mechanisms and the formulation of incentive policies to encourage investment in environmental protection. The governments of developing countries can refer to the experience of China's pilot demonstration zones to carry out urban green transformation and explore the economic development model of harmonious coexistence between humans and nature.

Second, there are differences in the promotion effects of green total factor productivity in different cities, and the government should objectively analyze the reasons for heterogeneity and constantly improve policies and regulations. In particular, the

characteristics of resource-based cities, nonresource-based cities and city sizes should be considered when formulating construction policies for ECPDA.

Third, the construction of ECPDA has a positive impact on the level of UGTFP by enhancing the government's environmental attention and promoting the development of high-tech industries in pilot areas. On the one hand, the government should strengthen the formulation and implementation of environmental protection policies, including the rectification of highly polluting industries, the construction of environmental protection infrastructure, and the formulation of strict environmental protection standards. The promotion of this attention will help to reduce environmental pollution and improve the ecological environment. On the other hand, the government should guide and support the development of high-tech industries, especially those related to environmental protection, clean energy and other fields. The introduction and application of this new high-tech technology will help to improve the technological level of urban industries, thereby improving the UGTFP.

Fourth, international comparative studies reveal that China's ECPDA model, characterized by top-down institutional innovation, offers distinct advantages for economies with strong state capacity. However, complementary approaches from global practices—such as the EU's Green City Accord emphasizing multi-stakeholder engagement and Singapore's market-incentive-driven Sustainable Blueprint—could further enhance policy effectiveness. Developing countries should adapt these models to their governance contexts to design place-based ecological policies.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: The datasets supporting the findings of this study are available upon reasonable request. Requests to access these datasets should be directed to ZW, zjwu@tju.edu.cn.

Author contributions

ZW: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Resources, Supervision, Writing – original draft, Writing – review and editing. LF: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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