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Original Research

How the Carbon Emissions Trading System Affects Green Total Factor Productivity in Logistics Industry?

Yanhong Zheng[1†], Zhaoyang Zhao[2†], Caihong You[3], Chong Ye[1], Rongwei Gao[4]*, Shijun Chen[5]**

[1] School of Advanced Manufacturing; Fuzhou University, Jinjiang, China; 218527305@fzu.edu.cn
[2] School of Public Administration, Sichuan University, Chengdu, China
[3] School of Management, Fuzhou Technology and Business University, Fuzhou, China
[4] Shanghai International College of Intellectual Property, Tongji University, Shanghai,China
[5] Carbon Neutrality Institute; Tongji University, Shanghai, China

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Abstract:

The carbon emissions trading system (CETS) is a crucial market-based tool aimed at achieving the goals of "carbon peaking" and "carbon neutrality", and plays a pivotal role in promoting the green development of the logistics industry. The green total factor productivity (GTFP) of the logistics industry is a key indicator used to measure the green development level of the logistics industry. The research on the CETS and the GTFP in the logistics industry(LGTFP) is currently lacking. Accurately assessing the impact of CETS on LGFP is crucial for improving the construction of the CETS and promoting the green transformation of the logistics industry. Utilizing a combined approach of system dynamics and econometrics, this study examines the effects of CETS on the LGFTP. In this study, the impact mechanism of CETS on the LGTFP is analyzed by constructing a causal relationship diagram using system dynamics theory. And then, we construct a multi-period difference-in-difference (DID) model using panel data from 30 Chinese provinces spanning from 2010 to 2020 to verify the impact of CETS on LGTFP. The findings reveal that: (1) CETS significantly promotes LGTFP, and this conclusion is consistent even after conducting robustness tests. (2) Green technological innovation is identified as the primary influencing mechanism of CETS in enhancing LGTFP, while industrial upgrading does not play a positive mediating role, contrary to established studies. (3) Heterogeneity analysis reveals that CETS has a significant promotion effect on LGTFP in central and western regions, and resource-based provinces, but not yet in eastern regions and non-resource-based provinces. Based on the empirical analysis, we propose relevant policy recommendations to improve China's CETS and promote the improvement of LGTFP.

Keywords: LGTFP; CETS; green technological innovation

Introduction

The logistics industry is a fundamental and strategic industry supporting the national economic development. China's logistics demand has been steadily increasing alongside rapid economic growth. In 2022, the total value of national social logistics reached 347.6 trillion RMB. However, this process has led to high levels of energy consumption and carbon emissions. Presently, China's logistics industry is responsible for approximately 9.0% of the country's energy consumption and 8.8% of its carbon emissions. Therefore, in light of the "double carbon" goal,

* e-mail: m17338880506@163.com
**e-mail: csj@tongji.edu.cn

the focus of domestic and foreign academia, as well as the Chinese government, has shifted towards promoting energy-saving, emission reduction, and coordinated development of the logistics industry with ecological environmental protection. In recent years, the Chinese government has issued policies such as "Guidelines on Accelerating the Establishment and Improvement of a Green, Low-carbon and Circular Development Economic System", and "Special Action Plan for High-quality Development of Business Logistics (2021-2025)" to drive the green and low-carbon transformation of the logistics industry. As a result, promoting the green and high-quality development of the logistics industry has become a critical agenda in China. Continuous enhancement in total factor productivity (TFP) is conducive to attaining high-quality and sustainable development in the logistics industry necessitates [1-2]. However, conventional TFP fails to account for the environmental damages and voluntary depletion resulting from the logistics development process. In the context of green development, it is imperative to consider environmental factors, actively implement appropriate policies and measures, and promote the green development of the logistics industry by enhancing GTFP. In this context, scholarly research has been conducted on LGTFP, with existing studies primarily focusing on the measurement and analysis of its driving factors.

To accelerate the process of reducing carbon emissions in high-emission industries, the National Development and Reform Commission proposed the gradual implementation of CETS in Shenzhen, Beijing, Tianjin, and other locations in 2011. In July 2021, China officially launched online trading for the national carbon market and included air freight in the logistics sector within the scope of carbon trading. In recent years, China has further promoted carbon emission accounting and trading in the logistics industry as a means of achieving carbon asset management, and the CETS has emerged as an important market-based tool to promote the green development of the logistics industry. Established studies have shown that CETS can significantly contribute to regional GTFP [3-4]. LGTFP serves as a critical indicator for measuring its green development and is key to achieving a win-win situation of high-quality development and environmental protection [5]. However, there remains a lack of a theoretical framework to analyze the influence of CETS on LGTFP. Can CETS truly promote LGTFP? If so, how can this be achieved? Are there regional differences in the impact of CETS on LGTFP due to varying geographical locations and resource endowments? Obtaining scientific answers to these questions will facilitate the promotion of LGTFP and encourage green and low-carbon transformation. Thus, this study aims to explore the impact of CETS on LGTFP. Through empirical analysis, relevant policy recommendations can be proposed, providing theoretical support for promoting the coordinated development of economic and ecological benefits in the logistics industry.

The main contributions of this study are as follows: Firstly, existing studies primarily investigate the influence of the CETS on regional GTFP, with limited discussion on the pilot policy's effects on the GTFP of a specific industry. Building upon prior research, this study focuses on the logistics industry as the research subject and provides an in-depth analysis of the impact of the CETS on its GTFP. This not only enhances the research on the CETS, but also extends the relevant research on logistics industry's GTFP. Furthermore, theories related to system dynamics can provide a better understanding of the influence mechanism of the CETS on LGTFP. Thirdly, in terms of research practice, the formulation of relevant policy recommendations not only facilitates the green and sustainable development of China's logistics industry, but also serves as a reference for the green transformation of other industries with high carbon emissions. Moreover, the findings of this study can assist the Chinese government in summarizing the experience of the CETS and establishing a solid decision-making foundation for promoting further development of the CETS.

Literature Review

The CETS Mechanism Design and Evaluation of CETS Effect

The CETS involves the process by which enterprises acquire carbon credits from government agencies and trade them on the carbon market. It is an institutional innovation created by the government and operated in the market. Its main objective is to achieve cost-effective quantitative control of greenhouse gas emissions [6]. Given the global security threat of climate change, CETS has emerged as a high-priority research topic [7]. Current research on CETS primarily centers on the design of CETS mechanisms and evaluating their effects.

Existing research on the CETS design primarily focus on analyzing the implementation status and coverage, comparing system design features across different pilot regions, summarizing the problems in system design, and providing relevant suggestions for improvement [8-10]. For instance, Ji et al. summarized the primary mechanisms of domestic and international carbon trading market prices, along with their associated problems [11]. In recent years, a limited number of studies have examined the impact of CETS design on willingness to participate [12].

The evaluation of the CETS primarily encompasses its effects on innovation, environment, and economy. There is no consensus on the effect of the CETS on innovation. Some studies suggest that implementing the CETS can promote innovation and technology application by enterprises, leading to an improvement in their innovation level [13-15]. However, other studies argue that implementing the CETS could increase pollution control costs, reduce R&D investment, and inhibit short-term technological innovation [16-18].

Studies assessing the environmental effects of the CETS indicate that the implementation of the policy has resulted in increased carbon emission reduction costs for enterprises. To mitigate the costs of carbon emission reduction, enterprises promote carbon emission reduction through increased R&D investment and the adoption of low-carbon energy-saving technologies and equipment [19-23]. Regarding the assessment of the economic effects of the CETS, most studies found that after the implementation of the pilot policy, enterprises in the pilot region either choose to innovate technologically or exit their operations to reduce pollution emissions, thereby improving the regional industrial structure and promoting regional economic growth [24]. However, some studies highlight that implementing the CETS results in higher carbon emission reduction costs for companies, leading to reduced production and a significant negative impact on economic growth [25-26].

Some studies have investigated the economic and environmental effects of the CETS as well. The findings indicate that the CETS is conducive to promoting regional carbon emission reduction without adversely affecting economic development, and may even promote economic growth to some extent [27]. The GTFP is a comprehensive indicator that accounts for both economic and environmental effects [28], and recent studies have examined the impact of the CETS on the GTFP. Previous studies have primarily examined the impact of CETS on GTFP in specific provinces or cities using econometric models. Most of these studies argue that CETS promotes the green transformation of enterprises through technological innovation, transformation and upgrading of industrial structure, clean-up of energy structure, and substitution of resource factors, which in turn leads to the growth of GTFP [29-31]. For instance, Li et al. demonstrated that GTFP increased by an average of 11.4% in pilot cities with carbon trading compared to non-pilot cities, and that the pilot policy had a significant spatial spillover effect on neighboring non-pilot cities [3]. Furthermore, variations in geographical location and resource endowments result in heterogeneity in the effects of CETS across regions, thereby influencing the pilot policy's impact on regional GTFP [31].

Calculation of LGTFP and Analysis of Its Influencing Factors

Numerous studies have investigated GTFP-related issues in the logistics industry, with a primary focus on employing diverse methodologies for its calculation and analysis of driving factors. Liu and Xu employed the GML model to calculate LGTFP in 30 provinces of China from 2003 to 2017, revealing an upward trend in the calculation results [32]. Li and Wang used the EBM model and GML index to assess LGTFP in 30 provinces of China. Additionally, they utilized the geographical and time-weighted regression (GTWR) model to analyze the impact of factors, such as industrial agglomeration level and informatization level, on LGTFP, revealing the presence of prominent spatial non-smooth characteristics in the influence of these factors [2]. Zhong computed the GTFP of China's agricultural logistics industry for the period of 2000-2018, utilizing the DDF function and the GML index, revealing a trend of initially decreasing and then increasing during the study period [33]. The results displayed relatively mature efficiency in terms of input-output and stable technology input-driven. Wang et al. employed the undesirable slack-based Malmquist Luenberger (ML) model to compute the LGTFP using panel data for 30 Chinese provinces from 2007 to 2019 [15].

The Impact of Environmental Regulations on LGTFP

In recent years, several studies have examined the relationship between environmental regulations and LGTFP, focusing on three main viewpoints: The first viewpoint argues that environmental regulations compel logistics enterprises to engage in green innovation, which, in turn, promotes the green transformation of the logistics industry and enhances its GTFP. For instance, Wang et al. highlighted that environmental regulations facilitate the improvement of LGTFP by enhancing innovation ability [34]. Liang et al. employed a dynamic GMM model and a Tobit model to examine the impact of environmental regulations on LGTFP. The findings revealed a significant positive effect of environmental regulations on the promotion of LGTFP, which varies significantly across space and time [35]. The second viewpoint posits that environmental regulations have raised the costs of emission reduction for logistics enterprises, diminished available funds, and hindered their green technological innovation and operation, thereby impeding the growth of LGTFP. Pei and Mue examined the impact of environmental regulations on LGTFP in the Beijing-Tianjin-Hebei region, and the results suggested that current environmental regulations should be more conducive to improving LGTFP [37]. The third perspective posits a nonlinear relationship between environmental regulations and LGTFP. Zhong employed a threshold model to examine the relationship between environmental regulations and the GTFP of China's logistics industry, revealing a dynamic correlation between the variables [36].

A comprehensive review of the existing literature reveals that the academic community has conducted extensive research on the CETS, with a primary focus on its mechanism design and the evaluation of its effects. Research on LGTFP primarily revolves around its measurement and analysis of influential factors. Nevertheless, there is a paucity of studies examining the influence of environmental regulations on LGTFP, particularly the impact of specific types of environmental regulations. Therefore, the purpose of this study is to investigate the impact of the CETS on LGTFP, with the aim of contributing to the existing body of literature on environmental regulations and LGTFP.

Impact Mechanism Analysis

The Impact of CETS on LGTFP

According to the Porter hypothesis, environmental regulations may increase short-term costs for enterprises. From a long-term dynamic perspective, strict and appropriate environmental regulations can stimulate technological innovation, reduce production costs, improve enterprise productivity, decrease pollutant emissions, and offset the increased costs of production due to environmental protection [38-39].

The CETS, or Carbon Emission Trading System, is a form of environmental regulation that is created by the government but operated in the market. It allows enterprises to choose and participate in environmental governance through market mechanisms. As an economic instrument, the CETS incentivizes companies to reduce emissions by allocating a predetermined amount of emissions space and permitting trading. When companies buy or sell carbon allowances, it results in additional revenue and cost reductions, leading to improved economic benefits for the company. Therefore, the CETS, as a rational and appropriate regulatory tool, can substantially enhance the GTFP in pilot areas. Moreover, at the micro-level of enterprises, the government allocates a fixed quantity of carbon quotas to emission control entities under the carbon trading mechanism. If a company exceeds its carbon quotas, it must purchase additional quotas at a cost, while any surplus quotas can be sold for profit. Due to the "push back effect" of cost pressures and the "incentive effect" of economic benefits, enterprises will not only enhance their efforts towards low-carbon and green transformations, such as investing in emission reduction equipment and adopting green technologies, but also reduce energy consumption and emission costs through effective management practices, thereby promoting LGTFP.

Based on the above analysis, this study proposes hypothesis H1:
The implementation of the CETS may significantly promote LGTFP.

Influence Mechanism Analysis

Building upon hypothesis H1, this study delves deeper into investigating the impact of the CETS on LGTFP. This study aims to better derive the necessary impact mechanisms by constructing model (1).

$$M_{i,t} = \alpha + \theta treat_i \times post_t + \gamma X_{i,t} + u_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

$M_{i,t}$ represent the intermediary variables, X_{it} represents the control variables for the LGTFP, μ_i denotes the Province fixed effect, δ_t represents the year fixed effect by δ_t and represents the random error term θ, represents the impact effect of CETS on the intermediary variables. If the coefficient θ is significant, it indicates that the CETS has a significant impact on the intermediary variable.

The construction model (2) is as follows, in order to provide supplementary evidence for the impact mechanism of CETS on promoting LGTFP.

$$LGTFP_{it} = \alpha + \emptyset_1 M_{i,t} + \emptyset_2 treat_i \times post_t + \gamma X_{i,t} + u_i + \delta_t + \varepsilon_{i,t} \quad (2)$$

$LGTFP_{it}$ represents the LGTFP of province i in year t, the estimated coefficient $\emptyset_1$ and $\emptyset_1$ are the focus of this mode. When both $\emptyset_1$ and $\emptyset_2$ are significant, it indicates that the CETS affects the LGTFP through wzór. The meaning of other variables is the same as equation (1).

In addition, this study considers that the impact of the CETS on LGTFP is complex and multi-faceted, influenced by a range of factors. To identify the key factors through which the CETS promotes LGTFP, this study builds upon the work of Mokgohloa et al. [40] and employs a system dynamics model to establish causal relationships

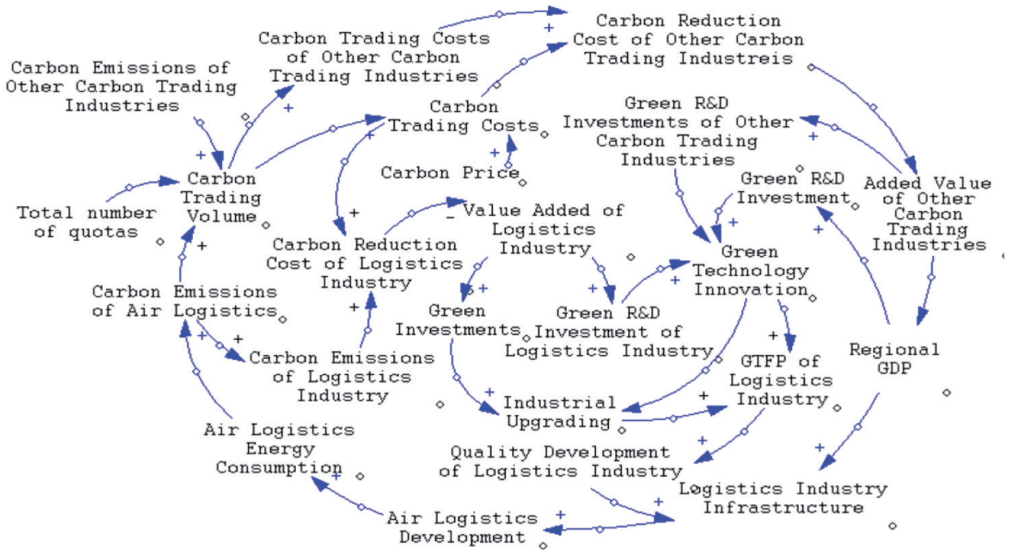

Fig 1. The CETS- LGTFP causality diagram.

between the CETS and LGTFP. Drawing causal diagrams can be helpful in analyzing the mechanisms of influence by depicting the direct and indirect effects among various variables, thereby uncovering critical factors and pathways. This approach facilitates the identification of important driving forces in the system and enhance. The CETS-LGTFP causality diagram is shown in Figure 1.

As can be seen from the Figure 1, the causality diagram contains multiple feedback loops, and the following two feedback loops are mainly introduced:

Logistics Industry Infrastructure → Air Logistics Development → Air Logistics Energy Consumption → Carbon Emissions of Air logistics → +Carbon Trading Volume → Carbon Trading costs → Logistics industry Carbon reduction costs → Logistics Industry Value Added → Green Investments→ +Industrial Structure Upgrading → LGTFP → +Quality Development of Logistics Industry→ Logistics Industry Infrastructure.

The enhancement of logistics infrastructure has facilitated the rapid growth of air logistics, resulting in increased energy consumption and carbon emissions. Inclusion of air logistics in the CETS has led to increased carbon trading costs and reduced value added in the logistics industry. The logistics industry should aim to reduce carbon trading costs, increase green investment, optimize the energy consumption structure of logistics enterprises, and promote the optimization of the logistics industry structure. Furthermore, in the context of pilot policy implementation, reducing pollution emissions can not only lower the emissions and pollution treatment costs for enterprises, but also generate economic benefits through the sale of emission allowances or government subsidies, among other means. This incentivizes relevant trading entities to make necessary adjustments to their factor and product structure, thus promoting the transformation and upgrading of the industrial structure [42]. The "structural dividend" resulting from the upgrading of industrial structure will further expedite the optimization of the logistics industry structure, drive the green transformation of the logistics industry, and consequently boost the GTFP and high-quality development of the logistics industry.

Logistics Industry Infrastructure → Air Logistics Development → Air Logistics Energy Consumption → Carbon Emissions of Air logistics → +Carbon Trading Volume → Carbon Trading costs → Logistics industry carbon reduction costs → Logistics Industry Value Added → Green R&D Investment of Logistics Industry → +Green technological innovation → LGTFP → +Quality Development of Logistics Industry → Logistics Industry Infrastructure.

Logistics companies have increased their investment in green research and development (R&D) in order to lower carbon trading costs, resulting in heightened levels of green technological innovation. Furthermore, the implementation of the CETS has, to some extent, heightened the stringency of regional environmental regulations, fostering a conducive environment for technological innovation. This facilitates the stimulation of relevant market players to augment their R&D investment, engage in independent research and development of green technology, or adopt advanced green technology from external sources, thereby enhancing the level of innovation. As technology tends to have spillover effects, advanced green technology will be disseminated to the logistics industry, driving the adoption of green technology in logistics and promoting the GTFP of the industry.

On the basis of causality diagram analysis, considering that industrial structure upgrading and promoting green technological innovation are critical factors in achieving the shift from crude to intensive economic growth and fostering sustainable development [41], and combining with the impact mechanism model constructed earlier, this study examines the mechanisms through which the CETS affects LGTFP from these dual perspectives. And this study finally selects industrial structure upgrading and green technological innovation as intermediary variables,

Building on the above analysis and combined with the research conclusion of Li et al. [42], hypothesis H2 and H3 are proposed:

H2: The CETS promotes LGTFP through industrial structure upgrading.

H3: The CETS promotes LGTFP through green technological innovation.

Research Design

Model Construction

Baseline Regression Model Settings

The Difference in Difference (DID) method, widely recognized in policy evaluation, is considered a classic technique. It involves treating policy implementation as a quasi-natural experiment, assigning regions under policy implementation as the treatment group and those without it as the control group. The evaluation entails quantifying the impact of policy implementation by comparing the variations in a specific indicator between the two groups before and after policy adoption. This method not only tackles endogeneity issues arising from policies but also utilizes the exogeneity of the explanatory variable in panel data effectively to control for unobserved heterogeneity across samples and the influence of time-invariant unobservable factors[43]. The DID method, of course, has certain limitations, such as the need to satisfy specific assumptions like the randomness of policy implementation; otherwise, the reliability of the analysis results will be affected. However, the non-randomness of China's policy advantages calls for rigorous parallel trend tests to determine the applicability of employing the DID method for policy effect analysis. In addition, the utilization of the DID method for policy evaluation can be prone to interference from other policies, resulting in potential overestimation or underestimation of the effects. Consequently, it becomes imperative to perform stringent robustness checks to ensure the credibility of the estimated outcomes. Therefore, building on the research of Qiu et al. [44], this study establishes a multi-period DID baseline regression model as follows:

$$\mathrm{LGTFP_{it}} = \alpha + \beta \mathrm{treat_i} \times \mathrm{post_t} + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

In the model, i and t denote the province and year, respectively. $LGTFP_{it}$ represents the LGTFP of province i in year t, while X_{it} represents the control variables for the LGTFP. Province fixed effect is denoted by μ_i, year fixed effect by δ_t, and ε_{it} represents the random error term. The estimated coefficient β is the focus of this study, serving as the DID estimator that quantifies the impact of CETS implementation on LGTFP. If $\beta > 0$ and statistically significant, it implies that the implementation of the CETS effectively promotes LGTFP. If $\beta = 0$, it suggests that the CETS has no significant impact on LGTFP. If $\beta < 0$ and statistically significant, it indicates that the implementation of the CETS inhibits LGTFP.

Mechanism Verification model settings

To rigorously examine the mechanism through which the implementation of the CETS impacts LGTFP, building upon our earlier analysis of this impact mechanism, this study leverages the research of Baron and Kenny [45] to establish a mechanism test model, formulated as follows:

$$\mathrm{Industry} = \alpha + \beta \mathrm{treat_i} \times \mathrm{post_t} + \gamma X_{i,t} + u_i + \delta_t + \varepsilon_{i,t} \quad (4)$$

$$\mathrm{LGTFP_{it}} = \alpha + \beta_1 \mathrm{Industry} + \beta_2 \mathrm{treat_i} \times \mathrm{post_t} + \gamma X_{i,t} + u_i + \delta_t + \varepsilon_{i,t} \quad (5)$$

$$\mathrm{Green\_patent} = \alpha + \varepsilon \mathrm{treat_i} \times \mathrm{post_t} + \gamma X_{i,t} + u_i + \delta_t + \varepsilon_{i,t} \quad (6)$$

$$\mathrm{LGTFP_{it}} = \alpha + \varepsilon_1 \mathrm{Green\_patent} + \varepsilon_2 \mathrm{treat_i} \times \mathrm{post_t} + \gamma X_{i,t} + u_i + \delta_t + \varepsilon_{i,t} \quad (7)$$

In equations (4)-(7), Equation (4) depicts the relationship between the core explanatory variable ($treat_i \times post_t$) and industrial structure upgrading (Industry). Equation (5) illustrates the relationship among the core explanatory variable ($treat_i \times post_t$), industrial structure upgrading (Industry), and the explained variable ($LGTFP_{it}$).

Equation (6) depicts the relationship between the core explanatory variable ($treat_i \times post_t$) and green technological innovation (Green_patent). Equation (7) illustrates the relationship among the core explanatory variable ($treat_i \times post_t$), green technological innovation (Green_patent), and the explained variable ($LGTFP_{it}$).

Variables Selection

Explained Variable

The explained variable is LGTFP, denoted as . This study builds upon the research conducted by Chen et al. [46] and employs the SBM-GML model to estimate LGTFP, utilizing selected input and output indicators.

Explanatory Variable

The China Emissions Trading Scheme (CETS) serves as the primary explanatory variable. This study employs a binary dummy variable, , to represent the implementation of the CETS at the provincial level. The value of is set to 1 if the province has implemented the CETS, and 0 otherwise. The CETS was launched in Beijing and seven other provinces and cities in the latter half of 2013. Due to the lag in policy implementation, the dummy variable for these seven provinces and cities is set to 1 starting from 2014. Fujian and Sichuan provinces adopted the CETS in 2016, and their dummy variables are set to 1 thereafter.

Control Variables

To explore the net effect of the CETS on LGTFP, it is important to control for a range of other factors that may affect LGTFP. The control variables were chosen as follows:

① Economic development level (Pergdp): Referring to the study of Dedecek and Dudzich [47], this study adopts per capita GDP to measure the level of provincial economic development. At the same time, in order to eliminate the impact of price changes, the GDP deflator with 2010 as the base period is used for processing. ② Degree of marketization (Market): Drawing on the methodology of Zeng et al. (2021) [48], the degree of marketization was calculated for each province. ③ Government support (Gov): This study uses the ratio of fiscal expenditures to general budget expenditures to measure government support. ④ Environmental regulation (ER): The ratio of investment in environmental management to GDP is used to measure the environmental

Table 1. Variable descriptive statistics.

Variables	Observations	Mean	Std	Min	Median	Max
$LGTFP_{it}$	330	1.164	.573	0.345	1.061	4.338
treat x post	330	.27	.446	0.000	0	1
InPergdp	330	9.739	.456	8.992	9.632	10.688
Market	330	9.195	1.056	6.615	9.224	11.233
Gov	330	.231	.098	0.119	.208	.583
ER	330	3.499	1.072	1.754	3.364	6.294
Eff	330	1.738	.529	0.896	1.685	2.991
Urban	330	.622	.139	0.363	.609	.892

regulation. ⑤ Logistics energy intensity (Eff): The ratio of energy consumption of the logistics industry to the value-added of logistics is used to measure the logistics energy intensity. ⑥ Urbanization level (Urban): This study uses the urban population as a share of the total population to measure the urbanization level.

Intermediary Variables

① Industrial structure upgrading: Drawing on Shiqian et al. [49], industrial structure upgrading is measured using the ratio of tertiary industry output to secondary industry output. ② Green technological innovation: Green patents can visually reflect the output of enterprises' green technological innovation activities [50]. This study uses total green patent applications to measure green technological innovation. Total green patent applications are the sum of green invention patent applications and green use-based patent applications.

Data Description and Descriptive Statistics

The research sample for this study comprises panel data from 30 provinces in China spanning the period from 2010 to 2020. The patent data is sourced from the "China Intellectual Property Library", while other data is obtained from the "China Statistical Yearbook", "China Labor Statistical Yearbook", and various regional statistical yearbooks. Missing values are imputed using either interpolation or the exponential smoothing method. Variables descriptive statistics are presented in the Table1.

Empirical Analysis

Parallel Trend Test

Prior to conducting the multi-period DID model analysis, it is necessary to perform a parallel trend test to ascertain if there are any significant differences in LGTFP between pilot and non-pilot provinces prior to the policy promulgation. Accordingly, drawing on the findings of Liu [51] and Niu et al. [52], the following model is constructed to assess the parallel trend by considering the initial three periods and the final five periods of policy implementation.

$$LGTFP_{it} = \alpha + \sum_{j=-3}^{5} \beta_j \, treat_i \times post_t + \gamma X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \quad (8)$$

In model (8), β_0 is the coefficient of the year when the CETS was implemented, β_{-3} to β_{-1} are the coefficients from 3 to 1 year before the implementation of the CETS, β_1 to β_5 are coefficients from 1 to 5 years after the implementation of the CETS. If the coefficients from β_{-3} to β_{-1} are insignificant, the parallel trend hypothesis is proved to be valid, and the results are shown in Figure 2.

Based on the results depicted in the Figure 2, it is evident that the coefficients for before1 to before3 are statistically insignificant, with confidence intervals that encompass 0. This implies that there is no significant

Table 2. Baseline regression analysis.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	LGTFP	LGTFP	LGTFP	LGTFP	LGTFP	LGTFP	LGTFP
treat x post	0.1990*	0.2035*	0.2069**	0.2068**	0.2458**	0.2509**	0.3125***
	(1.92)	(1.96)	(1.98)	(2.00)	(2.39)	(2.47)	(3.16)
	(5.74)	(5.78)	(4.26)	(3.73)	(2.54)	(2.81)	(1.35)
InPergdp		-0.3465	-0.3371	-0.0846	-0.1507	-0.1458	-0.0630
		(-0.68)	(-0.66)	(-0.16)	(-0.30)	(-0.29)	(-0.13)
Market			0.0215	0.0325	0.0554	0.0412	0.0545
			(0.40)	(0.61)	(1.05)	(0.79)	(1.08)
Gov				1.5036**	1.2277**	1.6599***	1.5968***
				(2.46)	(2.01)	(2.68)	(2.67)
ER					-0.1081***	1.0338***	1.0797***
					(-2.83)	(2.73)	(2.95)
Eff						-2.4420***	-2.5026***
						(-3.03)	(-3.22)
Urban							2.7758***
							(4.67)
_cons	1.0166***	4.3174	4.0755	1.2530	2.2711	2.4328	0.0241
	(13.54)	(0.90)	(0.84)	(0.25)	(0.46)	(0.50)	(0.01)
N	330	330	330	330	330	330	330
R^2	0.3360	0.3371	0.3375	0.3512	0.3690	0.3887	0.4325

Note: t statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

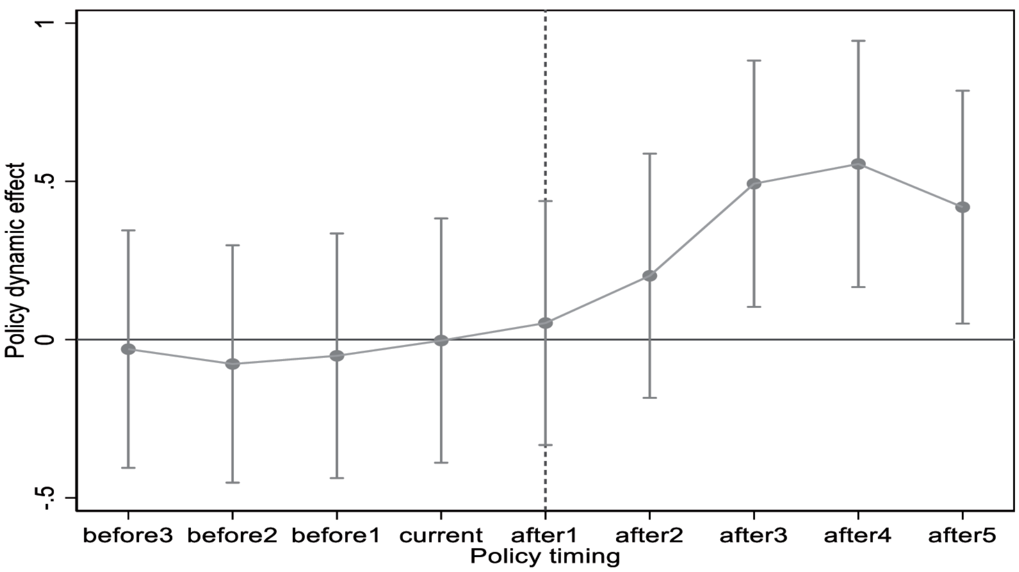

Fig. 2. Parallel trend test.

difference in LGTFP between the experimental and control groups prior to the implementation of the CETS. Following the implementation of the CETS, the coefficients for after1 to after5 exhibit a discernible trend of gradual increase. Notably, the confidence interval of after3 to after5 does not include 0, and all coefficients are statistically significant and positive. These findings suggest that the model employed in this study successfully passes the parallel trend test and indicates a certain time lag in the policy effect.

Baseline Regression Analysis

Table2 presents the findings regarding the impact of the CETS on LGTFP. Column (1) displays the estimated results of control variables that have not yet been included. Notably, the coefficient value of treat x post is 0.1990 and exhibits statistically significant positive effects at the 10% level. Column (7) presents the estimation results after incorporating all the control variables, revealing an increased estimated coefficient value of treat × post at 0.3125, which is statistically significant at the 1% level. Hence, hypothesis H1 of this study is confirmed.

The regression results of the control variables reveal that government support (Gov) exhibits a statistically significant positive effect at the 1% level, with a coefficient value of 1.5968. This indicates that Gov plays a favorable role in promoting LGTFP. This is because an increase in Gov stimulates enterprises to adopt low-carbon facilities and equipment, which in turn promotes the improvement of LGTFP.

The coefficient of environmental regulation (ER) has a significant positive effect, with a coefficient value of 1.0797. This suggests that as the ER increases, logistics companies experience higher costs associated with carbon reduction efforts. To mitigate carbon emission reduction costs, logistics companies are implementing technological changes and other measures to foster the green transformation of the logistics industry. Simultaneously,

Table 3. Robustness test results.

	Low carbon pilot	Tail reduction method	PSM-DID
	(1)	(2)	(3)
treat x post	0.3239***	0.2950***	0.1128***
	(3.11)	(3.00)	(0.62)
lowcarbon	-0.1138		
	(-0.84)		
_cons	0.3958	0.6203	3.4828
	(0.08)	(0.12)	(0.32)
N	330	330	150
	0.4377	0.4363	0.4274

Note: t statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

enterprises may also attract or nurture environmentally conscious employees, thereby accumulating expertise in green production and technological innovation, which contributes to the enhancement of LGTFP.

The coefficient of urbanization level (Urban) exhibits a statistically significant positive effect, with a coefficient value of 2.7758. This suggests that the urbanization level plays a significant role in promoting the improvement of LGTFP. The advancement of urbanization in each region has led to improvements in the related logistics infrastructure, thereby facilitating the rapid development of the logistics industry. Furthermore, the improvement in people's living standards has raised higher expectations for environmental quality. Consumers are increasingly opting for green products, thereby promoting the upgrading of green consumption. To cater to consumer demands, logistics companies are involved in green production, green transportation, and other practices, all of which contribute to the improvement of LGTFP.

The coefficient of logistics energy intensity (Eff) exhibits a statistically significant negative effect at the 1% level, showing that higher logistics energy intensity inhibits LGTFP. This may be attributed to the positive correlation between logistics energy intensity and logistics energy consumption. Furthermore, the inefficient energy consumption structure in the logistics industry results in higher carbon emissions [53], thereby impeding LGTFP. The coefficients of economic development level and marketization degree are found to be statistically insignificant. Relatively higher levels of economic development and marketization can contribute to the promotion of LGTFP to some extent. However, due to the combined influence of other factors that may hinder the promotion of LGTFP, these two variables exhibit a specific lag effect on GTFP promotion.

Robustness Tests

The baseline regression results suggest that the implementation of the CETS has a significant positive impact on LGTFP. Additional robustness tests are conducted to verify the reliability of the baseline regression results. The results of the robustness test are shown in Table 3.

Eliminate Possible Interference from Other Policies

In support of the CETS, the government has introduced a pilot policy for low-carbon cities. The implementation of this policy results in increased pollution control costs for enterprises. To mitigate the costs, enterprises are encouraged to promote technological innovation for low-carbon production and transportation. To address potential interference from the low-carbon pilot policy on the evaluation of CETS, this study incorporates the policy into the model and conducts regression analysis. The coefficient of treat × post is 0.3239, with a statistically significant positive impact at the 1% level, suggesting that the baseline regression results are robust.

Eliminate Interference from Abnormal Values

To mitigate the impact of outliers in the sample, this study applies trimming at the 2% level and conducts regression analysis anew. The results are displayed in column (2), revealing a coefficient of treat × post is 0.32950, which is statistically significant at the 1% level. This suggests that the positive effect of the CETS on LGTFP persists even after the exclusion of outliers. Thus, the baseline regression results are deemed robust.

PSM-DID

To address potential endogeneity issues arising from sample selection bias, this study employs the Propensity Score Matching – Difference-in-Differences (PSM-DID) method for testing. As evident from the findings in column (3), the coefficient of treat × post is 0.1128, which is statistically significant. This suggests that the implementation of the CETS has a significant positive impact on LGTFP. In summary, the aforementioned research findings are robust.

Placebo Test

Despite accounting for observable key characteristics in the baseline regression, it is possible that errors in the regression results may arise from unobservable factors that need to be included. The placebo test can assess the potential influence of other unobservable factors on the baseline regression results. In this study, the treatment group is randomized, and the treatment group variables are randomly sampled and regressed 500 times. Then, we observe whether the coefficients after randomization are concentrated around 0. The distribution of regression coefficients is depicted in Figure 3.

The figure illustrates that the coefficients of treat×post cluster around zero and exhibit a normal distribution after conducting 500 random samples from the data, indicating that the study successfully passed the placebo test. Therefore, the unobserved characteristics of the province do not have a potential impact on the regression results, rendering the previous findings more robust.

Heterogeneity Tests

Given China's extensive territory, variations in economic development levels and resource endowment may result in heterogeneous impacts of the CES across provinces. Consequently, this study employs two approaches to examine the heterogeneous effect of the CETS on LGTFP. First, the sample is divided based on geographical location into the eastern, central, and western regions. Second, the sample is categorized into resource-based and non-resource-based provincial samples, following the definition by Yu et al. [54].

Heterogeneity test results are shown in the Table 4. The influence of the CETS on LGTFP in the eastern, central, and western regions is presented in Columns (1), (2), and

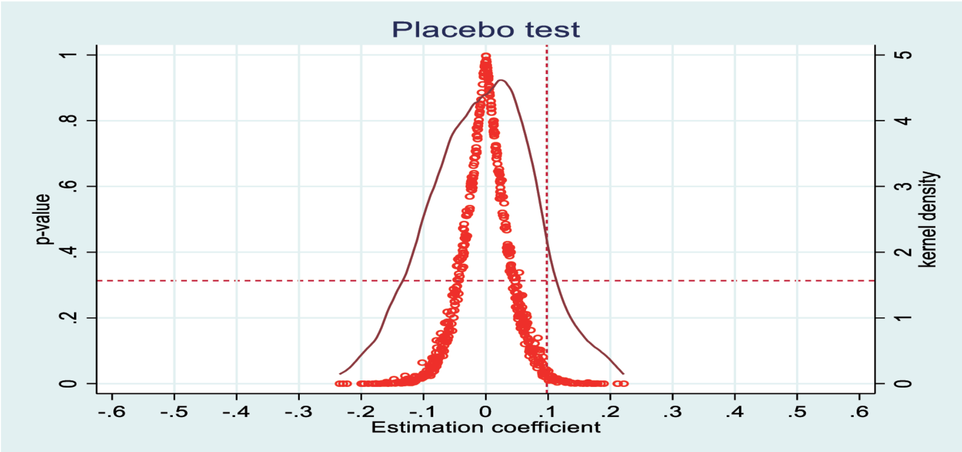

Fig. 3. Placebo test result.

(3) of Table 5, respectively. The findings indicate that the CETS has a significant positive impact on LGTFP in the central and western regions, with a more pronounced effect observed in the central region. However, LGTFP in the eastern region has not been significantly impacted by the CETS. This could be attributed to the greater potential for low-carbon transition in the logistics industry development of the central and western regions, as compared to the eastern region, resulting in a higher responsiveness of LGTFP to the CETS.

The impact of the CETS on LGTFP in resource-based and non-resource-based provinces is presented in Columns (4) and (5) of Table 5, respectively. The table indicates that the coefficient value of treat × post is significantly positive at the 10% level for resource-based provinces, but insignificant for non-resource-based provinces. That is, for resource-based provinces, the CETS has a significant positive contribution to LGTFP, while the opposite is true for non-resource-based provinces. This is mainly because resource-based provinces are more open to the global market and possess a stronger economic foundation, resulting in inherent advantages in terms of capital, technology, and talent, which facilitate greater investment in promoting the green transformation of the logistics industry and enhancing its GTFP. Non-resource-based provinces have relatively lower economic development compared to resource-based provinces, which limits their ability to invest a significant amount of capital in the green transformation of the logistics industry within a short timeframe, resulting in a lag in the impact of implementing the CETS on LGTFP.

Mechanism Tests

Based on assumptions H2 and H3, it is further tested whether the CETS will promote LGTFP by promoting industrial structure upgrading and green technological innovation level.

Mechanism tests results are shown in the Table 5.

The results in column (1) reveal that the coefficient of treat×post is significantly positive at the 1% level, with a coefficient value of 0.1361, indicating that implementing the CETS can significantly promote industrial structure upgrading. However, according to the results in Column (2), although the coefficient of treat × post remains significantly positive at the 1% level, the coefficient of industrial structure upgrading is significantly negative. This suggests that industrial structure upgrading has not played a positive intermediary role in the process of CETS affecting LGTFP. The possible reasons for this finding are as follows: after implementing the CETS, logistics enterprises may have carried out technological innovation or green industrial transformation to reduce carbon trading costs and promote industrial structure

Table 4. Heterogeneity test results.

	Different geographical locations			Resource endowment	
	Eastern	Central	Western	Resource based	Non-resource based
treat x post	0.2777	0.4471**	0.1919*	0.1893*	0.1691
	(1.29)	(2.49)	(1.70)	(1.68)	(0.76)
_cons	2.8651	-11.3430**	-9.9678	3.0827	-6.7299
	(0.43)	(-2.20)	(-0.92)	(0.70)	(-0.56)
N	88	121	121	220	110
	0.6315	0.7060	0.5277	0.5628	0.4238

Note: t statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5. Mechanism test results.

Variables	(1)	(2)	(3)	(4)
	Industry	LGTFP		LGTFP
treat x post	0.1361***	0.3960***	1.4726***	0.2420**
	(4.09)	(3.97)	(6.93)	(2.27)
Industry		-0.6133***		
		(-3.54)		
Green_patent				0.0479*
				(1.74)
_cons	7.0695***	4.3600	-7.7268	0.3940
	(4.47)	(0.91)	(-0.76)	(0.08)
N	330	330	330	330
R^2	0.7838	0.4566	0.6113	0.4385

Note: t statistics in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

upgrading. However, during this process, the impact of "factor stickiness" and "time lag" may have hindered the smooth flow of production factors among various departments, impeded the rational allocation of factors, and reduced productivity [55] As a result, industrial structure upgrading may not have been able to promote LGTFP in the short term.

The results from columns (3) indicate that the coefficient of CETS is significantly positive at the 1% level, with a coefficient value of 1.4726, suggesting that the implementation of CETS has a significant promotion effect on green technological innovation. Furthermore, the results from column (4) reveal that the coefficient of treat × post and green technological innovation is significantly positive at least at the 10% level, providing evidence that green technological innovation serves as the mechanism through which CETS promotes the improvement of LGTFP, thus confirming hypothesis H3. This finding suggests that the implementation of CETS incentivizes enterprises to invest in green technology and promote green technological innovation in order to reduce emission reduction costs [56]. This, in turn, leads to an enhancement in the innovation level of logistics enterprises, optimizing resource allocation by replacing traditional non-green elements with green innovation elements in production, transportation, and packaging, ultimately promoting LGTFP.

Conclusions and Policy Recommendations

This study uses a DID method to examine the impact of CETS on LGTFP. The findings of this research reveal several key insights: (1) The implementation of CETS positively affects the improvement of LGTFP. (2) The primary channel through which CETS promotes LGTFP is via green technological innovation, rather than industrial structure upgrading. (3) The impact of CETS on LGTFP varies across different geographical regions. Specifically, the western region experiences the most significant contribution, followed by the central region, while the eastern region shows no significant influence. Moreover, the impact of CETS on LGTFP is found to be significant in resource-based provinces, but insignificant in non-resource-based provinces.

Based on the conclusions, the recommendations are made as follows:

Firstly, the expansion of the CETS scale and improvement of the CETS mechanism are crucial. This study reveals that as the CETS expands, LGTFP also increases accordingly. Therefore, promoting the CETS in the logistics industry and encouraging participation of logistics enterprises is necessary. Simultaneously, it is important to gradually expand the scope of CETS to include other high carbon emissions industries, such as chemical, iron, in phases and batches, based on the carbon trading in electricity and other industries. Clear timelines for each industry's entry into the national carbon trading market should be established. Additionally, entities like carbon asset investment companies and securities companies should be encouraged to participate in CETS. Furthermore, the carbon market quota allocation mechanism should be optimized to reduce the proportion of free quota allocation gradually and accelerate the introduction of paid quota allocation. This will effectively regulate carbon prices and enhance enterprises' enthusiasm to engage in carbon market transactions. Moreover, leveraging carbon futures, carbon forwards, and other carbon financial products can guide clean energy investment and drive overall improvement of GTFP in the industry.

Secondly, it is imperative to augment investment in green technological innovation and elevate the innovation level. The findings reveal that green technological innovation serves as a critical channel for the CETS to enhance LGTFP. Therefore, the government should increase investment in green technological innovation, talent support, and other means to provide protection for innovation. Mechanisms such as green technological innovation subsidies and environmental protection subsidies should be established. Additionally, the government can establish a green technology exchange center to facilitate the flow of green innovation elements, foster a favorable innovation environment for enterprises, and elevate the overall innovation level of the logistics industry.

Thirdly, it is essential to implement differentiated policies for provinces with varying geographical locations and resource endowments. The disparities in geographic location and resource endowment result in diverse impacts of the CETS on different provinces. Hence, each pilot province should devise a targeted program based on its development status to enhance the effectiveness of the CETS. The eastern region should continue optimizing its energy structure, vigorously developing and utilizing clean energy, and utilizing the CETS to promote LGTFP positively. The central region should focus on adjusting its energy structure, improving energy use efficiency, and leveraging technological innovation as an intermediary to enhance LGTFP. The western region should make vigorous efforts to improve infrastructure construction, leverage the strategic opportunities of the national carbon market, accelerate factor accumulation and capital accumulation, and introduce advanced technology. Resource-based provinces should expedite the elimination of backward production capacity, establish a clean energy, efficient, and systematic technology system. Non-resource-based provinces should strive to improve the quality of their industries, extend the value chain of products.

Research Limitations

While this article makes a significant contribution, it is important to note the following research limitations:

(1) The implementation of CETS involves the allocation of quotas to various enterprises, rendering it a highly suitable context for conducting micro-level research at the corporate level. Nonetheless, the emission data and annual reports of numerous logistics enterprises are currently not publicly accessible. Consequently, this article focuses solely on examining the influence of CETS on CTFP from a provincial standpoint. Subsequent research can delve into a more in-depth analysis at the individual enterprise level.

(2) This study employs systems dynamics theory and adopts a national perspective to investigate the impact mechanism of CETS on LGTFP as a whole. However, there are significant disparities among different provinces in terms of economic development level, green technology innovation level and so on. Thus, future research can explore the impact mechanism of CETS on LGTFP by implementing regional divisions. Besides, this paper solely utilizes a system dynamics model to investigate the impact mechanism of the CETS on LGTFP, without undertaking any simulation-based predictive analysis on the future trends of this mechanism.

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Conflicts of Interest

The authors declare no conflict of interest.

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