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A market instrument to achieve carbon neutrality: Is China's energy-consumption permit trading scheme effective?

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Abstract: The Chinese government implemented the energy-consumption permit trading scheme (ECPTS) pilot program in 2016, in order to achieve energy saving and carbon reduction. Based on the PSM-DID model, we attempt to test the effects of the ECPTS on energy consumption and energy intensity. With a counterfactual simulation, this paper also evaluates the potential gains and different mechanisms of this policy. The results show that, under the constraints of the established resources and policy efficiency, there is a positive relationship between the energy-consumption permit trading scheme and low-carbon economic transformation; the implementation of the above policy in the pilot provinces brought about an average energy saving of 43 Mtce during the period of 2016 to 2019. However, the potential gains of this policy need to be further improved to meet China's energy control targets. Additionally, a complete mediating effect of the energy structure indicates that the impact of the energy-consumption permit trading scheme on energy consumption and energy intensity depends significantly on energy structure adjustments. Finally, this paper highlights the key policy implications associated with the empirical results.

Key words: energy-consumption permit; trading scheme; energy consumption; energy intensity; PSM-DID model

JEL Code: Q4; L5

Abbreviations

ATT, average treatment effect on the treated; CGE, computable general equilibrium; CNY, China yuan; DEA, data envelopment analysis; DID, difference-in-differences; DDD, triple difference; ECP, energy-consumption permit; ECPTS, energy-consumption permit trading scheme; ETS, emissions trading scheme; NDCs, nationally determined contributions; NDRC, the National Development and Reform Commission; PSM, propensity score matching; tce, tons of standard coal equivalent; Mtce, million tons of standard coal equivalent.

1 Introduction

Over the past decade, the energy transition to lower carbon forms of energy has become a key long-term goal for global sustainable development. Unfortunately, its progress has been being affected by the spread of COVID-19 [1]. As the world's largest energy consuming country, China has recently strengthened its nationally determined contributions (NDCs) to achieve carbon neutrality by 2060 [2]. This ambitious pledge comes with institutional innovation that shifts the country's energy regulation from the traditional command-and-control measures to market-oriented ones [3]. The permit trading system to cap and trade energy consumption rights is a recent initiative [4]. The objective of the energy-consumption permit trading scheme (ECPTS) is to minimize the economic costs of achieving carbon neutrality. It allows for the decisive role of the market in resource allocation, which is in line with the current overall national economic reform agenda [5].

Further studying the potential gains of the ECPTS, especially its impacts on energy conservation and energy efficiency improvement, not only has important practical value for low-carbon development everywhere, but also broadens the research fields of energy-saving policy evaluation. Different from the well-known emissions trading scheme (ETS), the ECPTS pays close attention to the source control, in pursuit of reducing energy consumption and energy intensity. However, to date there have been few relevant empirical studies of it [6-7]. According to the practice of the EU-ETS, carbon emissions trading attempts to curb the greenhouse effect in the terminal emissions-side, while the ECPTS focuses on restraining the energy use behaviors of supply-side manufacturers. Both of these two trading mechanisms are cap-and-trade policies. This indicates that the implementation of China’s ECPTS could draw on the experience of the ETS.

Despite making great progress in the transformation from the administrative regulations to the market-oriented ones in recent years, a recent study noted that the ECPTS has just begun and its actual effect is not yet known [7]. This may cause great uncertainties with respect to its nationwide application. Related research on the ECPTS remains qualitative, such as the allocation mechanism and the coordination with other energy policies. In addition, several studies that investigated the potential gains of economic growth and carbon emissions of the permit trading policies [3, 8-9] were found to be lacking in-depth analysis about the impacts of the ECPTS in energy conservation and energy intensity.

To fill the literature gap, this paper tries to investigate the impacts of the ECPTS on energy consumption and energy intensity following the implementation of the pilot program, and to evaluate the potential gains of this policy. An attempt is made to answer these questions: “Can the ECPTS play a positive role in energy conservation?” “To what extent could its potential gains in energy conservation meet China's carbon neutral target?” and “Does it have different paths to affect energy consumption and energy intensity?” To better summarize the experience of the pilot program, this paper opens with an examination of the effectiveness of the ECPTS through a counterfactual simulation method.

The contributions of this paper are two-fold. Firstly, taking the pilot provinces as the treatment group, this paper takes the lead in quantitative investigation of the ECPTS, enriching the existing empirical research. It also quantifies the potential gains in energy saving of this pilot policy based on the PSM-DID method, which has not been done before. Secondly, we examine the mediating effects of industrial structure and energy structure in order to reveal the transmission mechanisms of the ECPTS. The assessment of China's energy-consumption permit trading scheme (ECPTS) provides valuable references for the Chinese government to further improve and promote the ECPTS, and for the rest of the world to adopt or improve similar market instruments, such as the White Certificate Trading Schemes that are operating in some European countries [10].

The remainder of this paper is organized as follows: Section 2 briefly summarizes China's ECPTS and related literature. Section 3 introduces the models and data sources, followed by the estimated impacts of this policy on China's energy consumption and energy intensity with robustness tests in Section 4. Next, there is a discussion on the mediating effects in Section 5. Finally, Section 6 concludes the paper and provides some policy implications.

2 Background on China's energy-consumption permit trading scheme

2.1 A brief account of energy-consumption permit trading scheme

Following the experience of the ETS, the ECPTS was proposed by NDRC and NEA [11] in 2016 to achieve the dual energy control targets[1]. The National Development and Reform Commission (NDRC) issued the ECPTS pilot program in 2016, and four provinces, namely Zhejiang, Fujian, Henan, and Sichuan, were selected as the pilot regions [12]. Under this framework, local governments in the pilot regions agreed to issue a series of supporting policies and devote considerable effort towards the future national implementation of the ECPTS in 2020. By the end of 2020, nearly 1000 enterprises in the four pilot provinces had participated in the ECPTS with a volume of approximately 5 million tons of standard coal equivalent (Mtce), and the value of which exceeded 110 million CNY.[2]

According to the acquisition, use and bargaining of the energy-consumption permit (ECP), the implementation of the ECPTS can be divided into three stages: calculating the total amount of the ECPs, allocating initial free ECPs, and ECP trading. In general, the total amount of the ECPs is accounted based on the cap of each regional energy consumption control target, which determines the proportion of initial free allocation among participating companies to a certain extent. Given this, the ECPTS (see the Appendix for more details) includes two components: the ECP allocation scheme and the ECP trading mechanism.

[1] The dual energy control targets were proposed to control the total energy consumption within 5 billion tons of standard coal by 2020 and to reduce energy intensity by 15% compared with the 2015 level.

[2] Source: https://www.ndrc.gov.cn/xwdt/dt/sjdt/201812/t20181229_1130637.html; https://www.ndrc.gov.cn/xwdt/ztzl/qgjnxcz/dfjnsj/202006/t20200624_1232014.html

In the allocation method, the ECPTS pilot practice shows that the ECP allocation method is similar to the one used in the White Certificate Trading market [13], and the government-led allocation pattern may generate high, uncertain policy risks. Once deviations emerge in the implementation of the ECPTS, they may lead to distortions of resource allocation within the industry [14].

For the permit trading scheme, different trading patterns and pricing rules are used when the actual energy consumption of participating companies is higher or lower than their allocated ECP. Moreover, the ECP trading has a wider coverage than the ETS, including the petrochemical industry, building materials industry, steel industry and other energy-intensive industries. Currently, the ECP allocation method, the ECP trading system, and the related supporting platforms have been established in the four pilot provinces[3].

Data shows that from 2011 to 2019, energy consumption in all four pilot provinces increased slightly (see Fig. 1). After the application of the ECPTS in 2016, energy consumption in Zhejiang and Fujian maintained increasing trends, but there were significant fluctuations in Henan's and Sichuan's energy consumption. Meanwhile, the energy intensity of all four pilot provinces experienced sharp declines with varying degrees of fluctuation. After implementing the ECPTS, Zhejiang's energy intensity rebounded slightly in 2019 while that in Fujian, where the ECP trading price is determined by the

[3] Zhang, L. Analysis on the Progress and Effect of the Pilot Program of the National Energy-consumption Permit Trading Scheme, http://www.tanjiaoyi.com/article-31277-1.html

market[4], had a stepwise decline in 2018, which implies that the impacts of the ECPTS may be gradually appearing.

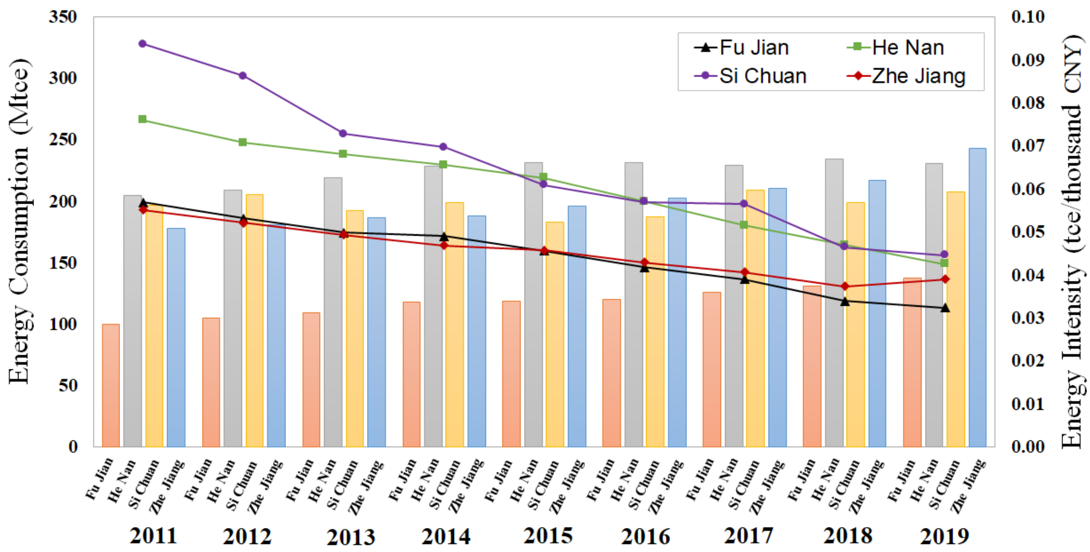


Fig. 1 The four pilot provinces' fluctuations in energy consumption and energy intensity of the four pilot provinces from 2011 to 2019

Note: The bar graph and line graph portray energy consumption and energy intensity, respectively.

2.2 Relevance to the literature

Market-oriented energy-saving regulation has always been a closely followed topic in academic circles, and the certificate trading policy, regarding the right to use a certain resource or output as a paid certificate for trading, is gradually attracting the attention of more energy economists. The Netherlands firstly applied this policy to the renewable energy power market in the late 1990s [15], and then Fouquet and Johansson [16] argued the validity of the initial certificate allocation scheme. Subsequently, this market-oriented energy-saving policy was introduced into the research field of emissions reduction and fruitful

[4] Notice on the pilot implementation plan of the paid use and trading of energy-consumption permit in Fujian, http://www.fujian.gov.cn/zwgk/zfxxgk/szfwj/jgzz/jmgjgz/201801/t20180108_1180669.htm

research results have been achieved [17-18].

In practice, the European countries have taken the lead in implementing tradable certificate mechanisms, such as the white certificate and green certificate trading programs. As one of the energy-saving certificate trading programs, the white certificate trading program was widely applied in the United States, Poland, Italy, France and Australia [10,19]. In China, the pilot white certificate market was put on hold after 2013 when the Chinese government decided to implement a cap-and-trade program [13], which includes the well-known ETS. Li and Jia [20] and Segura et al. [21] investigated the implementation effect of China's carbon emissions trading policy. In addition, several scholars have analyzed the synergetic effect of the ETS and green certificate trading program that is the green attribute to renewable energy generation [22-23].

Compared with the above energy-saving policies, the ECPTS is undoubted an innovative tool in China's energy regulation. However, to date, not as many as expected studies of it have been carried out [24]. Aldrich and Koerner [13] pointed out that energy use rights trading could address the gap of energy efficiency in China's cap-and-trade program. Zhang and Zhang [7] found that compared with the command-and-control policies, the ECPTS has advantages in energy saving and emission reduction. Yang et al. [6] designed an energy-consumption permit allocation scheme and trading scheme for China's 18 manufacturing sectors, without consideration of the effectiveness of the ECPTS.

Regarding the impacts of the ECPTS, although most of these studies are relevant to the ETS, the literature provides a theoretical reference for evaluating the ECPTS. Färe et al. [8-9] first calculated the potential gains accruing to coal-fired electric power plants when a tradable permit system is in place. Meanwhile, Zhou et al. [25] proved the economic dividends of an emission quota trading policy, and this is supported by other relevant scholars [26-27]. Shi et al. [28-29] assessed the economic benefit of a capacity permit trading scheme to facilitate cost-effective retirement of coal production capacity.

Apart from the environmental and economic dividends of energy policy, several scholars have analyzed its potential impact on energy conservation. This contributed to our interest in the topic. Cheng et al. [30] found that the ETS plays a positive role in energy saving. Then Lin and Jia [31-32] and Zhang and Zhang [33] further examined the impacts of China's ETS policy on CO_2 emissions, fossil energy consumption and energy intensity. More importantly, without examining the impacts of the ECTPS on energy intensity, Zhang and Zhang [7] concluded that it has great potential gains in economic growth and energy saving. The studies mentioned here all contribute to our understanding of the theoretical basis for the impact of China's ECPTS on energy consumption and energy intensity.

In addition, the influencing factors of permit trading policies have also been explored. Li et al. [34] and Zhang et al. [35] examined different mechanisms of economic development and industrial structure adjustment on the final effect of

China’s ETS, then Li et al. [36] proposed that the ETS can affect the carbon emissions intensity through industrial structure and energy intensity. This inspired us to analyze the different mechanisms of the ECPTS.

With respect to energy policy evaluation, the mainstream methods include the data envelopment analysis (DEA) model [37-38], computable general equilibrium (CGE) model [39-40] and difference-in-differences (DID) model [41]. Compared with DEA and CGE models, the DID model has advantages in solving the endogeneity problems of utilizing a policy as an explanatory variable. It is therefore becoming a popular way to evaluate a policy’s effect [33]. Li et al. [36] used the DID model to analyze the impacts of China’s ETS with the disturbance of control variables embodying permanent population, GDP, industrial structure, and the technical and income level. Similarly, Zhou et al. [41] and Dong et al. [42] adopted the DID approach to estimate the influence of China’s ETS.

To improve the robustness of the DID model, the propensity score matching-difference-in-differences (PSM-DID) model was introduced into the research field of policy evaluation. Also, for the impacts of China’s ETS, Wang et al. [43] employed the PSM-DID model to improve the reliability of empirical results while Zhang et al. [35] used both the PSM-DID and triple difference (DDD) method to prove that China’s ETS can simultaneously achieve “the Porter effect”.

In summary, there has been a growing interest in the development of energy-saving certificate trading policies throughout the world, but the related literature focuses mostly on the carbon emissions trading scheme. The limited discussions on the white certificate scheme do not include China's ECPTS issues. Moreover, the existing studies pay more attention to economic and environmental dividends instead of the different transmission mechanisms of the tradable permit instruments. To address this gap, we developed a PSM-DID model to analyze the impacts of the ECPTS on energy consumption and energy intensity and its different transmission mechanisms, in attempt to evaluate the effectiveness of China's ECPTS pilot program.

3 Methodology and data

3.1 Difference-in-differences model (DID)

The DID model is a natural experiment-based causality evaluation method [44]. It usually includes a treatment group and a control group under a specific policy intervention, and the policy's effect is embodied by the average treatment effect on the treated (ATT). That is, the DID model can effectively solve the problems of endogeneity and comparability caused by the policy [33, 41].

China's ECPTS can be regarded as a quasi-natural experiment. Adopting the DID model to assess whether the ECPTS plays a positive role in energy conservation in China, we chose 30 representative provinces and divided the sample into two groups: the treatment group (the 4 pilot provinces are Zhejiang, Sichuan, Fujian, and Henan) and the control group (the 26 non-pilot provinces excluding Tibet, Hong Kong, Macao, and Taiwan). Under the common trend hypothesis, the indicators in these two groups have the same time effect before the application of the ECPTS. Therefore, after implementing the ECP trading pilot program, the difference in the changes between these two groups represents the effect of this policy. The model is as follows:

$$Y_{it} = \alpha_0 + \alpha_1 Treated_{it} + \alpha_2 Time_{it} + \alpha_3 Treated_{it} * Time_{it} + \omega \chi_{it} + \varepsilon_{it} \quad (1)$$

where i and t represent the i^{th} province and t^{th} year, respectively; Y_{it} denotes energy consumption (or energy intensity); $Treated_{it}$ is the regional dummy variable, $Treated_{it} = 1$ and $Treated_{it} = 0$ represent the treatment group and the control group, respectively. $Time_{it}$ is the time dummy variable, in this case of the available data, $Time_{it} = 1$ denotes the period after the implementation of the ECPTS, that is, 2016–2019; $Time_{it} = 0$ denotes the period before the implementation of the ECPTS, that is, 2006–2015. χ_{it} represents the set of control variables and ε_{it} is a random error. α_0, α_1, α_2, α_3 and ω are the estimated parameters, in which α_3 is the core index to measure the impact of the ECPTS, reflecting the difference in energy consumption (or energy intensity) between the treatment group and the control group before and after this policy's application (see Eq.1).

3.2 Propensity score matching method (PSM)

In order to improve the reliability of the DID model, we adopted the PSM method first proposed by Rosenbaum and Rubin [45]. Theoretically, the PSM method is applicable to non-random data and its theoretical framework is the "counter-fact inference model." As mentioned in Section 2.1, the choice of the four pilot provinces of the ECPTS was not random but related to the essential conditions of economic development, urbanization construction, and industrial output scale, indicating that the samples in this study are non-random data. In addition, the PSM-DID method is capable of solving the bias and heterogeneity of the chosen sample by matching the probability of the treatment group and the control group [46-47].

Specifically, we first selected the related observed control variables (χ_i) that affect energy consumption and energy intensity to meet the negligibility hypothesis. A logit (or probit) model was then employed to identify the probability ($P_i(\chi)$) to be a pilot province of the ECPTS, that is, the propensity score. Finally, we matched the samples between the treatment group and the control group based on their propensity scores. The model is as follows:

$$P_i(\chi) = Pr(Treated_{it} = 1 \mid \chi_i) = F[f(\chi_i)] \quad (2)$$

In the following empirical analysis, a logit model was used to calculate the propensity score and the kernel matching method was adopted to obtain the matched samples of the DID model to estimate the impacts of the ECPTS on energy consumption and energy intensity.

3.3 Setting of variables

(1) Dependent variables

As the objective of the paid use and trading of energy-consumption permit is to achieve energy conservation and carbon reduction, we selected energy consumption (Mtce) and energy intensity (tce/thousand CNY) as the dependent variables to measure the progress of the market-oriented energy reform.

(2) Explanatory variables

According to Eq.1, the explanatory variables include the regional dummy variable, the time dummy variable, and the DID estimator. The regional dummy variable was used to distinguish whether the province is a pilot province to implement the ECPTS during the period of 2006 to 2019, while the time dummy variable represents the time before and after the pilot implementation of the ECPTS. The DID estimator refers to the product of $Treated_{it}$ and $Time_{it}$, which is the core index to analyze the effects of the ECPTS on energy conservation.

(3) Control variables

The existing literature has demonstrated that energy consumption and energy intensity could be affected by economic development, industrial structure, fixed asset investment, R&D investment, the expenditure of environmental protection, and other factors [35-36, 43]. Given this, we chose the following control variables: *(a)* Since economic growth has always been the main driving force for stimulating energy consumption, we used per capita GDP (thousand CNY) to describe the level of economic development, considering the difference in population size. *(b)* In general, investment in fixed assets is the main way for energy-consuming enterprises to expand capital scale. We adopted investment in fixed assets (billion CNY) as a share of GDP to measure the level of capital inputs. *(c)* Technical progress has always been the key constraint in energy transition and energy conservation [43, 48], so the proportion of R&D investment (billion CNY) to GDP was applied to represent technical progress. *(d)* To improve energy efficiency, various environmental measures were used to reduce energy consumption. Given this, we also used per capita energy conservation expenditures as a control variable.

As mentioned above, this paper is dedicated to evaluating whether the ECPTS has a positive influence on carbon neutrality, and one of our concerns is whether there are different pathways of the ECPTS to affect China's energy control targets, that is, the mediating effect. Based on the exiting literature about the ETS, we propose that after the implementation of the ECPTS, the paid energy-consumption permit could force energy-intensive firms to transform or even exit the market. The adjustment of local industrial structure then initiates a flow of capital and labor into other low energy-consuming industries, which will affect energy consumption and energy intensity.

The ECP trading mechanism also encourages the participating companies to take steps to replace the use of traditional fossil energy with renewable energy in order to achieve the surplus of energy-consumption permits, which can bring excess earnings. Moreover, with the paid use of the ECP, whether it is technical upgrading or energy substitution, the motivation of the participating companies continues to be increasing total factor productivity, that is, to reduce energy inputs through the improvement of production efficiency. This will undoubtedly promote a low-carbon transition of local energy structure and finally trigger changes in energy conservation. Based on the above analysis, this paper proposes the following hypotheses:

Hypothesis 1 (H1): The ECPTS accelerates the adjustment of the regional industrial structure, which in turn leads to reduction in energy consumption and energy intensity.

Hypothesis 2 (H2): The ECPTS stimulates the low-carbon transition, which in turn leads to reduction in energy consumption and energy intensity.

3.4 Data sources

Panel data for 30 provinces, spanning 2006 to 2019, were employed to evaluate the impacts of the ECPTS, and a total of 420 samples were obtained. The reason for selecting this time period as the sample scope was that the Chinese government first designated energy conservation as the primary task of energy development in the 11th Five-Year Plan period (2006–2010). Hence, we selected 2006 as the beginning of the sample scope.

The data used to conduct this research were drawn from a variety of sources as explained briefly below: Since the latest available edition of the *China Statistical Yearbook* published by the National Bureau of Statistics of China was the 2019 edition, the data for 2019 were retrieved from the *National Economic and Social Development Statistical Bulletin* of each province; the data of GDP, the permanent population, fixed assets investment, and energy consumption were taken from *China Statistical Yearbook*, while the data on R&D investment and energy conservation expenditures were obtained from *China Science and*

Technology Statistical Yearbook and *China Financial Yearbook*[5], respectively. In order to solve the problems of heteroscedasticity and variable stability, we took logarithmic processing on energy consumption, energy intensity, per capita GDP, the proportion of R&D investment to GDP and per capita energy conservation expenditures, which are represented by $lnen$, $lngen$, $lngp$, $lngrd$ and $lnpes$, respectively. As for the mediator, the added value of the secondary industry as a share of GDP ($indu$) and coal consumption as a share of total energy consumption (ens) refer to industrial structure and energy structure, respectively. The data of these two variables were also obtained from the *China Statistical Yearbook*. The descriptive statistics of all the variables are shown in Table 1.

Table 1 Descriptive statistics of the variables

Variable	Observation	Mean	Standard deviation	Minimum	Maximum
lnen	420	9.2974	0.6978	6.8249	10.5949
lngen	420	-0.2039	0.5425	-1.6220	1.3366
lngp	420	1.3160	0.6037	-0.4559	2.7988
ginvest	420	0.7181	0.2466	0.2100	1.5164
lngrd	420	0.2038	0.6253	-1.6094	1.8453
lnpes	391	0.9025	0.7724	-1.3624	5.9384
indu	420	0.4524	0.0845	0.1620	0.5930
ens	367	0.6499	0.2288	0.0491	1.5293

4 Empirical results and analysis

[5] According to Zhang [49], the government has long been implementing energy conservation policies, but there was no separate expenditure item for them until 2007. The energy conservation expenditures set by the Ministry of Finance include pollution reduction, natural ecological protection, comprehensive utilization of resources and other expenditure activities. Given this, we set its data in 2006 to zero in order to achieve data consistency.

4.1 Results of the DID method regression

Similar to the ETS, the ECPTS provides a good "quasi-natural" experiment for studying the dividends of this policy on energy consumption and energy intensity through a pilot program. The DID model was used to analyze the effects of the ECPTS and the estimated results are shown in Table 2.

With the region fixed effect and the time fixed effect, there are significant differences in the impacts of the ECPTS on energy consumption and energy intensity. Specifically, at the significance level of 10%, the coefficients of the DID estimator (*Treated*Time*), shown in column 2–5 in Table 2, indicate that without consideration of the sample selection bias, the ECP trading policy had a significant negative effect on energy intensity but its impact on energy consumption was insignificant.

The reason is that after the implementation of the ECPTS, the participating companies preferred to reduce costs by improving energy efficiency rather than by either reducing their total energy consumption or investing in self-generating renewables in the short term, which generates a reduction in energy intensity. For example, when energy consumption exceeds its initial free permits, a thermal power plant is likely to buy the ECP instead of investing in the construction of hydropower plants to reduce energy consumption in the short term due to the limits of capital and time.

When control variables are taken into account, the results in the third column of Table 2 show that the coefficients of economic development, environmental governance and capital inputs are 0.266, -0.251, and 0.029, respectively, indicating that investment expansion and economic growth can bring an increase in energy consumption while the growing energy conservation expenditures can reduce the dependence of economic development on energy use, thus fulfilling the theoretical expectations of this study.

Table 2 Impacts of the implementation of the ECPTS by the DID method

Dependent variable	**lnen**		**lngen**	
Independent variable	without control variables	with control variables	without control variables	with control variables
Treated*Time	-0.0204 (0.1116)	-0.0189 (0.1156)	-0.1127* (0.0554)	-0.1314** (0.0524)
lngp		0.2660*** (0.0833)		-0.5360*** (0.0490)
lngrd		0.2529 (0.1709)		-0.1248 (0.0825)
lnpes		-0.2513*** (0.0727)		-0.0471* (0.0285)
ginvest		0.0293** (0.1044)		0.0838 (0.0950)
Constant	9.1669*** (0.0458)	8.9864*** (0.1387)	-0.0816*** (0.0083)	0.5690*** (0.0945)
Region fixed effect	Control	Control	Control	Control
Time fixed effect	Control	Control	Control	Control
N	420	391	420	391
R^2	0.0737	0.2212	0.1352	0.5516

Note: The values in parentheses are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively.

The fifth column in Table 2 shows that, among all the control variables, only economic development and environmental governance had a significant negative impact on energy intensity. This is because, along with economic growth, residents' demand for environmental public goods increased remarkably. Under the guidance of the local government's environmental governance, residents preferred to use energy-saving products. Hence, energy consumption per unit of GDP dropped significantly.

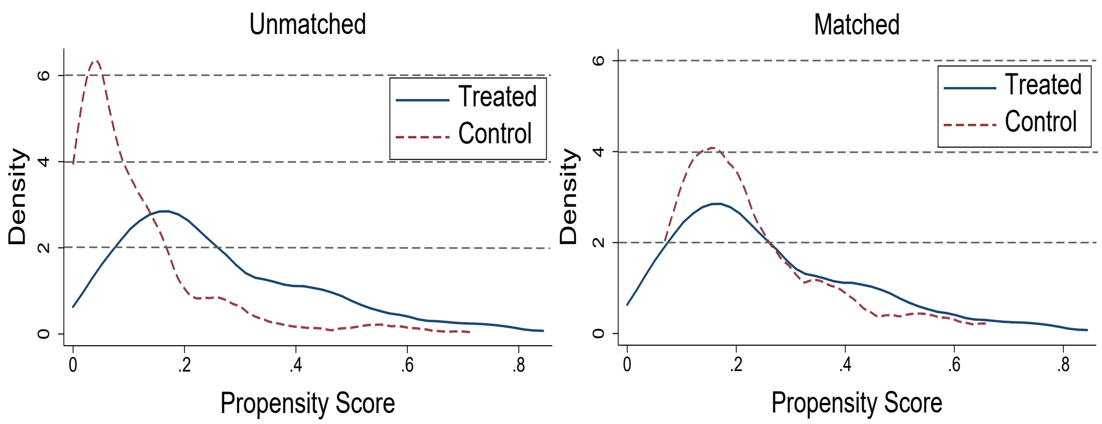
Furthermore, what surprised us was that technological progress had no significant influence on both energy consumption and energy intensity. We inferred that its effect could be underestimated and the reason was that there are obvious differences in the technique level among the pilot provinces and non-pilot provinces, and that this may lead to the failure of the common trend hypothesis. This issue can be resolved in the following analysis by the PSM-DID method.

4.2 Results of PSM-DID method regression

(1) Analysis of PSM test

To satisfy the common trend hypothesis, we selected the regional dummy variable as the dependent variable and all the above-mentioned control variables as the independent variables in the PSM analysis. The logit model and the kernel method were adopted to match samples, and the results of kernel density test and balance test are shown in Fig. 2 and Table 3.

As shown in Fig.2, a large distribution difference of propensity scores exists in the treatment group and the control group before matching samples, especially the scores in [0, 0.2]. However, after matching samples, the trends of these two groups' scores were almost consistent, which proves that the matched samples meet the common trend hypothesis.



(a) (b)

Fig.2 Kernel density distribution of propensity matching score

Moreover, the balance test results (see Table 3) show that the standardized bias of all the control variables decreased significantly after matching samples and their absolute values were all less than 10%, indicating that all that matched samples satisfied the balance hypothesis and there was no obvious difference of the control variables between the treatment group and the control group.

Table 3 The balance check of control variables

Variables	Unmatched Matched	Mean Treated	Mean Control	%bias	%reduct |bias|	t-test t	t-test p>|t|
lngp	U	1.0781	1.4265	-69.6	92.1	-4.26	0.000***
	M	1.133	1.1604	-5.5		-0.28	0.778
lngrd	U	.38269	.20719	34.3	98.0	1.91	0.057*
	M	.36367	.3672	-0.7		-0.04	0.969
lnpes	U	.47123	.96865	-71.9	93.0	-4.43	0.000***
	M	.50182	.4669	5.0		0.25	0.803
ginvest	U	.68491	.74208	-26.8	87.9	-1.56	0.120
	M	.70368	.71057	-3.2		-0.16	0.871

Note: *, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively.

(2) Effects of the energy-consumption permit trading policy

With the matched samples, the results of the DID estimation are shown in the second and fifth columns of Table 4. As in the DID method regression, the

ECPTS also had a significantly negative effect on energy intensity with a coefficient of -0.125, implying that the logarithm of energy intensity in the pilot area decreased by about 13% in the sample period after the implementation of the ECPTS (see the fifth column of Table 4).

Unlike the DID estimation, as shown in the second column of Table 4, the ECPTS now has a negative impact on energy consumption with a coefficient of -0.258. That indicates that after the implementation of the ECPTS, the logarithm of energy consumption decreased by approximately 0.26 times, which is equivalent to energy saving of about 43 Mtce during the sample period. The above results verify that China's ECPTS plays a positive role in energy conservation.

Table 4 Impacts of the implementation of the ECPTS by the PSM-DID method

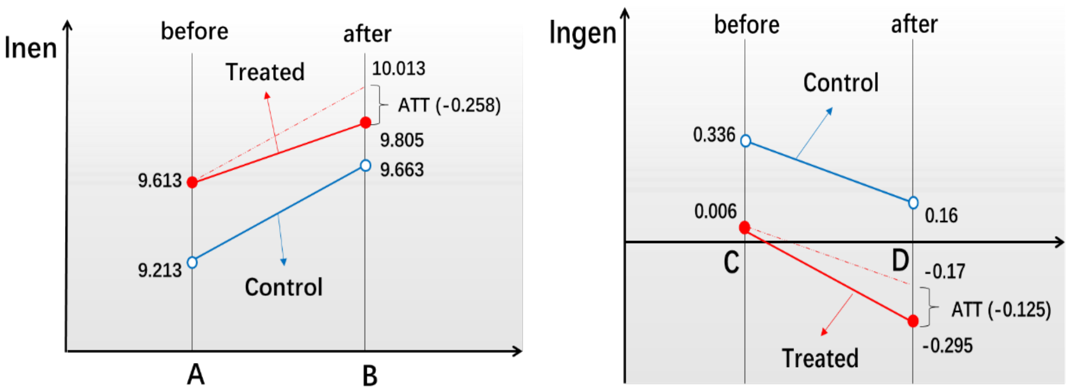
Dependent variable	**lnen**			**lngen**		
Independent variable	Kernel	1:1 Neighbor	Placebo test	Kernel	1:1 Neighbor	Placebo test
Treated*Time	-0.2582*	-0.2532*	-0.0177	-0.125***	-0.121***	-0.0652
	(0.1401)	(0.1485)	(0.0455)	(0.0437)	(0.0425)	(0.0603)
lngp	0.4174***	0.3927***	0.3717***	-0.583***	-0.593***	-0.576***
	(0.1131)	(0.1373)	(0.0434)	(0.0609)	(0.0739)	(0.0572)
lngrd	0.0026	-0.0214	-0.063	-0.1728**	-0.1516*	-0.1702**
	(0.1273)	(0.1586)	(0.0645)	(0.0753)	(0.0877)	(0.0757)
lnpes	-0.1655*	-0.1354*	0.024	-0.0088	-0.0156	-0.0174
	(0.0931)	(0.0931)	(0.0273)	(0.0294)	(0.0313)	(0.0287)
ginvest	-0.4815**	-0.4676*	0.1087*	0.0557	0.0676	0.1272
	(0.2363)	(0.2522)	(0.0564)	(0.0988)	(0.1033)	(0.1054)
Constant	9.2134***	9.2073***	8.7085***	0.6283***	0.6329***	0.5807***
	(0.1551)	(0.1682)	(0.1527)	(0.0945)	(0.0855)	(0.0704)
N	227	204	227	227	204	227
R^2	0.2343	0.2169	0.1318	0.6096	0.6190	0.6173

Note: The values in parentheses are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively.

Additionally, the higher the per capita GDP, the less conducive it is to control energy consumption, but it helps to reduce energy intensity. R&D investment also has a negative impact on energy intensity at the 5% significance level, providing evidence for the positive effect of technological progress on energy efficiency improvement. Moreover, the increase in the proportion of investment led to a significant decrease in energy consumption, which is contrary to the results with unmatched samples. The reason is that the pilot provinces for the ECPTS selected by the Chinese government are all relatively developed with well-developed infrastructure, and where ecological protection and environmental governance are key fields of fixed asset investment.

These findings also illustrated in Fig.3, unambiguously prove the contributions of the pilot ECPTS to energy consumption and energy intensity, and provide supporting evidence for the implementation of a national ECPTS. However, it is necessary to realize that the potential gains of the ECPTS in energy conservation still need to be improved. In the 13th Five-Year Plan, the government set dual energy control targets of total consumption and energy intensity for each province and the average additional energy consumption in the four ECPTS pilot provinces was 28.15 Mtce between 2015 and 2020 [50]. However, even with the effect of the ECPTS, the average incremental energy consumption was 31.7 Mtce, increasing $lnen$ from 9.613 in 2015 to 9.805 in 2019 (see Fig. 3(a)). Even there is no increase in energy consumption in 2020, the four provinces will still fail to meet the target.

Further, statistics show that China' energy intensity in 2018 was about 0.051 tce/thousand CNY while the world average level was 0.035 tce/thousand CNY[6], implying that there was still a large way for China's energy intensity to go. Given this, it is recommended that the Chinese government should continue to explore the potential gains of the ECPTS in terms of the allocation rules, pricing mechanism of permits, and supervision system of the energy-consumption permit trading market. Moreover, the national ECPTS should be promoted to achieve China's carbon neutrality during the 14th Five-Year Plan.



(a) (b)

Fig.3 The impacts of the ECPTS on energy consumption and energy intensity based on the PSM-DID estimation

Note：(a) and (b) show the changes of energy consumption and energy intensity before and after the implementation of the ECPTS, respectively. Vertical lines A and C denote the average level of $lnen$ and $lngen$ before implementing the ECPTS; vertical lines B and D denote the average level of $lnen$ and $lngen$ after implementing the ECPTS. The blue and red solid lines refer to the difference of the control group and the treated group before and after the implementation of the ECPTS, respectively. The red dotted line represents the difference of the treated group without implementing the ECPTS. ATT refers to the average treatment effect on the treated (the treatment group) in the pilot provinces of the ECPTS.

4.3 Robustness tests

[6] This fact shows that the world average level was 0.162 toe/thousand USD. According to the universal conversion factor (1 toe = 1.4286 tce) and the annual average USD/CNY exchange rate (6.6174 issued by National Bureau of Statistics), 0.162 toe/thousand USD is equivalent to 0.035 tce/thousand CNY.

To ensure the reliability of the aforementioned results, we conducted robustness tests that considered two aspects: changing the PSM matching method and changing the policy implementation time, that is, the placebo test. When changing the matching method, we replaced the kernel method with the 1:1 neighbor method to match the samples again. The results (see the third and sixth columns in Table 4) confirmed that the ECPTS still had a significant negative impact on energy consumption and energy intensity at the 10% significance level, and the coefficients of the independent variables were consistent with the results in Section 4.2.

We also ran a placebo test to further examine the reliability of the previous conclusions, aiming to eliminate the interference of other policies or random factors during the sample period. Specifically, we reset the time point of policy implementation to 2014 and designed a false treatment group. We then also adopted the kernel matching method to conduct the PSM-DID estimation. The results of the placebo test, shown in the fourth and seventh columns of Table 4, indicate that after changing the implementation time, the coefficients of the DID estimator did not pass the significance test, thus proving that the energy saved in the pilot area was not caused by other factors in the same period. This indirectly substantiates the robustness of the above-mentioned results.

5 Discussion of the mediating effects

To verify the presence of the mediating effect, we proposed that the energy-consumption permit trading policy would indirectly impact energy consumption and energy intensity through industrial structure and energy structure. Thus, in accordance with Ji [51], the model was set as follows:

$$X_{it} = \beta_0 + \beta_1 Time_{it} * Treated_{it} + \varphi\chi_{it} + \varepsilon'_{it} \quad (3)$$

$$Y_{it} = \alpha_0 + \alpha_1 Treated_{it} + \alpha_2 Time_{it} + \alpha_3 Time_{it} * Treated_{it} + \alpha_4 X_{it} + \omega\chi_{it} + \varepsilon_{it} \quad (4)$$

where X_{it} denotes the mediators including $indu$ and ens; α_4, β_0, β_1 and φ are the estimated parameters while ε'_{it} is the random error. We first tested the relations of the ECPTS and the mediators via Eq. 3, and then introduced the mediators into Eq.4 to conduct the PSM-DID estimation. The results are shown in Table 5.

5.1 Effects of industrial structure

As presented in the second column of Table 5, the coefficient of the DID estimator was -0.021 at the 10% significance level, proving that the ECPTS could generate a decline in the proportion of the secondary industry in GDP to optimize the local industrial structure. The results shown in the fourth column of Table 5 reveal that the industrial structure can stimulate an increase in energy intensity, but its coefficient has not passed the significance test, implying that there is no mediating effect of the industrial structure on the relation between the ECPTS and energy intensity.

Moreover, industrial structure had a partial mediation effect on energy consumption: the coefficients of the DID estimator and industrial structure were -0.26 and 3.16 at the 10% significance level, as shown in the third column of

Table 5. Given this, the *H1* has been partially verified.

Table 5 Examination of the mediating effects

Mediating effect	**Industrial Structure**			**Energy Structure**		
Dependent variable	indu	lnen	lngen	ens	lnen	lngen
Treated*Time	-0.021* (0.0119)	-0.2602* (0.1485)	-0.1* (0.0583)	-0.338*** (0.1081)	-0.1311 (0.1619)	-0.0366 (0.0351)
lngp	-0.0161 (0.0124)	0.4452*** (0.1147)	-0.578*** (0.0621)	0.0576 (0.0526)	0.4083*** (0.1105)	-0.5549*** (0.0333)
lngrd	-0.0202 (0.0188)	0.0695 (0.1586)	-0.1611** (0.078)	-0.273*** (0.0665)	0.1758 (0.117)	-0.1355* (0.0698)
lnpes	-0.029*** (0.0087)	-0.0935 (0.0907)	-0.0067 (0.0291)	-0.1126** (0.0474)	-0.0776 (0.0909)	0.0025 (0.0224)
ginvest	0.074** (0.0176)	-0.764*** (0.2283)	0.0833 (0.1022)	0.5692*** (0.123)	-0.887*** (0.2364)	0.0083 (0.0786)
indu		3.1597*** (0.5893)	0.1514 (0.3234)			
ens					0.7946*** (0.1155)	0.32*** (0.1008)
Constant	0.4699*** (0.0176)	7.7871*** (0.277)	0.5322*** (0.1765)	3.8563*** (0.0836)	6.0642*** (0.5047)	-0.7203* (0.4392)
N	227	227	227	210	210	210
R^2	0.2024	0.3214	0.6148	0.4136	0.3283	0.6448

Note: The values in parentheses are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% levels, respectively.

Interestingly, comparing the results in the second column of Table 4, the inhibitory effect of the ECPTS on energy consumption slightly strengthened with the mediation of the industrial structure. This indicates that, after the implementation of the ECPTS, energy-consuming companies triggered the transformation to high-tech industries, which indirectly released this policy's dividends. For local governments, the ECPTS could bring a loss risk of development rights to a certain extent. Therefore, local protection for energy-intensive firms is likely to appear in the process of implementing this policy. The above finding provides key incentives for local governments to enlarge the scope of the participating companies so as to achieve the win-win development of energy conservation and industrial upgrade. When building an energy-consumption permit trading market, it is suggested that the local government fills the gap between economic development planning, industrial layout and the ECPTS.

5.2 Effects of energy structure

The fifth column in Table 5 shows that the coefficient of the ECPTS is -0.338 at the 1% significance level, indicating that this ECP trading policy could greatly reduce the proportion of coal consumption (ens) in energy use to promote the low-carbon energy structure transition. In addition, ens also has a significant positive impact on energy consumption and energy intensity. Unlike ens, the effect of the DID estimator has changed obviously. As seen in the second and fifth columns of Table 4, the coefficients of the ECPTS pass the significance test. However, the coefficients in the sixth and seventh columns of Table 5 are not significant.

These findings confirm *H2* with the complete mediating effect of energy structure, that is, the direct effect of the ECPTS on energy consumption and energy intensity is not significant, but its indirect effect is significant. This implies that the actual impacts of this policy can be overshadowed by the increase in the proportion of coal consumption. Given this, we conclude that the contributions of the ECPTS on energy conservation depend significantly on energy structure adjustment. In the ECP trading market, the participating companies may try to obtain more excess earnings through ECP trading by consuming self-marketing renewable energy. Meanwhile, considering the motivation to reduce long-term production costs, the ECPTS would also force energy-intensive companies to carry out energy consumption structure adjustments through technological innovation. The above finding provides useful information for local governments in their quest to improve the effectiveness of the ECPTS. Several targeted incentive mechanisms (such as discounts on ECP trading price, and tax subsides) should be designed to stimulate the transformation of traditional industrial firms.

6 Conclusions and policy implications

One of the innovative policy tools being developed amidst China's ongoing market-oriented energy reforms is the pilot program of energy-consumption permit trading scheme. Under the ambitious pledge of carbon neutrality and “a beautiful China”, whether this energy-saving certificate trading policy can meet China's energy control needs during the 14th Five-Year Plan is a notable concern. The implementation of energy-consumption permit trading scheme provides a quasi-natural experiment to test whether the policy can reduce energy consumption and energy intensity. By examining the effectiveness of this trading policy, this paper offers interesting insights and implications for policymakers in China and other countries that are promoting energy efficiency through incentive mechanisms.

We chose panel data for 30 provinces in China from 2006 to 2019 and then applied the propensity score matching method and difference-in-difference model to empirically test whether energy-consumption permit trading scheme could play a positive role in achieving carbon neutral targets. With a counterfactual simulation, we also tested the different mechanisms of this policy that affect energy consumption and energy intensity. The empirical results are as follows.

(1) There was a positive relationship between China's energy-consumption permit trading scheme and low-carbon economic transformation under the constraints of the established resources and policy efficiency, which can achieve the potential gains in energy conservation significantly.

(2) At the 10% significance level, energy-consumption permit trading scheme had significant negative impacts on energy consumption and energy intensity. Following the implementation of the above policy, the logarithmic level of energy consumption in the pilot provinces decreased by about 0.26 times, which is equivalent to average energy savings of approximately 43 Mtce during the sample period. More importantly, the average energy consumption increased by about 31.7 Mtce, larger than the control target (28.15 Mtce), indicating that the potential gains in energy conservation of China's energy-consumption permit trading scheme need to be further improved to reduce the obstacles for nationwide application.

(3) Through the indirect path of industrial structure, the restraining effect of energy-consumption permit trading scheme on energy consumption could be slightly strengthened, but there is no such mediating effect between this policy and energy intensity.

(4) The complete mediating effect of energy structure was identified to indicate that the impact of this policy on energy consumption and energy intensity depends significantly on energy structure adjustment.

The results suggest several policy implications: first, drawing lessons from the experience of the ETS, the Chinese government should continue to expand the scope of the participating companies to release the policy dividend of energy-consumption permit trading scheme in the short term. Second, to expand the ECPTS policy beyond the pilot areas, we suggest that the local government builds an equitable allocation mechanism and an efficiency-oriented trading market to vigorously promote cooperation with participating companies. Third, the Chinese government has proposed a target to establish a national energy-consumption permit and carbon emissions trading market, but so far it lacks a detailed plan. Therefore, the combined application of the ECPTS and other related policies (such as the ETS and green certificate trading) should be explored actively to exert positive impacts on energy saving under a unified trading system. Lastly, in the long run, the government could consider building a market-based pricing mechanism and a replicable pilot model for energy-consumption permit trading to achieve China’s carbon neutrality.

Due to the volume limitations of the sample data, the evaluation of energy-consumption permit trading scheme in this paper is still limited to the dividend effect of energy conservation. Two possible directions for future research are: (1) introduce more control variables into the PSM-DID model to improve the propensity matching degree between the pilot provinces and other control provinces, aiming at strengthening the robustness of conclusions, and (2) note that as the trading areas of the ECPTS and other energy-saving certificate trading policies will inevitably overlap, a synergetic effect of these policies could be evaluated to identify the former's effectiveness in other pilot regions.

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References

[1] Klemeš J, Fan Y, Jiang P. COVID-19 pandemic facilitating energy transition opportunities. International journal of energy research, 30 September 2020.

[2] Xinhua. Xi announces China aims to achieve carbon neutrality before 2060. China Daily, 23 September 2020. http://www.chinadaily.com.cn/a/202009/23/WS5f6a5791 a31024 ad0ba7b1d f.html

[3] Liu H, Wang Y. The economic bonus effect generated by the tradable policy mixes of energy-consuming right and CO_2-emission right. China population, resources and environment 2019;29(5):1-10. (In Chinese)

[4] Yang Y. Xi calls for building a 'beautiful China' at 19th CPC National Congress. 18 October 2017. http://www.xinhuanet.com/english/2017-10/18/c_136689148.htm

[5] 18th Central Committee of the Communist Party of China. Decision of the Central Committee of the Communist Party of China on some major issues concerning comprehensively deepening the reform. 2013, China.org.cn.

[6] Yang M, Hou Y, Fang C, Duan H. Constructing energy-consuming right trading system for China's manufacturing industry in 2025. Energy Policy 2020;144:111602.

[7] Zhang N, Zhang W. Can energy quota trading achieve win-win development for economic growth and energy savings in China? Economic Research Journal 2019;54(01):165-81. (In Chinese)

[8] Färe R, Grosskopf S, Pasurka C. Tradable permits and unrealized gains from trade. Energy Economics 2013;40:416-24.

[9] Färe R, Grosskopf S, Pasurka C. Potential gains from trading bad outputs: The case

of U.S. electric power plants. Resource and Energy Economics 2014;36:99-112.

[10] Franzò S, Frattini F, Cagno E, Trianni A. A multi-stakeholder analysis of the economic efficiency of industrial energy efficiency policies: Empirical evidence from ten years of the Italian White Certificate Scheme. Applied Energy 2019;240:424-435.

[11] NDRC, NEA. Notice of NDRC and NEA on issuing the 13th five-year plan for energy development. National Development and Reform Commission and National Energy Administration 2016. http://www.nea.gov.cn/2017-01/17/c_135989417.htm

[12] NDRC. Letter from NDRC on the pilot program for paid use and trading system of energy-consuming rights. National Development and Reform Commission, 2016. http://www.gov.cn/xinwen/2016-09/21/content_5110262.htm

[13] Aldrich E, Koerner C. White certificate trading: A dying concept or just making its debut? Part I: Market status and trends. The Electricity Journal 2018;31:52-63.

[14] Sun Y, Xue J, Shi X, Wang K, Qi S, Wang L, Wang C. A dynamic and continuous allowances allocation methodology for the prevention of carbon leakage: Emission control coefficients. Applied Energy 2019;236:220-30.

[15] Jensen S.G, Skytte K. Interactions between the power and green certificate markets. Energy Policy 2002;30:425-35.

[16] Fouquet D, Johansson T. European renewable energy policy at crossroads--Focus on electricity support mechanisms. Energy Policy 2008;36:4079-92.

[17] Jiang J, Xie D, Ye B, Shen B, Chen Z. Research on China's cap-and-trade carbon emission trading scheme: Overview and outlook. Applied Energy 2016;178:902-17.

[18] Song X, Lu Y, Shen L, Shi X. Will China's building sector participate in emission trading

system? Insights from modelling an owner's optimal carbon reduction strategies. Energy Policy 2018;118:232-44.

[19] Rosenow J, Skoczkowski T, Thomas S, Węglarz A, Stańczyk W, Jędra M. Evaluating the Polish White Certificate scheme. Energy Policy 2020;144:111689.

[20] Li W, Jia Z. The impact of emission trading scheme and the ratio of free quota: A dynamic recursive CGE model in China. Applied Energy 2016;174:1-14.

[21] Segura S, Ferruz L, Gargallo P, Salvador M. Environmental versus economic performance in the EU ETS from the point of view of policy makers: A statistical analysis based on copulas. Journal of Cleaner Production 2018;176:1111-32.

[22] Zhao X, Zhou Y, Yi Z, Meng J, Zhang Y. Research on optimal benchmark price of tradable green certificate based on system dynamics: A China perspective. Journal of Cleaner Production 2019;230:241-252.

[23] Yu X, Dong Z, Zhou D, Sang X, Chang C, Huang X. Integration of tradable green certificates trading and carbon emissions trading: How will Chinese power industry do? Journal of Cleaner Production 2021;279:123485.

[24] Yu Z, Meng Z. Some thoughts about the trading of energy-consuming right. 19 May 2017. http://www.tanjiaoyi.com/article-21418-1.html.

[25] Zhou P, Zhang L, Zhou D, Xia W. Modeling economic performance of interprovincial CO_2 emission reduction quota trading in China. Applied Energy 2013;112:1518-28.

[26] Zhang D, Rausch S, Karplus V, Zhang X. Quantifying regional economic impacts of CO2 intensity targets in China. Energy Economics 2013;40:687-701.

[27] Cui L, Fan Y, Zhu L, Bi Q. How will the emissions trading scheme save cost for

achieving China's 2020 carbon intensity reduction target? Applied Energy 2014;136:1043-52.

[28] Shi X, Shen Y, Wang K, Zhang Y. Capacity Permit Trading Scheme, Economic Welfare and Energy Insecurity: Case Study of Coal Industry in China. The Singapore Economic Review 2019: 1-21. doi:10.1142/s0217590819500589

[29] Shi X, Wang K, Shen Y, Sheng Y, Zhang Y. A Permit Trading Scheme for Facilitating Energy Transition: A Case Study of Coal Capacity Control in China. Journal of Cleaner Production 2020;256:120472.

[30] Cheng B, Dai H, Wang P, Zhao D, Masui T. Impacts of carbon trading scheme on air pollutant emissions in Guangdong Province of China. Energy for Sustainable Development 2015;27:174-185.

[31] Lin B, Jia Z. The impact of emission trading scheme (ETS) and the choice of coverage industry in ETS: A case study in China. Applied Energy 2017;205:1512-27.

[32] Lin B, Jia Z. Impact of quota decline scheme of emission trading in China: A dynamic recursive CGE model. Energy 2018;149:190-203.

[33] Zhang Y, Zhang J. Estimating the impacts of emissions trading scheme on low-carbon development. Journal of Cleaner Production 2019;238:117913.

[34] Li J, Wang X, Zhang Y, Kou Q. The economic impact of carbon pricing with regulated electricity prices in China—An application of a computable general equilibrium approach. Energy Policy 2014;75:46-56.

[35] Zhang H, Zhang R, Li G, Li W, Choi Y. Sustainable feasibility of carbon trading policy on heterogenetic economic and industrial development. Sustainability 2019;11:6869.

[36] Li L, Dong J, Song Y. Impact and acting path of carbon emission trading on carbon emission intensity of construction land: Evidence from pilot areas in China. Sustainability 2020;12:7843.

[37] Wang K, Wei Y, Huang Z. Potential gains from carbon emissions trading in China: A DEA based estimation on abatement cost savings. Omega-international Journal of Management Science 2016;63:48-59.

[38] Sun J, Wang Z, Li G. Measuring emission-reduction and energy-conservation efficiency of Chinese cities considering management and technology heterogeneity. Journal of Cleaner Production 2018;175:561-571.

[39] Bor Y, Huang Y. Energy taxation and the double dividend effect in Taiwan's energy conservation policy - an empirical study using a computable general equilibrium model. Energy Policy 2010;38:2086-2100.

[40] Liu Y, Tan X, Yu Y, Qi S. Assessment of impacts of Hubei Pilot emission trading schemes in China – A CGE-analysis using TermCO$_2$ model. Applied Energy 2017;189:762-9.

[41] Zhou B, Zhang C, Song H, Wang Q. How does emission trading reduce China's carbon intensity? An exploration using a decomposition and difference-in-differences approach. The Science of the total environment 2019;676:514-23.

[42] Dong F, Dai Y, Zhang S, Zhang X, Long R. Can a carbon emission trading scheme generate the Porter effect? Evidence from pilot areas in China. The Science of the total environment 2019;653:565-77.

[43] Wang H, Chen Z, Wu X, Nie X. Can a carbon trading system promote the

transformation of a low-carbon economy under the framework of the porter hypothesis? —Empirical analysis based on the PSM-DID method. Energy Policy 2019;129:930-38.

[44] Ashenfelter O. Estimating the effect of training programs on earnings. The Review of Economics and Statistics 1976;60:47-57.

[45] Rosenbaum P, Rubin D. The central role of the propensity score in observational studies for causal effects. Biometrika 1983;70:41-55.

[46] Heckman J, Ichimura H, Todd P. Matching as an econometric evaluation estimator: Evidence from evaluating a job training programme. The Review of Economic Studies 1997;64:605-54.

[47] Heckman J, Ichimura H, Todd P. Matching as an econometric evaluation estimator. The Review of Economic Studies 1998;65:261-94.

[48] Lee K, Min B.S. Green R&D for eco-innovation and its impact on carbon emissions and firm performance. Journal of Cleaner Production 2015;108:534-42.

[49] Zhang S. Current situations and suggestions on the fiscal expenditure of environmental protection. Journal of Hebei University of Economics and Business 2016;37(06):80-85. (In Chinese)

[50] State Council. Notice of the State Council on issuing the comprehensive work plan for energy conservation and emission reduction during the 13th Five-Year Plan. 2016. http://www.gov.cn/zhengce/content/2017-01/05/content_5156789.htm

[51] Ji X. Research on the impact of central China's rising strategy on urban environmental quality—An analysis based on PSM-DID Method. Inquiry into Economic Issues 2020;8:157-169. (In Chinese)

Appendix

Detailed background of China’s energy-consumption permit trading policy

Currently, the energy-consumption permit trading scheme (ECPTS) implemented by the Chinese government has two components: the energy-consumption permit (ECP) allocation method and the permit trading scheme. Due to differences in the economic development level, industrial structure, and energy consumption structure, the scope of the participating companies that apply the ECPTS are not the same across the pilot provinces. Through data mining methods to collect related policy materials and ECP trading information, this paper describes the ECPTS from two perspectives: the allocation method and the trading scheme.

(1) The energy-consumption permit allocation method

Although there are differences in the final allocation scheme of the four pilot provinces, their policy allocation methods are consistent. First, the local government works out the total amount of ECPs considering regional economic growth and resource endowment, and subject to the dual constraints of energy consumption and energy intensity targets. Second, different types of energy-consuming enterprises may be subject to different allocation methods, such as the historical trend method and the benchmark method, ensuring the fairness of the ECP allocation scheme. Lastly, the local government implements the initial free ECP allocation for all the participating companies in line with the ETS.

Note that self-produced renewable energy is not within the statistical scope of the energy-consumption permit. In other words, enterprises can use self-produced renewable energy to replace non-renewable energy, achieving more surplus of the ECP. This measure may guide investment to flow into the renewable energy industry and promote the transition of energy-consuming companies through integrating industry chains.

Overall, the above allocation methods are the same as the ones used in the ETS, and the government-led allocation pattern can generate high, uncertain policy risks. Once deviations emerge in the implementation of the ECPTS, such as the unfair ECP allocation scheme, it may lead to distortions within the industry and inhibit the energy-saving motivation of energy-intensive enterprises.

(2) The energy-consumption permit trading scheme

Considerable differences exist in the ECP trading mechanism in the current four pilot provinces, especially the qualifications of participating companies and the trading price. Also, a pattern characterized by the transaction between the local government and companies is adopted in the pilot program, derived from China's ETS pilot trading market experience. Additionally, the ECP trading policy primarily covers the energy-intensive industries such as petrochemical, building materials, and steel industry, while the policy has a wider coverage than the ETS.

Furthermore, the ECP trading policy puts a floating price into practice to match the above-mentioned trading pattern. Specifically, the government first sets a benchmark trading price based on the energy spot price in the same period, then puts forward a reasonable floating range in line with the local energy consumption and total ECP. What is remarkable is that the above pricing rule has not been adopted in Fujian, where the trading price is determined by the supply and demand of the ECP without government interventions.