The impact of pilot carbon emission trading policy on energy efficiency and energy structure

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Abstract. In July 2021, China's national carbon market was officially launched, after years of carbon pilots laid the institutional foundation for the establishment of the market. The study of the impact of carbon pilot on energy efficiency and energy structure can provide important reference for China's energy transformation and sustainable development. Using a sample of 283 prefecture-level cities, the paper finds that carbon emission trading policies have a significant impact on reducing the use of energy with high carbon content, while the view that policies can improve energy efficiency fails to be proved for some reasons. Finally, the paper summarizes the conclusion and puts forward the possible research direction in the future.

Keywords: carbon emission trading, energy utilization efficiency, energy structure, differential method, parallel trend

1 Introduction

As global climate warming and environmental pollution become increasingly serious, reducing carbon emissions has become one of the important tasks of governments around the world. In this context, the carbon emission trading (CET)system came into being to achieve the goal of reducing carbon emissions through the market mechanism and effectively reduce emission reduction costs. This paper will further study the impact mechanism of CET on energy utilization efficiency and energy structure through the method of difference-difference.

2 Literature review

In 2008, a study by M. Kara et al. [6]showed that carbon dioxide emission trading would bring huge competitive advantages to carbon-free energy sources. At present, the research on CET has achieved some results[7], but most of the research focuses on energy conservation and emission reduction, environmental pollution improvement and the impact on economic growth. In terms of economic growth, the research of Zhang Youzhi, Liu Yinke and Zhao Jing[3] shows that CET policies can promote economic growth, which is reflected in the optimization of industrial structure, and the

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optimization of industrial structure often involves the utilization efficiency of energy and energy transformation. Liu Yuan and Wen Zuomin[5] found that the CET policy has a positive impact on green technology innovation, while Jing Guowen and Chen Guang[4] found that the CET policy does have a restraining effect on pollution reduction. In addition, Li and Jiang[1] have found that technological innovation and emission reduction are usually manifestations of energy efficiency.

Based on the collation of existing literature, this paper puts forward the following hypotheses: 1. The implementation of policies has a significant impact on the improvement of energy utilization efficiency; 2. Policy changes the energy mix, that is, the composition of primary energy use.

The possible innovation of this paper is that the natural experiment based on the CET pilot policy is used to explore the above hypothesis for the experimental city and the control city by using the different-difference method.

3 Theoretical framework

3.1 Construction of the model 1

Using differencing method to evaluate the effect of policy can eliminate individual differences and estimate the net effect of policy. Considering that the policy implementation time of the first batch of pilot cities was concentrated in late 2013 and early 2014, this paper takes 2014 as the first year of implementation of the policy after referring to other literatures on the impact of pilot policies on CET.

Firstly, this paper studies the impact of CET pilot on energy efficiency, refers to the relevant factors affecting energy efficiency studied in existing literature, such as the environmental supervision and other related factors involved in Mandal S.K.'s research[8], and then establishes the following model (1) by referring to the research of Zhang Kun and CAI Shuxun[2]:

$$Y_1 = \beta_0 + \beta_1 * D + \beta_2 * T + \beta_3 * DT + \beta_4 * \ln a + \beta_5 * \ln b + \beta_6 * \ln c + \beta_7 * \ln f + \varepsilon \quad (1)$$

3.1.1 Explained variables.

Y1: Energy intensity, that is, energy consumption per unit of GDP (tons of standard coal / 10,000 yuan).

3.1.2 Explanatory variable.

D: Dummy variables for pilot areas (1 for pilot areas, 0 for non-pilot areas); T: dummy variable of time (since the implementation year of the policy is 2014, set the years 2006-2013 as 0, 2014 to 2019 as 1); DT: The interaction term of the pilot region dummy variable and the time dummy variable, as the core explanatory variable.

3.1.3 Control variables.

a: GDP per capita (yuan), used to measure economic factors; b: The proportion of added value of secondary industry in GDP of each region is used to measure industrial structure; c: 1+ the number of municipal green patent applications in each year (number), which is used to measure the level of science and technology. The purpose of adding 1 is to avoid the situation that a large number of samples will be lost when the number of green patent applications is 0; f: Energy structure, expressed as the proportion of coal consumption in total energy consumption.

3.1.4 Final model 1.

Due to the serious multicollinearity between dummy variables in the actual process, the model (1) was changed to the model (2) in which only the core explanatory variable DT was retained:

$$Y_1=\beta_0+\beta_1*DT+\beta_2*lna+\beta_3*lnb+\beta_4*lnc+\beta_5*lnf+\varepsilon \quad (2)$$

3.2 Construction of the model 2

The second question of the paper is studied, which is to explore the impact of the pilot CET on the energy structure. Based on the first model and according to the research of references, some variables are transformed. The specific model (3) is shown as follows:

$$Y_1=\beta_0+\beta_1*D+\beta_2*T+\beta_3*DT+\beta_4*lna+\beta_5*lnb+\beta_6*lnc+\beta_7*lnf+\varepsilon \quad (3)$$

3.2.1 Explained variables.

Y2: Total use of natural gas, liquefied petroleum gas and electric energy (10,000 tons of standard coal).

3.2.2 Explanatory variable.

D: Dummy variables for pilot areas (1 for pilot areas, 0 for non-pilot areas); T: dummy variable of time (since the implementation year of the policy is 2014, set the years 2006-2013 as 0, 2014 to 2019 as 1); DT: The interaction term of the pilot region dummy variable and the time dummy variable, as the core explanatory variable.

3.2.3 Control variables.

a: GDP per capita (yuan), used to measure economic factors; b: The proportion of added value of secondary industry in GDP of each region is used to measure industrial structure; d: The proportion of government fiscal revenue in GDP, which is used to measure the role of macro-control; f: Energy structure, expressed as the proportion of coal consumption in total energy consumption.

3.2.4 Final model 2.

Due to the serious multicollinearity between dummy variables in the actual process, the model (3) was changed to the model (4) in which only the core explanatory variable DT was retained:

$$Y_2 = \beta_0 + \beta_1 * DT + \beta_2 * lna + \beta_3 * lnb + \beta_4 * lnd + \beta_5 * lnf + \varepsilon \quad (4)$$

4 Data source

The data sample studied in this paper included 283 prefecture-level cities in China, some of which were not considered due to the lack of data. Most of the missing values were filled in by linear interpolation. The remaining missing values were filled in with ARIMA.

There are two data that need special attention, namely energy structure and city-level energy consumption. At present, the main types of energy in Chinese cities are coal, natural gas, liquefied petroleum gas and electric energy. Due to the lack of data on coal consumption in some cities, this paper assumes that the energy structure of prefecture-level cities is the same as that of the provinces where they are located, based on the hypothesis of Li Lei and Jiang Qinyi. The total energy consumption of prefecture-level cities is calculated by dividing the total use of natural gas, liquefied petroleum gas and electric energy by their proportion. The statistical results are shown in Figure 1.

Variable	Obs	Mean	Std. Dev.	Min	Max
lny1	3,961	-1.26875	.7902708	-4.279995	3.129528
lny2	3,961	4.402048	1.270379	.0889161	8.310742
lna	3,962	10.41624	.7239032	4.59512	13.05569
lnb	3,961	-.7536434	.2652188	-2.145464	.2202424
lnc	3,962	3.010884	1.327358	0	5.26269
lnd	3,962	-2.695383	.3796688	-3.976442	-1.405886
lnf	3,962	-1.383301	.3160214	-2.184614	-.5495181

Fig. 1. Descriptive statistics.

5 Empirical results

5.1 Regression results of hypothesis 1

```
. xtreg lny1 DT lna lnb lnc lnf ,fe

Fixed-effects (within) regression               Number of obs     =      3,960
Group variable: Administrative code             Number of groups  =        283

R-sq:                                           Obs per group:
     within  = 0.1213                                         min =         13
     between = 0.0321                                         avg =       14.0
     overall = 0.0009                                         max =         14

                                                F(5,3672)         =     101.38
corr(u_i, Xb)  = -0.4719                        Prob > F          =     0.0000

------------------------------------------------------------------------------
        lny1 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          DT |  -.0470015   .0413384    -1.14   0.256    -.1280501     .034047
         lna |  -.2761947   .0297613    -9.28   0.000     -.334545    -.2178444
         lnb |   -.674997   .0622344   -10.85   0.000    -.7970144    -.5529796
         lnc |   .0518425   .0092222     5.62   0.000     .0337615     .0699236
         lnf |   -.396594   .0613004    -6.47   0.000    -.5167802    -.2764077
       _cons |   .3971823   .3721879     1.07   0.286    -.3325331     1.126898
-------------+----------------------------------------------------------------
     sigma_u |  .75338987
     sigma_e |  .44616916
         rho |  .74034633   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(282, 3672) = 27.43                  Prob > F = 0.0000
```

Fig. 2. Regression results of hypothesis 1.

The results in Figure 2 show that the explanatory variables, that is, the influence of policies on energy efficiency, are not significant and negatively correlated, which is not in line with our hypothesis. Economic factors, industrial structure, scientific and technological level and energy structure all have significant influences on energy use efficiency, but the explanatory power (R^2) of the model is very low, which indicates that the variables considered by the model may not be the main factors leading to the improvement of energy efficiency.

There may be several reasons for this result:

The model may not satisfy the parallel trend; If the model does not meet the parallel trend, it will lead to the estimation bias, which is also analyzed in detail in the robustness test below.

Data deviation; On the one hand, there are missing values in the original data, which may not be appropriate for the linear interpolation and ARIMA's supplementary value adopted in the paper. On the other hand, the correct calculation of total energy consumption requires the assumption that the energy structure of the prefecture-level city is the same as that of the province where it is located. Therefore, optimizing the process of data processing may be a viable solution.

It is also possible that the efficiency of energy use is largely determined by science and technology, and the implementation of policies cannot improve the scientific and technological level of pilot cities in a short time, but based on existing research, this guess is largely untrue.

5.2 Regression results of hypothesis 2

```
. xtreg lny2 DT lna lnb lnd lnf ,fe

Fixed-effects (within) regression               Number of obs     =      3,960
Group variable: Administrative code             Number of groups  =        283

R-sq:                                           Obs per group:
     within  = 0.5876                                         min =         13
     between = 0.3644                                         avg =       14.0
     overall = 0.4129                                         max =         14

                                                F(5,3672)         =    1046.28
corr(u_i, Xb)  = 0.1445                         Prob > F          =     0.0000

------------------------------------------------------------------------------
        lny2 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          DT |   .0690519   .0408315     1.69   0.091    -.0110028    .1491065
         lna |   .7598762   .0267268    28.43   0.000     .7074753     .812277
         lnb |   -.842239   .0590362   -14.27   0.000     -.957986    -.726492
         lnd |  -.2180605   .0397873    -5.48   0.000    -.2960678   -.1400532
         lnf |   .9317123   .0600039    15.53   0.000      .814068    1.049357
       _cons |   -3.45025   .3954754    -8.72   0.000    -4.225623   -2.674877
-------------+----------------------------------------------------------------
     sigma_u |  .88653575
     sigma_e |  .44118261
         rho |  .80150466   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(282, 3672) = 41.95                  Prob > F = 0.0000
```

Fig. 3. Regression results of hypothesis 2.

The results in Figure 3 show that the influence of explanatory variables, namely policies, is significant at the 90% confidence level, which is basically in line with our hypothesis, while the influence of economic factors, industrial structure, government macro-control and energy structure on the total energy consumption except coal is significant, and the explanatory power (R^2) of the model is also considerable.

It can be found that the policy has a positive impact on the consumption of major energy sources except coal, which may be the most influenced by the policy because the carbon content of coal is much higher than that of the other three energy sources, resulting in the gradual replacement of coal by other energy sources.

6 Robustness test: Parallel trend test

To reach a scientific conclusion, we must show that there was no significant difference between the experimental group and the control group before the implementation of the emissions trading pilot policy, that is, there was a "common trend" between them. This paper takes the pilot implementation year of the CET policy (2014) as the base year and takes the three years before and after the implementation as the interval to conduct parallel trend test. The dummy variables pre_1, pre_2, pre_3 and post_1, post_2, post_3 are used to represent the first, second and third years before and after the implementation of the policy, respectively. The dummy variables in the year of policy implementation are represented by current, and the regression results and the trend graphics are shown in Figure 4 and Figure 5.

```
. xtreg lny1 pre_3 pre_2 pre_1 current post_1 post_2 post_3 ,fe

Fixed-effects (within) regression               Number of obs      =      3,961
Group variable: Administrative code             Number of groups   =        283

R-sq:                                           Obs per group:
     within  = 0.0232                                         min =         13
     between = 0.0001                                         avg =       14.0
     overall = 0.0060                                         max =         14

                                                F(7,3671)          =      12.46
corr(u_i, Xb)  = -0.0373                        Prob > F           =     0.0000
```

lny1	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
pre_3	-.213685	.0827083	-2.58	0.010	-.3758437	-.0515262
pre_2	-.3093512	.0827083	-3.74	0.000	-.47151	-.1471925
pre_1	-.4634476	.0827083	-5.60	0.000	-.6256064	-.3012889
current	-.4688186	.0827083	-5.67	0.000	-.6309774	-.3066598
post_1	-.4811402	.0827083	-5.82	0.000	-.643299	-.3189815
post_2	.0012982	.0827083	0.02	0.987	-.1608605	.163457
post_3	-.0959658	.0827083	-1.16	0.246	-.2581246	.0661929
_cons	-1.249777	.0079513	-157.18	0.000	-1.265366	-1.234187
sigma_u	.64616307					
sigma_e	.47060224					
rho	.65341341	(fraction of variance due to u_i)				

```
F test that all u_i=0: F(282, 3671) = 26.33                 Prob > F = 0.0000
```

Fig. 4. Results of the parallel trend test for hypothesis 1.

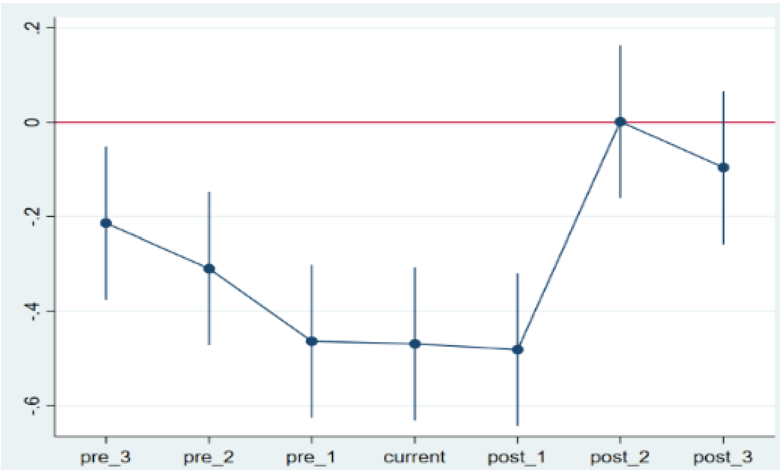

Fig. 5. The parallel trend of hypothesis 1.

It can be seen that the variables before the implementation of the policy are significant, while the one-year variables after the implementation are significant, and the two-year and three-year variables are not significant, which means that the model does not meet the hypothesis of parallel trends, that is, there may be some differences between cities before the implementation of the policy, which will have an impact and error on the subsequent empirical analysis, which is probably hypothesis 1 of the paper: "The implementation of the policy has a significant impact on the improvement of energy efficiency" proves the reason for the failure.

```
. xtreg lny2 pre_3 pre_2 pre_1 current post_1 post_2 post_3 ,fe

Fixed-effects (within) regression               Number of obs     =      3,961
Group variable: Administrative code             Number of groups  =        283

R-sq:                                           Obs per group:
     within  = 0.0162                                         min =         13
     between = 0.0378                                         avg =       14.0
     overall = 0.0155                                         max =         14

                                                F(7,3671)         =       8.61
corr(u_i, Xb)  = 0.0621                         Prob > F          =     0.0000

------------------------------------------------------------------------------
        lny2 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       pre_3 |  -.0977427   .1197764    -0.82   0.415    -.3325776    .1370922
       pre_2 |  -.0583869   .1197764    -0.49   0.626    -.2932218     .176448
       pre_1 |   .0543469   .1197764     0.45   0.650     -.180488    .2891818
     current |   .1729424   .1197764     1.44   0.149    -.0618925    .4077772
      post_1 |   .2084663   .1197764     1.74   0.082    -.0263685    .4433012
      post_2 |   .3087125   .1197764     2.58   0.010     .0738776    .5435473
      post_3 |   .8482421   .1197764     7.08   0.000     .6134072    1.083077
       _cons |   4.388628   .0115149   381.12   0.000     4.366052    4.411205
-------------+----------------------------------------------------------------
     sigma_u |   1.080169
     sigma_e |  .68151618
         rho |  .71526731   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(282, 3671) = 34.72                 Prob > F = 0.0000
```

Fig. 6. Results of the parallel trend test for hypothesis 2.

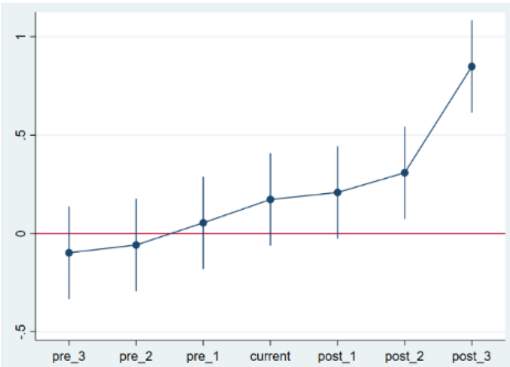

Fig. 7. The parallel trend of hypothesis 2.

Figure 6 and Figure 7 are the regression results and trend charts of the parallel trend test of Hypothesis 2. It can be seen that variables before the implementation of the policy are not significant, and variables after the implementation of the policy are significantly positive at the 90% confidence level, which indicates the hypothesis of parallel trend in hypothesis 2 is valid.

7 Conclusion and further research direction

This paper mainly examines whether the pilot CET policy can promote the improvement of energy efficiency and its impact on the energy structure, using the panel data of 283 prefecture-level cities from 2006 to 2019, and establishing a difference-difference model for analysis. The empirical study finds that the CET pilot policy may not be the main factor affecting the improvement of energy efficiency, but the implementation of the policy can significantly change the energy structure, and coal is gradually replaced by natural gas, liquefied petroleum gas and electric energy. The robustness of the conclusion is further verified by parallel trend test.

The shortcoming of this paper is that when solving the problem of lack of coal consumption data in some cities, it assumes that the energy structure of prefecture-level cities is the same as that of the provinces where they are located, and the data of total energy use is derived backwards, which may be the main reason for the poor effect of Model 1. Therefore, how to better deal with the missing data is one of the directions of this paper to be researched in the future. Secondly, when the model was established, it was found that there was a serious collinearity problem between the time dummy variable and the city dummy variable, which may be caused by the municipal unit as the sample. If you want to explore the differentiation between cities, you can consider using the DID model with multiple time points for optimization.

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