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# Market-based Environmental Regulation, Green Technology Innovation and Green Total Factor Energy Efficiency: A PSM-DID Test Based on an Emissions Trading System

**Yuxin Zhao[1]*, Cong Wang[2], Xin Wang[2]**

[1]School of Business, Hong Kong University of Science and Technology, Hong Kong SAR, China

[2]School of Economics and Management, Taiyuan University of Technology, Taiyuan, Shanxi Province, China

***Corresponding author:** Yuxin Zhao, zhaoyx960211@163.com

**Abstract:** Based on the panel data of 30 provinces in China and the SBM-Malmquist-Luenberger model, a comprehensive evaluation of all-factor green energy efficiency in each province is conducted. It is found that the energy structure and all-factor green energy efficiency in southeast China are significantly higher than those in central and western China. On this basis, this paper empirically tests the impact of the pilot policy of emission trading on total factor green energy efficiency in 2008 by using the double difference method. The research shows that the emission trading system can significantly improve the regional total factor green energy efficiency; further research finds that green technological innovation is the main path for the policy to promote green total factor energy efficiency; heterogeneity analysis shows that in the high pollution pilot areas, the emission trading system plays a more significant role in promoting all-factor green energy efficiency and green technology innovation.

**Keywords:** Emission trading scheme; Total factor green energy efficiency; Green technology innovation; DID; SBM-ML index

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## 1. Introduction

High-quality ecological and environmental protection is currently a crucial theme related to the destiny of all mankind. The “Chinese 14th Five-Year Plan” and the 2035 long-term goal recommendations clearly stated that by 2035, green production and green lifestyles will be widely formed, and carbon emissions will steadily decline, and the ecological environment is fundamentally improved. Up to now, China’s economy has indeed achieved sustained high-speed growth, but it is undeniable that China’s rapid economic growth is driven by energy consumption, which has also caused high pollution, waste of resources, and low energy efficiency problem. Although there are countless measures to improve environmental pollution, it is more practical to improve energy efficiency in view of the increasing energy demand during the accelerated process of industrialization and urbanization in China. In recent years, the Chinese government has formulated relevant policies to improve energy efficiency, one of which is the pilot policy for emissions trading scheme. The operation of the emission trading system is based on the carbon emission credit trading market, in which a certain amount of emission allowances are provided by the government and allocated to enterprises for free. Low-emission companies can sell the remaining emission allowances to the open market, and high-emission companies must purchase insufficient allowances from other companies. The resulting cost increase may stimulate companies to improve energy efficiency to reduce their emissions. In other words, reducing emissions by improving energy use efficiency is a feasible way for companies to reduce greenhouse gas emissions and improve environmental pollution in a cost-effective manner. This paper uses panel data from 30 provinces across the country from 2004 to 2017 as a research sample to analyze the impact of the emission trading system on China's green energy efficiency, using night light data to simulate and measure energy consumption. On this basis, SBM-ML index is used to scientifically measure and evaluate the green all-factor energy efficiency of all provinces in China and solve the endogenous problems that may exist in the emission trading policy. Besides, this paper incorporates green technology innovation between emissions trading and energy efficiency, enriches the contextual literature on green all-factor energy efficiency, and also provides greater flexibility in the implementation of emission reduction strategies.

## 2. Literature review

Emissions Trading Scheme (ETS) was first proposed in Europe in 2005 and has now become an active policy tool whose main purpose is to reduce greenhouse gas emissions cost-effectively [1, 2]. The "Porter Hypothesis" claimed that strategically investing revenue in energy efficiency measures can achieve energy conservation and emission reduction at the lowest economic and social costs. However, some economists disagree that defining external cost of greenhouse gas emissions as the only unsolved market problem. Theoretically, the emission trading system can internalize externalities and effectively encourage emission reduction, but any top-level policy will distort the power of market to a certain extent [3]. Under these circumstances, a large number of scholars have studied whether the trading of emission rights has promoted the improvement of energy efficiency. For example, Lundgren et al. confirmed that the EU's emissions trading system has no significant impact on the improvement of energy efficiency of Swedish companies [4]; Meng analyzed the impact of emissions trading on the Australian energy sector and the overall economy. It is believed that this system can effectively reduce emissions, but has little impact on the overall economy [5]. As far as emissions trading in China are concerned, there has not yet been a consensus on whether emissions trading policies can improve energy efficiency. Some scholars affirmed that the emission trading system can improve energy efficiency [6, 7], but some scholars also deny the promotion of emission rights trading to the improvement of energy efficiency [8, 9], they believe that the emission trading market is inefficient and fails to effectively support the effective operation of the emission trading system. But it is undeniable that both economic advantages and environmental advantages exist for a long time [10]. In the long run, the economic and environmental advantages brought by the emission trading system can promote the improvement of energy efficiency, and most of the literature measures energy efficiency only using total factor productivity that exclude undesired output, or the use of single-factor energy efficiency for verification, lacks a systematic measurement of green total-factor energy efficiency.

Based on the above analysis, this article proposes the opposite hypothesis I:
**H1a: The emission trading system can improve regional green all-factor energy efficiency.**
**H1b: The emission trading system cannot improve regional green all-factor energy efficiency.**

The impact of environmental regulations on regional technological innovation usually exists in two ways: one is to force R&D innovation by increasing environmental costs; the other is to give economic dividends to green enterprises and encourage the development of green technological innovations [11]. As a market-oriented environmental regulation measurement, the emission trading system links environmental costs with compensation for enterprise innovation, and can achieve a "win-win" situation of reducing costs and promoting technological innovation [12]. Specifically, the increase in environmental costs depends on the initial allowances for emission rights that need to be purchased by the enterprise itself, but the initial purchase cost is smaller than the policy dividends obtained in the later period. Based on the profit maximization goal, the enterprise will improve the green technology and the willingness to innovate and reduce environmental costs. In terms of economic advantages, companies can trade excess initial allowances of emission rights in the secondary emission rights market, that is, when their environmental protection capabilities improve, companies can sell extra initial allowances of emission rights to the companies that do not have enough initial quotas for emission rights. In order to continue to obtain economic dividends, the enterprises that transfer the initial quotas of pollution rights will have more motivation to carry out green technology research and development, while the transferee has to carry out green technology innovation in order to reduce its own environmental costs and survive better in the market. In addition, the implementation of emissions trading provides companies with more market information on technological improvements, thereby reducing the uncertainty of technological innovation. The improvement of green technology innovation capability is regarded as the improvement of primary energy efficiency utilization: technological innovation in energy can cause changes in energy prices [13], leading to the breakdown of supply and demand balance and changes in energy consumption structure, which in turn leads to target input and changes in energy efficiency [14].

Therefore, this article proposes hypothesis II:
**H2: The emission trading system can improve the energy efficiency of regional green all-factors by improving the ability of green technology innovation.**

The specific implementation of the system still requires systematic efforts due to the implementation process of the emission trading system is complicated and difficult to operate. The effectiveness of policy implementation is closely related to the institutional environment of local institutions, which includes decentralization, environmental law enforcement, and the degree of marketization. China has a vast territory, and the system environment of the provinces in the pilot emission trading rights is very different. The actual implementation of the emission rights trading policy may be more dependent on the level of pollution in the pilot areas and the government's supervision. That is, in the high-pollution pilot areas, the government has stronger policies. The motivation to improve the discharge of pollutants, strengthen the supervision of policy implementation, so that the emission trading system can be implemented well, in order to obtain better political performance.

Therefore, this article proposes hypothesis III:
**H3: Compared with low-pollution areas with better environments, high-pollution areas are more sensitive to the implementation of emission rights trading policies.**

## 3. Data and variables

This paper uses the panel data of 30 provinces across the country from 2004 to 2017 as the research sample (excluding Hong Kong, Macao and Taiwan regions and the Tibet region where data is severely missing), and divides the sample experimental group and the control group considering the implementation of the emission trading policy in 2008: The prefecture-level cities involved in 11 provinces mentioned above are the experimental group, and the prefecture-level cities of the remaining provinces are the control group. The data mainly comes from the "China Statistical Yearbook," "China Energy Statistical Yearbook," "China Environment Statistical Yearbook," "China Industrial Statistical Yearbook" and relevant statistical databases of various provinces.

This study is based on the SBM model of undesired output and the Malmquist-Luenberger index to calculate the total factor green energy efficiency. Since traditional DEA models are mostly radial and angular measurements, they do not include the relaxation improvement part of the invalid DMU. The non-radial and non-angle SBM model effectively solves the problem that the radial model does not include relaxation variables in the measurement of inefficiency.

Defining each province as a DMU, and each DMU has m inputs $X=(x_1,x_2,...x_m)$ and S outputs, which include $S_1$: expected output $Y^g=(y_1^g,y_2^g,...y_{s_1}^g)$ and $S_2$: undesired output $Y^b=(y_1^b,y_2^b,...y_{s_2}^b)$. Defining $\lambda$ as the weight vector representing the cross-sectional observation value. For each specific DMU, we have the following SBM model:

$$\min\rho=\frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1+\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{rk}^{\ g}}+\sum_{r=1}^{s_2}\frac{s_r^b}{y_{rk}^{\ b}}\right)} \qquad s.t.\begin{cases}X\lambda+s_i^-=x_k\\ Y^g\lambda-s^g=y_k^{\ g}\\ Y^b\lambda-s^b=y_k^{\ b}\\ \lambda,s_i^-,s^g,s^b\geq 0\end{cases} \tag{1}$$

($\rho$ is the efficiency score, if and only if $\rho=1$, the current DMU is valid.)

Therefore, based on the directional distance function, this paper measures the green total factor energy efficiency in the case of considering undesired output. Under the technical level of period t, the Malmquist-Luenberger index from period t to period t+1 is:

$$\begin{cases}ML_t^{t+1}=\left[\frac{1+D_0^t(x^t,y^t,b^t;y^t,-b^t)}{1+D_0^t(x^{t+1},y^{t+1},b^{t+1};y^{t+1},-b^{t+1})}\times\frac{1+D_0^{t+1}(x^t,y^t,b^t;y^t,-b^t)}{1+D_0^{t+1}(x^{t+1},y^{t+1},b^{t+1};y^{t+1},-b^{t+1})}\right]^{1/2}\\ TEC_t^{t+1}=\frac{1+D_0^t(x^t,y^t,b^t;y^t,-b^t)}{1+D_0^{t+1}(x^{t+1},y^{t+1},b^{t+1};y^{t+1},-b^{t+1})}\\ TC_t^{t+1}=\left[\frac{1+D_0^{t+1}(x^{t+1},y^{t+1},b^{t+1};y^{t+1},-b^{t+1})}{1+D_0^t(x^{t+1},y^{t+1},b^{t+1};y^{t+1},-b^{t+1})}\times\frac{1+D_0^{t+1}(x^t,y^t,b^t;y^t,-b^t)}{1+D_0^t(x^t,y^t,b^t;y^t,-b^t)}\right]^{1/2}\end{cases} \tag{2}$$

(ML is total factor productivity, TEC is technical efficiency, and TC is technological progress change.)

If the values of the three indicators are greater than 1, then the efficiency is improved, and vice versa. Based on the above model and referring to the research of Shi Dan and Li Shaolin (2020) [7], labor, capital and the total consumption of energy is selected as the input, the gross regional product is the expected output, and the discharge of sulfur dioxide, dust and industrial wastewater is taken as the unexpected output. Applying the SBM-Malmquist-Luenberger model to calculate the total factor green energy efficiency which is the explanatory variable in this article (the capital is calculated based on the fixed asset value and fixed asset investment price index of 30 provinces in 2009-17, using the "perpetual inventory method"; other variables are from the yearbook). The main explanatory variable in this paper is the emission trading policy, and the Difference-in-Difference model (DID) is used to evaluate the effect of emission trading scheme. First, the sample is divided into a control group, which is the pilot city for the implementation of the non-emission trading system, and a treatment group, which is the pilot city for the emission trading system. In addition, take 2008 as the time node for policy effect evaluation to control system differences, and using dummy variables to measure them. Therefore, the whole sample is divided into four groups: the control group and the treatment group before the implementation of the policy, and the control group and the treatment group after the implementation of the policy. The specific model is as follows:

$$Grefee_{i,t}=\partial_0+\partial_1(Treat_{i,t}\times Post_{i,t})+\partial_2 Control_{i,t}+\mu_t+\gamma_i+\eta_{it}+\varepsilon_{it} \tag{3}$$

$Grefee$ is the all-factor green energy efficiency of the explained variable; $i$ is the corresponding prefecture-level city, $t$ is the year, $Treat$ is the city grouping variable (the emission trading pilot city is 1, otherwise it is 0), $Post$ is the time dummy variable (after implementation of the policy, that is, after 2008, it is 1, and before 2008, it is 0; $Control$ is the control variable group; $\mu_t$ is the time fixed effect; $\gamma_i$ is the province fixed effect; $\eta_{it}$ is the individual fixed effect; $\varepsilon_{it}$ is the random disturbance item. In Model 1, the main observation values of $\partial_1$ are used to analyze the impact of emissions trading policies on the efficiency of all-factor green energy. In addition to the above variables, the Green Technology Innovation (Gretinrate) involved in Hypothesis II is mainly based on the research of Wang Zhenyu et al. [15]. According to the “IPC Green Inventory (International Patent Classification Green Inventory)” launched by WIPO, the number of environmentally-friendly green patent applications in first-tier cities, and its proportion in the total number of patent applications in each region that year is used as the core indicator to measure green technological innovation. Assume that the less polluted and severe polluted areas mentioned in the third section are distinguished by $SO_2$ emissions. Specifically, samples above the average value are classified as high-pollution areas, and those below the sample average are classified as low-pollution areas. The control variable group contains the following variables (**Table 1**):

**Table 1.** Definition of control variables

| Variables | Measurement | Definition |
|---|---|---|
| GDP per capital（pergdp） | Gross Regional Product /Total Population at the End of the Year | Regional economic development level |
| Total energy consumption（tolenergy） | Calculated by night light data [16, 17] | Regional energy consumption |
| Industrial structure（indstr） | Gross Industrial Output Value /Gross Regional Product Value | Regional industrial composition |
| $SO_2$ emissions（$SO_2$） | Data from Yearbook | Regional pollutant emission levels |
| Population density（density） | Regional population /Administrative area area | Population density |
| R&D intensity | Proportion of applications for invention patents | R&D and innovation ability |

## 4. Empirical findings and discussions

### 4.1. Descriptive statistics and correlation analysis

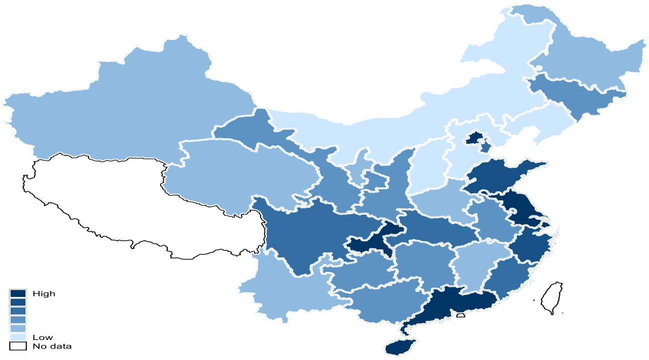


**Figure 1.** Spatial distribution map


**Figure 2.** Changes in green all-factor energy efficiency

It is shown that the energy utilization efficiency in southeast coastal provinces is generally higher than that of the central and western regions, especially Beijing, Shanghai, Tianjin, Guangdong, Fujian, Zhejiang, Chongqing and other places (**Figure 1**). However, a high efficiency value may be caused by the relative optimization of the energy structure. The energy using efficiency of these non-pilot areas seems to be higher than that of the pilot areas, but it cannot be ignored that, before the implementation of emission rights trading policies, high-efficiency provinces may have a superior energy structure. Therefore, we conduct a DID analysis and examine the impact of the emission trading system on green total-factor energy efficiency. The descriptive statistics of related variables in the sample interval of this paper are shown in **Table 2**. The descriptive statistics of variables are all within a reasonable range. The mean (median) value of green total factor energy efficiency is 0.96 (0.91), which is close to that reported by Shi Dan and Li Shaolin (2020). Green technology innovation is represented by the logarithm of the number of green inventory patents, and its mean value is 6.27, which indicates that due to different regions, The green innovation level and energy utilization efficiency in China are quite different. In addition, there are significant differences in the research time interval of each variable, which lays the foundation for the subsequent research. The correlation coefficients of the dummy variable DID set by the emission trading system and the green total factor energy efficiency is significant at the 1% level, meanwhile, the correlation coefficients of the DID and green energy innovation is also significant at the 1% level, which preliminarily verifies the hypothesis H1a With H2. VIF test was performed on some variables with correlation coefficients greater than 0.5, and the VIF of each variable was less than 10, which ruled out the possibility of multicollinearity among variables.

**Table 2.** Descriptive statistics table of main variables

| variable | N | mean | sd | p25 | p50 | p75 |
|---|---|---|---|---|---|---|
| Grefee | 3934 | 0.960 | 0.330 | 0.770 | 0.910 | 1.090 |
| Gretinrate | 3934 | 6.270 | 1.820 | 4.980 | 6.150 | 7.470 |
| pergdp | 3934 | 8.520 | 0.710 | 8.020 | 8.510 | 9.040 |
| tolenergy | 3934 | 6.810 | 0.890 | 6.220 | 6.850 | 7.430 |
| indstr | 3934 | 0.420 | 0.670 | 0.0900 | 0.480 | 0.830 |
| lnso2 | 3934 | 10.49 | 1.040 | 9.860 | 10.65 | 11.25 |
| rdintensity | 3934 | 3.830 | 1.960 | 2.400 | 3.660 | 5.050 |
| density | 3934 | 5.720 | 0.860 | 5.220 | 5.840 | 6.410 |

### 4.2. Benchmark regression and parallel trend testing

Plotting the average change of all-factor green energy efficiency before and after the policy implementation in the sample interval (**Figure 2**), we can observe that since 2008, when the emissions trading scheme was officially implemented, the efficiency of all-factor green energy has steadily improved. However, from 2013 to 2015, the total factor energy efficiency showed a downward trend, which may be caused by the impact of the international financial crisis. After 2015, all-factor energy efficiency has improved year by year; and the all-factor green energy efficiency of pilot cities has stabilized above that of non-pilot cities, indicating that the emission trading system has a continuous positive effect on all-factor green energy efficiency, which is preliminarily confirmed that H1a holds.

According to model (3), the benchmark regression results of the main variables are shown in **Table 3**. The column (1) in the table is the DID estimation result of how the emission trading system affects the green total factor energy efficiency after controlling the time, province, and individual fixed effects. Among them, the impact coefficient of the interaction term DID (treat*post) on the green total factor energy efficiency is significant at the level of 10%, indicating that the emission trading system officially implemented in 2008 has significantly improved the green total factor energy efficiency of the corresponding regions, the hypothesis H1a has been verified. Column (2) reports the impact of the emission trading system on green technology innovation. The impact coefficient is 3.193, which is significant at the 1% level, indicating that the level of green technology innovation measured by the proportion of patent applications has increased significantly, indicating that the emission trading policy can trigger innovation. The regression results in column (3) show that green technological innovation has not played an intermediary effect in the promotion of green all-factor energy efficiency in the pilot project of emissions trading. Although the innovation compensation effects caused by market-oriented environmental regulations can be divided into product compensation and process compensation (Tao Feng et al, 2021) [18], the current innovation effects have not been transformed into higher green all-factor energy efficiency. However, in the estimation results in column (4), the cross-term coefficient of green technology innovation and emissions trading is significantly positive at the 10% level, and the regression coefficient of DID decrease by 34.7% compared with column (1), indicating that Green technological innovation can positively regulate the promotion of emission rights trading on all-factor green energy efficiency, and the hypothesis H2 has been verified.

**Table 3.** DID benchmark regression analysis

| **Variables** | **Grefee** | **Gretinrate** | **Grefee** | **Grefee** |
|---|---|---|---|---|
| DID | 0.521* | 3.193*** | 0.528* | 0.174* |
| | (1.911) | (7.003) | (1.930) | (1.823) |
| Gretinrate | | | -0.00223 | |
| | | | (-0.240) | |
| Gretinrate* DID | | | | 0.0365* |
| | | | | (1.850) |
| Control Var | YES | YES | YES | YES |
| Province FE | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| City FE | YES | YES | YES | YES |
| Ajusted $R^2$ | 0.358 | 0.507 | 0.358 | 0.167 |

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

The premise of the consistency of DID estimation results is that both the treatment group and the control group conform to the time trend assumption, that is, before the policy intervention, the outcome variable trends of the treatment group and the control group are consistent. This research adopts the event research method proposed by Jacobson et al. [19], and establishes the following model (2):

$$Grefee_{i,t} = \beta_0 + \sum_{t=2003}^{2007} \beta_t (Treat_{i,t} \times Post_{i,t}) + \partial_2 Control_{i,t} + \mu_t + \gamma_i + \eta_{it} + \varepsilon_{it} \qquad (4)$$

Taking 2008 as the base year, it represents a series of coefficient estimates from 2004 to 2017. Other variables have the same meaning as those in model (3). It can be seen from the regression results that the period from 2004 to 2007 was not significant, indicating that before the implementation of the emission trading policy, there was no obvious difference between the treatment group and the control group. This conforms to the parallel trend assumption, that is, the results of DID estimation model are consistent.

### 4.3. Heterogeneity analysis

The effect of environmental regulation will be restricted by many factors [18]. It can be seen from Figure 1 that the energy efficiency in China is different in different regions. In order to make the research more comprehensive, this paper examine whether the high-polluted areas are more sensitive to the emission trading system. Based on the industrial sulfur dioxide emissions per unit of GDP, a dummy variable is set to distinguish high-polluted areas from low-polluting areas. The emissions above the average value are recorded as 1, otherwise, recorded as 0. The results of group regression are shown in **Table 4**. The explanatory variables in columns (1) and (2) in the table are green total factor energy efficiency. Among them, the interaction term did (treat*post) in high-polluted areas is significant at the level of 10%, while it is insignificant in low-polluted areas; the explanatory variables in columns (3) and (4) are green technology innovations, and it is also significant in high-polluted areas at the 1% level, while in low-polluted areas is insignificant. It shows that in high-polluted pilot areas, the promotion effect of emission trading system on all-factor green energy efficiency and green technology innovation is more significant, that is, hypothesis H3 is verified.

**Table 4.** Analysis of Heterogeneity of Pollution Degree

| Variables | Grefee High-polluted area | Low-polluted area | Gretinrate High-polluted area | Low-polluted area |
|---|---|---|---|---|
| DID | 0.499* | 0.404 | 2.621*** | -0.463 |
| | (1.067) | (1.181) | (2.830) | (-1.233) |
| Control Var | YES | YES | YES | YES |
| Province FE | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| City FE | YES | YES | YES | YES |
| Ajusted $R^2$ | 0.408 | 0.321 | 0.416 | 0.602 |

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

### 4.4. Robustness test

#### 4.4.1. Placebo test

In order to eliminate the influence of other factors in this study, and ensure that the changes in green total factor energy efficiency are caused by the emission trading system, this paper conducts a placebo test. If the regression results of the estimators under different methods are still significant, then it means that the original estimation results are likely to be biased, the changes in variables are likely to be affected by other policy changes or random factors. Specifically, this article conducted 1000 random samplings in the full sample, and each time randomly selected 11 provinces as the hypothetical treatment group, and set the remaining provinces as the hypothetical control group, to get a nuclear density map of green all-factor energy efficiency (**Figure 3**). The x-axis in the figure represents the t value of the estimated coefficient, and the absolute value of t is stable within 2; the y-axis represents the p value, and most of the p values are greater than 0.1; overall, the coefficients are concentrated around 0, it can be inferred that the missing coefficient of other variables is 0. That is to say, the conclusion of this paper has passed the placebo test, and the impact of the emission trading system on the green total factor energy efficiency is incorrelated with the impact of other unknown factors.

### 4.4.2. PSM-DID estimation method test

In order to overcome the systematic differences of green technology innovation and green total-factor energy efficiency trends between emission trading scheme pilot areas and non-pilot areas, and reduce the inherent deviation of DID method estimates, this paper uses the propensity score matching (PSM-DID) method to further verify Benchmark regression results. First, logit regression is performed on the matching variables, and the dummy variable ETSi is used to represent the implementation of the emission trading system, the propensity score value is obtained. This study uses the aforementioned control variable group as the matching variable. Secondly, according to the above matching variables and propensity scores, companies in the pilot and non-pilot areas of emissions trading are matched 1:1. **Table 5** reports the results of the PSM-DID robustness test. The dependent variable in the first column is green total-factor energy efficiency, and the corresponding interaction coefficient ETSi*Post is positive and significant at the level of 5%, indicating that pollution is discharged after the matching of rights trading, there is still a significant positive impact on the green total factor energy efficiency of the pilot area, which is consistent with the results of the above-mentioned benchmark analysis; the second column of interaction coefficient ETSi*Post is also positive at 1%, indicating that emissions trading has a significant impact on green technology innovation, which is also consistent with the results of the benchmark regression. In short, this study shows that the pilot scheme of emission trading has promoted green technology innovation in China and also significantly promoted the development of green total-factor energy efficiency. The benchmark regression results are robust.

**Table 5.** PSM-DID estimation

| VARIABLES | Grefee | Gretinrate |
|---|---|---|
| ETSi×Post | 0.704** | 3.530*** |
| | (2.153) | (6.800) |
| Control Var | Yes | Yes |
| Observations | 3,216 | 3,216 |
| Province FE | YES | YES |
| Year FE | YES | YES |
| City FE | YES | YES |
| Ajusted $R^2$ | 0.346 | 0.488 |

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

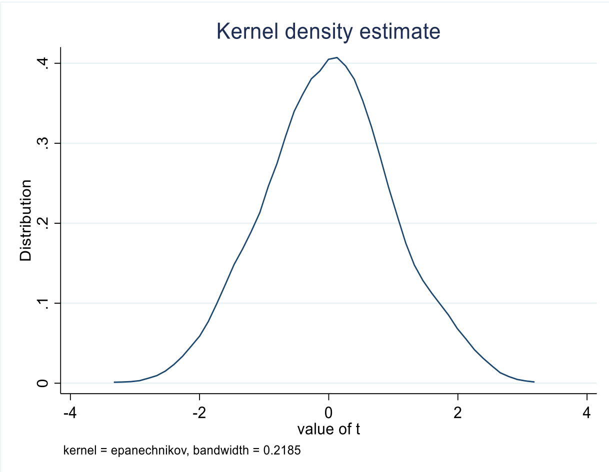


**Figure 3.** Placebo Test

## 5. Conclusions and suggestions

Emissions trading scheme is a market-oriented environmental regulation tool, which is of great significance to promote cleaner production and sustainable development. Based on the DID method, this study analyzed the data of 30 provinces from 2004 to 2017, and discussed whether the implementation of emission rights trading in pilot areas can effectively improve energy efficiency. The conclusions obtained from the study mainly include three aspects:

(1) In the pilot areas, the emission trading system can indeed improve the green total-factor energy efficiency, and green technological innovation as an internal driving force, positively regulates the promotion.

(2) The implementation of the emission trading system depends on the level of regional pollution, and high-polluted areas are more sensitive to this policy.

(3) 30 provinces have obvious diversity of energy efficiency, and the Southeastern provinces are

generally higher than Midwestern provinces. Based on the above results, it is necessary to improve the design of the emission trading system and the incentive measures of the trading market from top to bottom in order to achieve the dual goals of cleaner production and economic growth.

Accordingly, this article proposes the following policy recommendations: First, vigorously support enterprise innovation, especially in environmental protection and energy conservation. The state can give fiscal and tax incentives, such as relaxing the income tax of enterprises involved in emissions trading, which will help enterprises have greater motivation to invest funds in research and development green innovation, promote high-quality development of enterprises, and achieve the best allocation of corporate resources. Second, gradually implement the emission trading system based on geographical characteristics. Specifically, considering the large differences in energy efficiency among provinces, cities and industries, the implementation of emissions trading needs to be adapted to local energy consumption such as pilot implementation in high-polluted areas, key implementation in central and western regions, all of these measures can effectively improve green all-factor energy efficiency and improve energy consumption structure. Third, establish a sound emission trading market. Local governments should actively formulate reasonable trading rules and initial emission rights allocation quotas to prevent vicious transactions such as monopoly trading quotas. At the same time, it is necessary to increase the frequency of monitoring pollution sources, strengthen local governance, and use the power of media and public opinion to help enterprises rectify and reform when necessary. Finally, the implementation of all processes should be included in the supervision of government regulatory agencies to prevent local governments from protecting local heavily polluted enterprises.

## Disclosure statement

The author declares no conflict of interest.

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