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The Effect of Energy Quota Trading on Energy Saving in China: Insight from a Quasi-Natural Experiment

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Abstract: Saving energy is an important strategy to address the current energy crisis and environmental degradation. Regarding the pilot policy of the energy quota trading as a quasi-natural experiment by employing a difference-in-differences method, the purpose of this paper is to investigate the effect of this pilot policy on energy saving and its mechanisms based on city-level data in China from 2006 to 2020. We find that the energy quota trading policy can reduce the total energy consumption and energy consumption intensity of pilot cities, and the effect of the policy can gradually strengthen over time. The market-oriented reform of energy factor allocation can effectively promote energy saving and economic growth. These results are convincing through a series of robustness checks. The heterogeneity test shows that the energy quota trading has a significant energy saving effect on economically developed cities, densely populated cities and southern cities, but not in economically underdeveloped cities, sparsely populated cities and northern cities. Further mechanism inspection suggests that the pilot policy of energy quota trading mainly achieves energy conservation through industrial structure upgrading and green technology innovation. Our findings provide a valuable insight for China to control energy consumption and promote the high-quality development of the energy economy.

Keywords: energy quota trading; energy saving; industrial structure upgrading; green technology innovation; difference-in-differences method

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1. Introduction

Human-induced climate change is already bringing about widespread adverse impacts on human societies. The substantial emissions of greenhouse gases and other pollutants resulting from higher fossil fuel combustion consumption are an important influence on climate change, which has driven governments to focus on the management of energy consumption. China is currently the world's top energy consumer and carbon emitter [1]. In 2021, China's primary energy consumption reached 157.65 EJ, accounting for 26.5% of total global energy consumption, and caused 10.52 gigatons of carbon emissions, accounting for 23.1% of total global carbon emissions [2]. If greenhouse gas emissions are not cut, the resulting climate shocks will have widespread negative impacts on society, and China will be one of the regions most affected by climate change [3]. As a result, the Chinese government has continued to strengthen its determination to optimize energy consumption and has stated that it will achieve carbon neutrality by 2060. With the advancement of factor market-based reforms, China has started trading environmental permits. In particular, China launched a pilot energy quota trading policy in 2016, which aims to promote a more efficient allocation of energy factors and thus achieve energy saving and emission reduction targets.

Market-based policy instruments have been widely practiced and studied over the past 30 years [4], and these includes GHG emissions allowance trading, green certificates and white certificates [5]. In the past, well-established emissions allowance trading has gained more attention. While emissions allowance trading aims to tax corporate GHG emissions, energy quota trading is somewhat different in that it enables energy-saving producers to receive subsidies through the sale of energy use rights and enables energy buyers to pay taxes when they purchase energy use rights [6].

With the implementation of energy quota trading (or white certificates) in countries such as the Netherlands, Italy and the UK, more and more scholars are focusing on this policy [7]. This policy tool is considered an important way to achieve energy consumption management targets [8]. The implementation of energy quota trading (or white certificates) is characterized by high equity, flexibility and political acceptability compared to existing policies that target emissions reductions [9]. More importantly, a large number of scholars argue that energy quota trading has a cost effect and can stimulate energy saving potential at minimal cost [10–12]. Rosenow and Bayer [8] showed that energy quota trading can not only achieve energy savings and emissions reductions through market mechanisms, but also create jobs and stimulate the economy, while the policy can enhance the living environment and the health of the population. This means that the policy tool of energy quota trading has a positive impact on the vast majority of participating agents [13]. In summary, energy quota trading has a great potential to save energy and achieve carbon neutrality.

Most of the above studies are based on practice in countries other than China, and the need for relevant research has increased with the implementation of energy quota trading in China. The Chinese government has requested an evaluation of the effectiveness of this pilot policy, with the hope that the shortcomings of the policy can be identified in practice, so that the system can be adjusted and lessons learned to lay the groundwork for the expansion of energy quota trading. Simultaneously, the randomly selected pilot provides a quasi-natural experimental scenario that can be used to verify the impact of the policy on energy consumption. There is currently a gap in the study of energy consumption in China [14]. Although a large number of studies discussed the relationship between emissions trading and energy consumption, there are relatively few studies on the relationship between energy quota trading and energy consumption. Energy quota trading and emission trading are both sub-fields of resource use rights trading. The study on energy quota trading could not only enrich the research of energy quota trading and energy consumption, but also provide new inspirations for the theoretical and empirical evidences of resource use rights trading.

Therefore, the main purpose of this paper is to assess the impact of the energy quota trading policy on energy consumption in China, which adopts a difference-in-differences (DID) model to explore whether the policy promotes regional energy conservation and economic growth, based on panel data for cities in China from 2006 to 2020. In particular, firstly, the core goal of this paper is to examine whether the policy promotes regional energy conservation and economic growth, which could validate the win–win effects of the pilot policy in terms of energy saving and its economic growth. Secondly, we conduct a heterogeneity analysis in terms of the degree of economic development, city size, and geographic location of cities, and attempt to explore the differences in the energy saving effect of the energy quota trading policy with respect to the characteristics of these cities. Thirdly, this paper further explores the mechanisms of this policy from industrial structure upgrading and green technology innovation, which can provide an effective path for the policy improvement. If it can be proved that the policy has positive effects and remarkable mechanisms, we can provide practical suggestions based on our results.

This paper seeks to extend existing literature in three ways. First, this paper provides new evidence by using a difference-in-differences approach based on a quasi-natural experiment to assess the policy effects of market-based energy trading in developing countries. On the one hand, in the process of policy implementation, developing and developed country governments have different preferences [15], which could lead to different policy outcomes. Therefore, there is a need to assess energy quota trading in developing countries in order to make targeted recommendations. On the other hand, as the market parameters are similar to those of other developing countries [16], the results of this study can be used as a reference for these countries. Second, this paper takes into account both energy saving effects and economic effects in assessing the policy and examines the dynamic effects of its energy savings. The benefits of energy quota trading include limitations on energy consumption and also the suppression of GDP losses [17]. As an energy policy, it is also possible to cause large fluctuations in energy prices, thus posing a threat to economic stability. Some studies show that capacity licensing trading, also as an energy policy, can improve the economic efficiency of enterprises [18]. However, some studies believe that energy policies may have negative socio-economic benefits in the short term [8]. Third, environmental regulation not only achieves the main policy objectives, but also brings unexpected impacts. Resource use rights trading may weaken the negative environmental effects by reducing the output of enterprises but not just innovation. [19], which can promote the upgrading and transformation of enterprises. Thus, this paper analyses the mechanism of action of energy quota trading in two dimensions, such as industrial structure upgrading and green technology innovation in a comprehensive manner. This helps to explore the deeper implications of market-based energy quota trading and optimize the policy paths.

The rest of the paper is structured as follows. Section 2 provides an overview of the literature related to energy consumption policies. Section 3 presents the empirical estimation strategy, including the DID model and data description. Section 4 discusses the empirical results. Conclusions and policy implications are proposed in Section 5.

2. Literature Review

Market-based energy policies are regarded as more efficient energy management tools [6,20,21]. Energy quota trading is a market-based policy instrument. It can deal with the market failure in energy markets and narrow the gap in energy efficiency [22]. In terms of the process of implementing policy instruments, energy quota trading is cost-effective and economically efficient [8,21]. It could achieve savings with minimum total cost by promoting cooperation and competition among energy users [23]. For governments, energy quota trading is popular because it could reduce the financial burden [24]. From the perspective of the results of the implementation of the policy instrument, energy quota trading can have an impact on energy consumption. Brtoldi and Huld [25] believed that energy quota trading can result in significant savings in energy consumption. On this basis, Child et al. [26] argued that energy quota trading can have a positive chemical reaction with other policy instruments, reducing electricity generation and increasing the use of renewable energy. Ringel et al. [27] and Amin et al. [28] examined the positive effects of energy quota trading in Germany and Iran based on ASTRA model and market interaction model, respectively.

However, studies still question the ultimate effect of energy quota trading on energy consumption, suggesting that energy policies often achieve policy objectives to the detriment of other social objectives, such as socio-economic effectiveness [29]. Moreover, energy and emissions policies alone may not provide sufficient incentives to save energy. Some studies show that the policies related to energy efficiency may increase carbon emissions due to a possible rebound effect of energy consumption [30,31]. Furthermore, if energy users' energy efficiency or energy consumption is inelastic in response to prices, then an increase in energy prices due to energy quota trading could not have an impact on energy users' energy efficiency or energy consumption [32]. Therefore, more literature is still needed to assess the relationship between energy quota trading and energy consumption.

The energy quota trading policy implemented in China in 2016 provides a new scenario to explore the relationship between energy quota trading and energy consumption. Pan and Dong [14] argued that energy quota trading can alleviate energy vulnerability, i.e., alleviate macro energy security as well as energy poverty at the micro level. Wang et al. [17] indicated that energy quota trading can reap potential economic gains.

Currently, Wang et al. [33] and Zhang et al. [34] assessed the impact of policies on energy consumption based on a pilot energy quota trading policy using a difference-in-differences model. However, there may be a short- to medium-term trade-off between the role of energy policies in reducing emissions and other socio-economic objectives, and a win–win situation between environmental and economic effects cannot be achieved [9]. Luo and Zhang [35] used a DEA model to find that the effect of the energy-use rights trading policy is uncertain, with all enterprises after the policy implementation having positive energy saving potential, but some enterprises have negative economic potential. Therefore, the evaluation of energy trading needs to measure both the emission reduction and economic effects of the policy.

Based on the above studies, we propose Hypothesis 1: After the energy quota trading policy is implemented, the pilot cities could achieve energy saving and economic growth compared with the non-pilot cities.

Energy consumption is not strictly exogenous, and energy policies can affect energy consumption through direct and indirect channels [36]. There is now a substantial literature on the impacts of energy quota trading, and changes in these factors will have a profound impact on energy consumption. In terms of policy outcomes, energy quota trading could have economic, environmental and cost benefits [37], and could improve regional energy efficiency, industrial upgrading and technological innovation [38]. Regarding the content of the policy, the subject of energy consumption, trading mechanism and pricing mechanism determined by the policy could have a great impact on energy efficiency and energy consumption [39]. Mundaca [40] showed that the pricing system determined by the policy and the resulting transaction costs would affect energy efficiency.

The mechanisms by which the policy works have yet to be uncovered in the study of energy quota trading in China. Energy policies may influence local energy consumption by changing the structure of local industries. The structural transformation could help improve energy efficiency and the economy to achieve China's target of carbon neutrality [41]. On the energy demand side, energy quota trading will increase the production costs of energy-intensive enterprises, thus eliminating outdated production capacity or transforming and upgrading [42,43]. On the energy supply side, energy quota trading will increase the number of energy supply agents, allowing energy to be traded between industries, promoting gains in energy-rich industries and forcing energy-intensive industries to transform, upgrade and green production [44,45]. Therefore, the industrial restructuring resulting from energy quota trading will have a huge potential for energy saving and emission reduction.

Therefore, we propose Hypothesis 2: Energy quota trading could save energy through industrial structure upgrading.

Moreover, in the process of energy quota trading exerting its emission reduction effect, technological progress is then of great concern. This is because technological progress is an important pathway for the role of environmental regulations [46], and technological progress also has an important impact on energy consumption [47–49]. Oikonomou and Mundaca [50] and Morganti and Garofalo [51] argued that the objective of energy quota trading should not only address energy savings but also promote innovation. Energy quota trading should be a sustainable mechanism oriented towards technological innovation.

Thus, we propose Hypothesis 3: Energy quota trading could save energy through green technology innovation.

In summary, it is necessary to test the pilot energy quota policy, and the existing literature may have the following limitations or merit further research. First, the energy quota trading effect is assessed from the perspective of energy consumption control and GDP loss suppression. Few studies have considered the potential benefits of the policy, such as energy effects and economic effects [17]. Second, existing tests of the mechanisms of energy quota trading are not clear. Existing studies have failed to clarify the mechanisms by which the policy works in a market-based manner. Third, current studies on energy quota trading in China have focused on the provincial level. This paper uses city-level data to refine the study of inter-city energy quota trading more than provincial-level data.

3. Methodology

3.1. Data

The dataset in this paper covers a panel of 280 cities at prefecture level and above in China during the period 2006–2020. The list of pilot regions for energy quota trading in this paper is taken from the National Development and Reform Commission in China. Other data are obtained from the China Urban Statistical Yearbook, the China Urban Construction Statistical Yearbook, the statistical offices of each city and the Development and Reform Commission, etc. For the explanatory variables measuring the effect of energy savings, the total energy consumption and energy consumption intensity of each city are selected. The main sources of energy used in Chinese cities include electricity, gas, liquefied petroleum gas and natural gas. Northern cities also have thermal energy supplies for winter heating. These energy sources are converted into tones of standard coal and summed up to obtain the total energy consumption of each city. The energy consumption intensity of each city is measured using total energy consumption as a proportion of real gross domestic product (GDP). With regard to the core explanatory variables, the establishment of the pilot energy trading policy is treated as an exogenous policy shock, represented by the interaction term between the group dummy variable $Treat_i$ and the time dummy variable $Time_t$. The treatment group in this paper includes 55 cities in the energy quota trading pilot regions, with the remaining 225 cities belonging to the control group.

In order to control for other potential confounding influences on energy consumption levels, and drawing on the existing literature [52,53], a series of control variables are also included in this paper. These control variables include the level of economic development (GDPP), population concentration (POPDEN), infrastructure development (ROAD), degree of industrialization (IND), foreign direct investment (FDI) and climatic conditions (TEMP). In particular, the degree of economic development is an important factor influencing energy consumption, so this paper uses GDP per capita to capture the role of the level of economic development. During the rapid urbanization phase, population is an important driver of energy consumption growth. Population density, namely the total number of people per unit area at the end of the year, is therefore used to measure the impact of population agglomeration. Investment boosts the demand for energy. Therefore, this paper uses the amount of actual foreign investment used in the year to measure the level of foreign direct investment. The industrial sector is a high energy consuming sector. The level of industrialization is expressed using the share of the secondary sector in GDP. Climate change can exacerbate the increased demand for energy consumption, so this paper uses annual temperatures to measure climatic conditions. Taking into account the effect of price fluctuations across years in the sample interval, this paper deflates GDP and foreign direct investment separately.

3.2. Estimation Strategy

In this paper, we employ a difference-in-differences model to examine how pilot regions of energy quota trading, which began to be established in China in 2016, affect energy consumption and assess their energy saving effects. The DID method is based on a counterfactual framework to assess differences when policies occur and when they do not [54]. Specifically, we regard all cities in the pilot areas of the energy quota trading policy as the treatment group and those without the pilot as the control group. Total energy consumption and energy consumption intensity are used as explanatory variables. The net impact of the energy quota trading policy on energy savings is estimated by comparing the difference between the treatment and control groups before and after the energy quota trading pilot. As for the analysis flow, this paper initially constructs an estimation model for the benchmark, then performs a series of robustness tests, followed by a heterogeneity analysis, and finally tests the mechanism of the effect of the policy. The baseline econometric model for this paper is then formulated as follows:

$$Energy_{it} = \alpha + \beta Treat_i \cdot Time_t + \theta Control_{it} + \gamma_i + \delta_t + \varepsilon_{it} \quad (1)$$

where the explanatory variables $Energy_{it}$ denotes total energy consumption and energy consumption intensity in cities. The subscripts i and t represent city i and year t, respectively. $Treat_i \cdot Time_t$ is the core explanatory variable. $Treat_i$ is used to identify the city in which the energy quota trading pilot region is located. If a city is located in an energy quota trading pilot area, this variable takes the value of 1, otherwise 0. $Time_t$ is used to identify the time when the energy quota trading pilot policy was implemented. It takes the value of 1 if a city is located in the year 2016 and after the implementation of the energy quota trading policy, and 0 otherwise. $Control_{it}$ indicates other control variables affecting energy consumption or the choice of the pilot policy. γ_i depicts the city fixed effect and δ_t depicts the year fixed effect. ε_{it} is a random disturbance term. The core regression coefficient β measures the net effect of the impact of the energy quota trading policy on energy consumption. If the energy quota trading policy makes energy consumption increase, then β is positive. Conversely, β is negative if the energy quota trading policy leads to a decrease in energy consumption, indicating that the energy quota trading pilot policy has an energy saving effect.

4. Empirical Results

4.1. Benchmark Results

The definitions of the main variables and descriptive statistics are shown in Table 1. Table 2 reports the results of the baseline regression of the impact of the pilot policy of energy trading on energy consumption. Columns (1)–(3) show the estimated results of the impact of the pilot policy on total energy consumption. Columns (4)–(6) show the estimated results of the impact of the pilot policy on energy consumption intensity. Columns (7) and (8) estimate the impact of the pilot energy trading policy on economic development and growth. The results in columns (1) and (4) are estimated using OLS regression without any control variables and fixed effects. With the exception of columns (2) and (5), control variables are added to the results in all other columns. As can be seen from the regression results in columns (3) and (6) of Table 2, the estimated coefficients of the energy quota trading policy are both significantly negative when total energy consumption and energy consumption intensity are the explanatory variables, indicating that the pilot policy of energy quota trading has generally contributed to a reduction in total energy consumption and energy consumption intensity. As shown by the estimated coefficients in columns (3) and (6), compared to the non-pilot cities, the energy quota trading policy in the pilot cities led to a 5.5% and 4.8% reduction in the logarithm of total energy consumption and energy consumption intensity, respectively. In summary, these results suggest that the energy quota trading policy significantly reduces the level of energy consumption and has a significant energy saving effect. Also, these results may answer the doubts about whether energy quota trading can achieve policy goals [30,32].

Table 1. Descriptive statistics.

Variable	Definition	Obs.	Mean	S.D.
ET	Total energy consumption	4200	5.510	1.016
EI	Energy consumption intensity	4200	0.277	0.286
POPDEN	Population density	4200	5.732	0.923
ROAD	Road area per capita	4200	4.648	6.185
GDPP	GDP per capita	4200	4.199	4.447
IND	Industrialization	4200	47.175	11.078
FDI	Foreign direct investment	4200	11.544	2.294
TEMP	Temperature	4200	14.580	5.204

Table 2. Benchmark results of the effect of energy quota trading on energy saving.

Variable	(1) ET	(2) ET	(3) ET	(4) EI	(5) EI	(6) EI	(7) GDP	(8) GDPR
Treat ∗ Time	−0.021 *	−0.021	−0.055 ***	−0.041 *	−0.041 ***	−0.048 ***	0.022 ***	0.841 ***
	(0.012)	(0.016)	(0.016)	(0.023)	(0.008)	(0.008)	(0.004)	(0.177)
POPDEN			0.072 *			0.026 **	−0.006	0.849
			(0.044)			(0.011)	(0.007)	(0.564)
ROAD			−0.004 **			0.000	−0.000	0.044 *
			(0.002)			(0.002)	(0.001)	(0.023)
GDPP			−0.018 ***			−0.008 *		
			(0.004)			(0.004)		
IND			0.013 ***			0.001 **	0.008 ***	0.132 ***
			(0.001)			(0.001)	(0.000)	(0.012)
FDI			0.030 ***			0.011 ***	0.014 ***	0.361 ***
			(0.006)			(0.004)	(0.002)	(0.065)
TEMP			−0.022 *			−0.007	−0.018 ***	0.207
			(0.011)			(0.009)	(0.004)	(0.140)
Constant	5.222 ***	5.511 ***	4.546 ***	0.270 ***	0.280 ***	0.076	6.734 ***	−8.433 **
	(0.020)	(0.004)	(0.308)	(0.006)	(0.003)	(0.101)	(0.068)	(3.929)
City fixed effect	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Year fixed effect	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Obs.	4200	4200	4200	4200	4200	4200	4200	4200
Adj.R^2	0.161	0.939	0.945	0.021	0.407	0.410	0.996	0.623

Notes: *, **, *** indicate statistical significance at the 1%, 5% and 10% levels, respectively. All columns control for city and year fixed effects. Standard errors in parentheses are clustered at the city level. GDP in column (7) represents the total gross domestic product. GDPR in column (8) represents the annual growth rate of GDP.

The next step is to verify whether the energy saving effect of energy quota trading policy comes at the expense of economic development. The regression coefficients of columns (7) and (8) are significantly positive for both GDP per capita and economic growth rate, indicating that the pilot policy of energy quota trading is conducive to promoting economic development and growth. Compared to non-pilot cities, the energy quota trading policy led to an increase in GDP per capita and GDP growth rate of 0.022 and 0.841, respectively, in the pilot cities. Unlike Mundaca's study [29], energy quota trading does not save energy at the expense of the social economy. Therefore, the energy quota trading policy not only saves energy use, but also promotes economic growth, achieving a win–win situation for both energy saving and economic development. In a word, these results above verify that Hypothesis 1 is valid.

4.2. Robustness Checks

4.2.1. Alternative Dependent Variable

Although this paper examines the energy saving effects of trading energy use rights from both aggregate and intensity perspectives, the degree of population agglomeration also affects energy consumption. As the regression coefficients of POPDEN in Table 2 show, the higher the population density, the more energy could be consumed. Therefore, this paper uses energy consumption per capita to replace the explanatory variable. Per capita energy consumption is expressed by the ratio of total energy consumption to the total urban population. The regression results in columns (1) and (2) of Table 3 show that the estimated coefficients of the energy quota trading policy are significantly negative, regardless of the inclusion of control variables, indicating that the pilot policy of energy quota trading reduces per capita energy use and has an energy saving effect.

In addition, the energy quota trading policy tends to affect the use of energy resources, while other resources are unaffected by it, that is, there is no policy effect of the implementation of the policy on the conservation of other resources. For this reason, the explanatory variables in this paper are replaced with total water consumption and water consumption intensity. As shown in the regression results in columns (3) and (4) of Table 3, the estimated coefficients for the energy quota trading policy are both significantly positive, indicating that the pilot policy of energy quota trading does not reduce the use of water resources and does not have a water conservation effect. This result also indicates that the placebo test is satisfied.

Table 3. Robustness test results.

Variable	(1) EP	(2) EP	(3) WATER	(4) WATERI	(5) ET	(6) EI
Treat ∗ Time	−0.323 ***	−0.304 ***	0.088 ***	0.066 ***	−0.123 ***	−0.060 ***
	(0.042)	(0.035)	(0.020)	(0.020)	(0.018)	(0.010)
Control variables	No	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	4200	4200	4200	4200	3030	3030
$Adj.R^2$	0.806	0.845	0.937	0.863	0.947	0.333

Notes: *** indicate statistical significance at the 1%, 5% and 10% levels, respectively. All columns control for city and year fixed effects. Standard errors in parentheses are clustered at the city level. Control variables include POPDEN, ROAD, GDPP, IND, FDI, and TEMP. EP stands for energy consumption per capita. WATER represents the amount of water sales in the city's municipal districts. WATERI represents the water sales per unit of GDP in the city's municipal districts. The control groups in columns (5) and (6) selected cities adjacent to the pilot provinces.

4.2.2. Replacing the Control Group

The cities in the treatment and control groups may differ significantly in other ways than in the energy quota trading policy. To further avoid the impact of these differences, cities in the region adjacent to the pilot area are re-selected as the control group in this paper. As can be seen from the regression results in columns (3) and (4) of Table 3, the estimated coefficients for the energy quota trading policy remain significantly negative and become larger in absolute value. This means that compared to non-pilot cities, the energy quota trading policy contributes to a 12.3% decrease in the logarithm of total energy consumption and a 6% decrease in energy consumption intensity in the pilot cities, and the energy saving effect of the policy is even more pronounced.

4.2.3. PSM-DID Estimation

In order to minimize differences in individual characteristics between the treatment and control group cities and to prevent sample selection bias that might lead to selective bias in the estimation results of this paper, a propensity score matching and difference-in-differences method (PSM-DID) is used for robustness testing. We estimate propensity score values by selecting control variables as covariates and find the most appropriate matched sample for the treatment group within the control group based on the propensity score values. Table 4 displays the estimation results of the PSM-DID. The sign and significance of the core coefficients are largely consistent with the underlying regression results, and the absolute values of the coefficients have even become larger. The estimation results in columns (2) and (4) show that the implementation of the energy quota trading policy in cities can significantly curb the growth of energy consumption, with energy saving effects of 6.4% and 4.9%, respectively. These results again validate the robustness of the benchmark results.

4.2.4. Event Study

Causal inference with a difference-in-differences approach requires the parallel trend assumption to be satisfied, that is, energy consumption does not differ in trends of change between the treatment and control groups prior to the energy quota trading policy intervention. To ensure that the baseline regression results are indeed caused by the energy quota trading pilot and do not stem from temporal trend changes that differ between the two groups of cities, this paper uses event study analysis to test for dynamic effects [55,56]. The model is then constructed as follows:

$$Energy_{it} = \alpha + \sum\nolimits_{j=-5}^{j=4} \beta_j treat_{i,t_0+j} + \theta Control_{it} + \gamma_i + \delta_t + \varepsilon_{it} \quad (2)$$

where $treat_{i,t_0+j}$ denotes the j-th year of the pilot energy quota trading city. If j = 0, it indicates the year of the pilot energy trading city. If $j > 0$, it indicates the year after the implementation of this pilot policy. If $j < 0$, it indicates the year before the implementation of this pilot policy. If the parameter β_j is not significantly different from 0 during $j < 0$, then this paper confirms that the parallel trends hypothesis is satisfied. Figure 1 visually depicts the parallel trends and dynamic effects of the regression coefficients. As can be seen from Figure 1, these regression coefficients are basically insignificant for both total energy consumption and energy consumption intensity before the implementation of the policy, indicating that there is no systematic difference in energy consumption levels between pilot and non-pilot cities before the implementation of the energy quota trading policy, and the parallel trend hypothesis is tested. In terms of dynamic effects, these regression coefficients are all significantly negative after the implementation of the pilot policy, suggesting that the impact of the energy quota trading policy on mitigating energy consumption is persistent. More importantly, the dynamic effect is more significant as the policy has an increasing impact on reducing energy consumption intensity after its implementation.

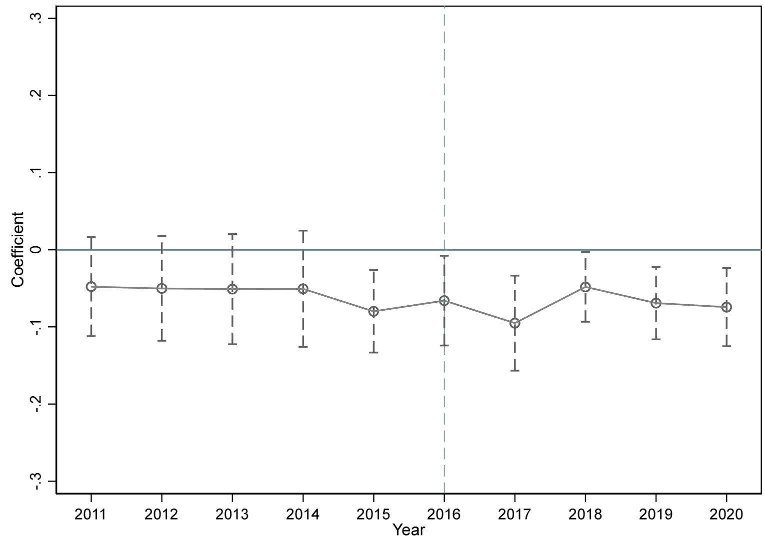
Table 4. PSM-DID estimation results.

Variable	**(1)** **ET**	**(2)** **ET**	**(3)** **EI**	**(4)** **EI**
Treat ∗ Time	−0.032 * (0.017)	−0.064 *** (0.017)	−0.044 *** (0.009)	−0.049 *** (0.008)
Control variables	No	Yes	No	Yes
City fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Obs.	4057	4057	4057	4057
$Adj.R^2$	0.938	0.944	0.389	0.391

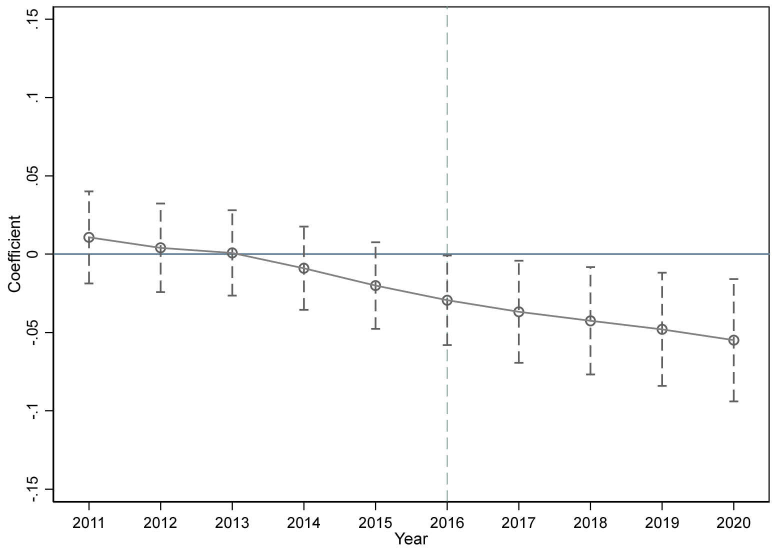
Notes: *, *** indicate statistical significance at the 1%, 5% and 10% levels, respectively. All columns control for city and year fixed effects. Standard errors in parentheses are clustered at the city level. Control variables include POPDEN, ROAD, GDPP, IND, FDI, and TEMP.

4.2.5. Placebo Test

To further rule out the possibility that the energy savings effect of the energy quota trading policy is confounded by other random factors or omitted variables, a placebo test is conducted using a randomly selected treatment group [56]. Concretely, the same number of cities as the real energy quota trading pilot are randomly selected as the treatment group among all cities, and the other cities are used as the control group. The paper then constructs dummy policy variables to be regressed to produce a pseudo "energy quota trading policy" coefficient and repeats the process 500 times at random to produce 500 estimated coefficients accordingly. Figure 2 illustrates the kernel density plot of the estimated coefficients for the placebo test. Regardless of the total energy consumption or the intensity of energy consumption, Figure 2 highlights that the estimated coefficients of the energy quota trading policy are around 0 and normally distributed, which is far from the estimated coefficients of the baseline results. Therefore, it can be further verified that the impact of the energy quota trading policy on energy consumption levels is not due to the interference of other unobservable factors.



(**a**). Total energy consumption.

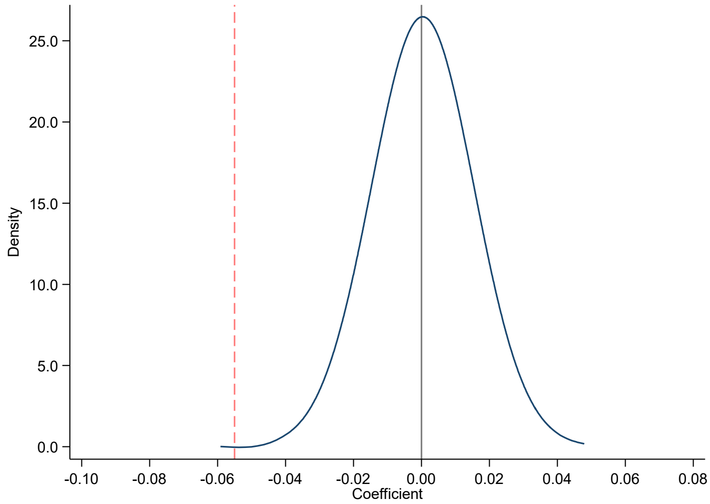


(**b**). Energy consumption intensity.

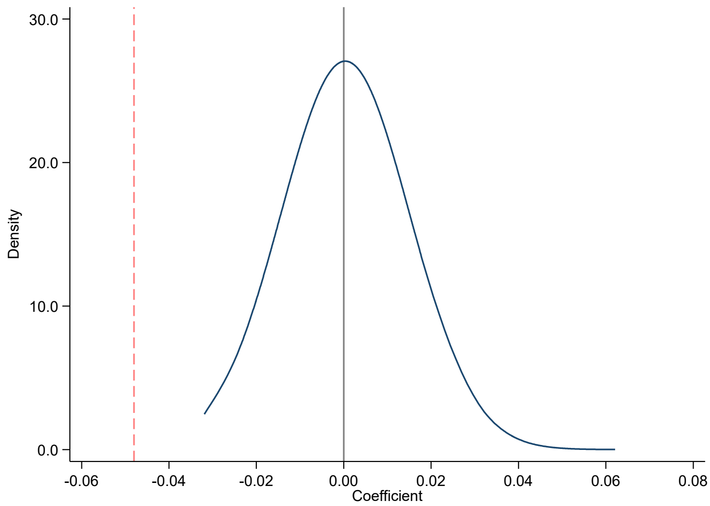
Figure 1. Parallel trends and dynamic effects.

4.3. Heterogeneous Effects

The pilot policy of energy quota trading provides better conditions for energy users to trade energy through the market-based optimal allocation of energy production factors. However, the level of energy savings is not only dependent on energy policy factors, but also on some characteristic environment of the city. There are significant differences between cities in terms of their degree of economic development, size and geographical location. Although this paper controls for city characteristics by controlling for city fixed effects, differences in city characteristics are an important factor affecting urban energy consumption and can have a heterogeneous effect on energy savings. Therefore, this paper explores the heterogeneity of energy saving effects of the energy quota trading policy in terms of degree of economic development, cities size and geographical location. The estimated results of the heterogeneity are presented in Table 5.



(**a**). Total energy consumption.



(**b**). Energy consumption intensity.

Figure 2. Kernel density plot of estimated coefficients.

Table 5. Heterogeneous effects of energy quota trading on energy saving.

Variable	(1) Developing Cities	(2) Developed Cities	(3) Small Cities	(4) Large Cities	(5) Northern Cities	(6) Southern Cities
Treat ∗ Time	0.045	−0.095 ***	−0.055	−0.053 ***	0.077 ***	−0.182 ***
	(0.030)	(0.020)	(0.034)	(0.018)	(0.025)	(0.020)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	2940	1260	1905	2295	2145	2055
$Adj.R^2$	0.911	0.959	0.914	0.952	0.925	0.967

Notes: *** indicate statistical significance at the 1%, 5% and 10% levels, respectively. All columns control for city and year fixed effects. Standard errors in parentheses are clustered at the city level. Control variables include POPDEN, ROAD, GDPP, IND, FDI, and TEMP.

In respect of the economic development degree of a city, this paper classifies it according to the average value of GDP per capita in the year in which the policy is implemented. A city is classified as developed if its GDP per capita is not less than the mean value, otherwise it is classified as developing. The results in columns (1) and (2) of Table 5 show that the coefficient of the effect of the pilot policy on energy consumption in developing cities is positive and insignificant, while the coefficient in developed cities is -0.095 and statistically significant at the 1% significance level. This indicates that the pilot policy is more effective in saving energy in developed cities than in developing cities. This may be due to the fact that cities at different levels of economic development have varying degrees of policy support and technical conditions. Economically developed cities tend to have more advanced energy-using technologies and a more rational industrial structure, which enable efficient use of energy and reduction in energy use, thus promoting energy saving.

Regarding the size of cities, this paper considers those with a resident population of more than one million in the municipal area as large cities, and the rest as small cities. As shown in columns (3) and (4) of Table 5, although both regression coefficients are negative, the coefficient is only statistically significant at the 1% significance level in large cities, that is, the energy quota trading policy can significantly slow down the level of energy consumption in large cities, while the effect on energy consumption in small cities is not significant. This result implies that the implementation of the energy quota trading in large cities is more conducive to energy saving. The reason for this may be the population siphoning effect in large cities, where the population agglomeration due to the increase in population size is conducive to the concentration of energy supply and use, promoting energy efficiency and thus energy saving.

As for the geographical location of cities, this paper classifies the northern areas of the Qinling and Huai Rivers as northern cities, and the areas to the south as southern cities. The energy consumption shows different patterns from south to north in China, and the impact of the energy quota trading policy on energy saving in cities may vary depending on their geographical location. As can be seen from columns (5) and (6) of Table 5, the implementation of the energy quota trading in northern cities significantly contributes to an increase in energy consumption, and increases energy consumption by 7.7% compared to the period before the policy was piloted. In contrast, the implementation of the energy quota trading in southern cities significantly slows down the increase in energy consumption and reduces it by 18.2% compared to the period before the policy was piloted. This is likely due to the fact that northern cities tend to have more energy-intensive heavy industries and higher energy demand for winter heating, which increases energy consumption. Southern cities, on the other hand, can effectively reduce their energy dependence because of the upgrading of industries and the development of light industries.

4.4. Mechanism Analysis

Although the above benchmark regression results have confirmed the significant energy saving effect of the energy quota trading policy, the pathways through which the pilot policy affects energy consumption in cities need to be further explored. In this paper, we examine the impact of energy trading policies on the mitigation of energy consumption through two pathways: industrial structure upgrading (ISU) and green technology innovation (GTI). Practically, this paper uses the indicator of the advanced industrial structure as a proxy variable for industrial structural upgrading. The advanced industrial structure is calculated based on the proportion of the value-added of the three industries using the angle cosine method. The greater the value, the higher the level of industrial restructuring in the city. To express the measurement of green technology innovation, this paper uses the number of green inventions and utility patents matching the green list of the International Patent Classification issued by the World Intellectual Property Organization (WIPO). The more patents of green technology a city has, the higher the level of green technology innovation in that city. Table 6 provides regression results on the influencing mechanisms of the energy quota trading policy on energy saving.

Table 6. Mechanism tests of energy quota trading on energy saving.

Variable	(1) ISU	(2) ET	(3) EI	(4) GTI	(5) ET	(6) EI
Treat ∗ Time	0.054 ***	−0.073 ***	−0.044 ***	0.003 **	−0.054 ***	−0.048 ***
	(0.008)	(0.017)	(0.013)	(0.001)	(0.016)	(0.008)
ISU		−0.343 ***	−0.088 **			
		(0.060)	(0.038)			
GTI					−0.285 ***	−0.093 ***
					(0.035)	(0.025)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	4200	4200	4200	4200	4200	4200
$Adj.R^2$	0.929	0.946	0.410	0.750	0.945	0.411

Notes: **, *** indicate statistical significance at the 1%, 5% and 10% levels, respectively. All columns control for city and year fixed effects. Standard errors in parentheses are clustered at the city level. Control variables include POPDEN, ROAD, GDPP, IND, FDI, and TEMP. Column (1) estimates the effect of energy quota trading policy on industrial structure upgrading (ISU). Column (4) estimates the effect of energy quota trading policy on green technology innovation (GTI).

Columns (1)–(3) of Table 6 report the results of the impact of energy quota trading on the upgrading of industrial structure and the effect of both on energy consumption, respectively. The estimation results of column (1) show that the regression coefficient is significantly 0.054 at the 1% level, implying that the trading of energy quota has led to a 5.4% upgrading of the industrial structure of the pilot cities. Further, the estimation results in columns (2) and (3) show that the regression coefficient of ISU is significantly negative at the 1% level, suggesting that upgrading the industrial structure can lead to a reduction in energy consumption. These results support the Hypothesis 2. Therefore, the energy quota trading policy can optimize the allocation of energy resources through the upgrading of industrial structure, which in turn can reduce the energy consumption. On the other hand, columns (4)–(6) of Table 6 report the results of the impact of the energy quota trading on green technology innovation and the effect of both on energy consumption, respectively. The estimated results in column (4) show that the regression coefficient is statistically significant at the 1% level with a value of 0.003, which means that the energy quota trading can lead to an increase in green technological innovation in the pilot cities. Moreover, the estimated results in columns (5) and (6) show that the regression coefficient of GTI is significantly negative at the 1% level, highlighting that an increase in green technological innovation can effectively curb energy consumption. The results are consistent with Hypothesis 3. Consequently, energy trading policies can improve the technology and efficiency of energy use by increasing the ability to innovate in green technologies, ultimately leading to a slowdown in energy consumption.

5. Conclusions and Policy Implications

Against the backdrop of extreme global climate change and the push to achieve the goal of carbon neutrality, China is experiencing strong pressure to control the total energy consumption and intensity, which urgently requires policies to efficiently allocate energy resource elements, improve energy efficiency and promote energy saving. To do so, this paper takes the pilot policy of energy quota trading as a quasi-natural experiment. Based on panel data from Chinese cities over the period 2006–2020, a difference-in-differences approach is conducted to assess the effects and mechanisms of the pilot policy on energy saving. The paper finds that the energy quota trading policy can significantly reduce energy consumption and has a good energy saving effect. At the same time, the dynamic effect test shows that the saving effect on energy consumption intensity tends to increase year by year. The findings remain robust through a series of robustness checks including substitution of explanatory variables, substitution of controls, PSM-DID, event study and placebo tests.

Heterogeneity analysis indicates that with respect to the level of economic development, the effect of energy quota trading on energy saving in economically developed cities is more significant, while the effect on energy saving in economically developing cities is not significant. With regards to the city size, the effect of energy quota trading on energy savings in large cities is significant, while the effect on energy saving in small cities is not significant. In terms of geographic regions, the effect of energy quota trading on energy saving in southern cities is significant, but there is an increase in energy consumption in northern cities. Furthermore, the mechanism test found that the pilot policy of energy quota trading promotes energy savings in cities mainly through the promotion of industrial structure upgrading and the enhancement of green technology innovation capacity.

Several policy implications are implied by the findings of this paper. First, energy quota trading can achieve the twin goals of long-term energy savings and economic growth, and it is worth promoting nationwide. These inspirations complement the research on the relationship between energy use right and energy consumption, and provide scientific evidence for the promotion of pilot policies. The energy policy achieves the coexistence of energy saving effect and economic effect, rather than achieving the goal of energy saving by damaging social economy [8]. Additionally, other developing countries can also learn from China's experience and achieve energy saving and emission reduction through factor marketisation. However, the current promotion of energy quota trading in China has not met expectations [57], and the energy quota trading market is not active. China needs to appropriately relax pricing power and provide a trading platform for the secondary market for quota trading to facilitate factor mobility. Most importantly, China needs to summarize the experience of the pilot regions and unify the policy mechanisms for energy quota trading, forming clear policy content and specific policy instruments. On this basis, administrative orders should be used to proliferate the scope of policy implementation and build a unified national energy quota trading market to help achieve the national dual carbon goal.

Second, China should prioritize the implementation of the policy in southern cities with relatively large cities and high urban economies when gradually promoting energy quota trading. Because these regions have greater potential for energy efficiency, the policy could achieve larger emission reduction targets in the early stages of implementation. Subsequently, the strong demand for energy quota trading in these regions could lead to the construction of energy quota trading in neighboring regions. This could also help alleviate energy mismatches between regions, improve energy allocation efficiency and achieve optimal energy consumption targets.

Third, the restructuring and upgrading of industrial structure can promote energy saving. Industrial structure has a significant role in energy saving and emission reduction, but its potential has not been realized [58]. We find that the energy saving potential of the industrial structure can be further developed through energy quota trading. Currently, the Chinese economy of cities is mainly driven by industry and cities have high productive energy consumption, but Chinese industrial industries suffer from low energy efficiency [59]. The implementation of energy quota trading in China needs to be complemented by supporting industrial policies to incentivize industrial transformation and upgrading and to push backward industries out of the market. In addition, the Chinese government should work to reduce the inter-industry factor mismatch problem and establish a reasonable regulatory, price and subsidy mechanism to provide a good market environment for inter-industry energy quota trading.

At last, technological advancement is another important avenue for energy efficiency management. Energy trading can control energy consumption by promoting regional green innovation input and output, rather than inhibiting enterprise innovation in the short term [19]. However, China's current technology accumulation is weak [60], and in the short term it can be improved by introducing cutting-edge technologies in order to upgrade technology. In the long term, Chinese government should develop tax incentives and financial subsidies to boost the incentive for enterprises to engage in technological innovation and reduce their innovation costs, so that technological progress becomes a long-term grip on energy efficiency in energy quota trading. Beyond that, China should also introduce more science and technology in the construction of the trading market to provide technical support for scenarios such as cross-zone trading of energy quotas.

This paper has some limitations as well. Firstly, the prevalence of teleworking and new modes of transportation in the wake of the COVID-19 pandemic will lead to changes in the energy structure, which are not explored in this paper due to data availability. Secondly, the energy quota trading is still in an immature stage, and actual energy trading may not be very active. As an energy policy and resource use rights policy, energy quota trading has many similar policies in China. The synergies and overlaps between them are often neglected [29]. As the volume of transactions rise, these transaction data can be used for in-depth research in the future. Finally, market-based trading of energy quotas will allow efficient allocation of energy and transformation of the energy structure, as well as affect carbon emissions, which will require attention in future research on issues such as energy efficiency and carbon reduction.

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Abbreviation

OLS	Ordinary Least Square
DID	Difference-in-differences
PSM	Propensity score matching
DEA	Data envelopment analysis
GHG	Greenhouse Gas
COVID-19	Corona Virus Disease 2019

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