Effects of China's environmental policy on carbon emission efficiency

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Abstract

Purpose – The purpose of this paper is to analyze the effect of environmental policy *China's national program to address climate change* on carbon emission efficiency.

Design – Based on the directional distance function, the provincial total factor carbon emission efficiency was measured. Then, the authors analyzed the effect of environmental policy on carbon emission efficiency based on a difference in difference model.

Finding – Carbon emission efficiency has been significantly improved since the environmental policy *China's national program to address climate change* was put forwarded, but the positive impact in different periods and regions is different. In addition, the environmental policy improves the carbon emission efficiency through the reduction of energy intensity and adjustment of the industrial structure.

Originality/value – This is the first time to use difference in difference model to use a difference in difference model to quantitatively assess the influence of environmental policy *China's national program to address climate change* on carbon emission efficiency.

Keywords Environmental policy, Carbon emission efficiency, Difference in difference method

Paper type Research paper

1. Introduction

Global climate warming caused by the "greenhouse effect" has caught considerable attention worldwide. Recently, urbanization and industrialization have taken a great stride forward in China. Coal is one of the most important supporting elements; the total energy consumption in 2015 amounted to 43 tons of standard coal, which increased by 2.93 times compared to that in 2000. Cheap coal with abundant reserve has become the first choice of resource element considering that the conditions of resource endowment and economic development cost constraints. The *Statistical Communique of the 2015 National Economic*

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and Social Development revealed that the proportion of coal consumption was as high as 64 per cent in 2015. Large-scale exploitation and utilization of coal resources have driven national and local economic development, but it has caused serious environmental problems simultaneously. According to the annual global carbon emission data of 2013 published by the Global Carbon Project, China's total carbon emission exceeded the summation of European Union (EU) and the USA, wherein the per capita carbon emission reached 7.2 tons and exceeded that of Europe for the first time. Accordingly, the Chinese Government has committed to the reduction of carbon emissions and to the improvement of carbon emission efficiency for a long period. In 2007, the China Development and Reform Commission promulgated the environmental policy *China's national program to address climate change* (hereafter referred to as *national program*). As an essential task of performing climate convention, the *national program* pointed out the special goals, basic principles, key areas and policy measures. In accordance with the requirements of the scientific concept of development, the Chinese Government implemented various tasks stipulated by the *national program* earnestly, striving to build a resource-conserving and environment friendly society.

The *national program* has been implemented for more than 10 years. However, it is uncertain whether the implementation of the *national program* has improved the carbon emission efficiency and relieved the climate problems. Thus, this study calculated the carbon emission efficiency on the basis of the sample of provincial panel data in China and then evaluated the abatement effect caused by the implementation of the *national program*. The authors believe that the findings can help to demonstrate the gains and losses of the implementation of the *national program*. This study provides a theoretical basis for the formulation of environmental policy in the future.

The rest of the paper is organized as follows: Section 2 discusses the relevant literature; empirical methodology is presented in Section 3; Section 4 presents the data; in Section 5, the empirical results and their implications are reported and discussed; finally, Section 6 summarizes the research findings and conclusions.

2. Literature review

2.1 Effect of environmental policy on carbon emission efficiency

Fundamentally, the improvement of carbon emission efficiency reflects the progress of carbon emission reduction technology. A considerable number of useful information from the literature that discussed the relationship between environmental policy and technology innovation can be obtained. A review of the previous studies on the relationship between environmental policy and technology innovation shows inconsistent conclusions. The most diret change is the operating cost caused by environmental degradation when firms are faced with environmental policy. However, different enterprises may have different reflections when dealing with environmental degradation cost. On the one hand, along with the increase in operating cost, enterprise investment scale of other production factors (equipment update, innovation elements) will reduce. As a result, the enterprises face technology constraint or cost effect, which has a negative effect on technology innovation (Martin *et al.*, 2013; List *et al.*, 2003; Greenstone and Gayer, 2009; Taylor, 2012; Lange and Bellas, 2005; Feng *et al.*, 2017). On the other hand, according to the "porter hypothesis" proposed by Porter *et al.* (1995), the competitive advantage is dependent not only on the game behavior under static standard, which is the environmental policy that increases the carbon emission cost of countries and regions but also on the effective simulation of the technological innovation and production of the innovation compensation effects (Brunnermeier and Cohen, 2003; Popp, 2012; Aghion *et al.*, 2016).

2.2 Policy evaluation

Previous theoretical studies on policy evaluation can be divided into broad sense and narrow sense. The broad sense policy evaluation is aimed at comprehensively evaluating policy implementation process, methods and objects comprehensively. For example, Lasswell (1951) introduced the concept of broad sense policy evaluation as a statement of the causation. Contrary to broad sense policy evaluation, the narrow sense policy evaluation was in favor of judging the value, performance, and efficiency. Charles (1984) pointed out that the policy evaluation was used to explain, examine and analyze the effect after policy implementation. The role of policy evaluation is related to the gains and losses of policy implementation. Similarly, Nachmias and Nachmias (1976) and Dye (1995) believed that policy evaluation is an objective and systematic testing, which confirms whether the policy implementation has achieved the desired goal.

The empirical analysis methods of narrow sense policy evaluation are mainly categorized into three types: social indicator, multiple attribute effect analysis and policy experiment. The social indicator method judges the policy effect on the basis of the change of social indicators before and after policy implementation (Nachmias and Nachmias, 1979; Lehrman, 2013). This method is simple and direct but lacks stringency and scientific support. Thus, it does not have a significant advantage in the field of policy evaluation. The multiple attribute effect analysis method segments the indicators into various levels such as policy implementation process and output end and then evaluates the effectiveness of policy implementation (Edwards and Newman, 1982; Lazarides and Drimpetas, 2011). Contray to the aforementioned methods, the policy experiment method judges the policy effect through comparing of the change of tendency in different groups before and after policy implementation. In accordance with the principle of policy experiment method, the model of difference in difference (DID) has been widely developed and used (Petrick and Zier, 2011; Piracha and Zhu, 2012; Deschacht and Goeman, 2015; Adan and Fuerst, 2015; Sunak and Madlener, 2016; Winkey, 2017; Hosken *et al.*,2018).

In summary, the literature has laid a solid foundation for the study on the effect of environmental policy on technology innovation, and provides a reference for policy evaluation. However, few scholars have studied the influence of environmental policy on the carbon emission efficiency. To realize the sustainable development of economy and society, this study takes the *national program* as an example and uses the DID method to test the influence of environmental policy on the carbon emission efficiencyin accordance with the provincial panel data. In comparison with the present literatures, the contribution of this work mainly covers the following aspects:

First, on the basis of the *national program* proposed by the Chinese Government in 2007 that encountered various problems in the implementation process, such as the lack of execution rigidity, planning lag and region-oriented differences, the authors estimate the total factor carbon emission efficiency of 30 provinces in China in accordance with the directional distance function, discuss the reduction effect of the environmental policy *national program* implementation and present an in-depth analysis of the mechanism of improving the total factor carbon emission efficiency.

Second, this study tests the relationship between the environmental policy and the carbon emission efficiency in accordance with the DID model. This model can effectively exclude the factors that influence both the environmental policy implementation and carbon emission efficiency, deal with the problem of endogeneity and assess the effect of environmental policy on the carbon emission efficiency effectively.

Finally, this study finds that the carbon emission efficiency has been improved significantly since the *national program* was implemented in 2007. In addition, the *national* *program* can improve the carbon emission efficiency through reducing energy intensity and accelerating the upgradation of industrial structure. However, the influence of economic growth rate on the carbon emission efficiency is relatively weak.

3. Methodology

3.1 Total factor carbon emission efficiency

Various indicators have been developed and applied to demonstrate the carbon emission efficiency. For instance, Kaya and Yokobori (1993) suggested the concept of carbon productivity [the level of carbon emissions per unit of gross domestic product (GDP)]. Tol *et al.* (2009) showed that both carbon emission intensity and per capital carbon emissions can be considered as useful indicators. The aforementioned indicators were easy to calculate, but they may be interpreted as partial indicators because they can only reflect partial aspects of carbon emission performance. Hence, an increasing number of scholars added the relevant indicators, such as energy consumption, economic activity and carbon emissions into an overall index, evaluated the carbon emission efficiency (Charnes *et al.*, 1978) on the basis of the data envelopment analysis (DEA). The basic idea of measuring technical inefficiency by DEA is to compare the distance between the production unit and the optimal production frontier (Ali and Yang, 2016). In this study, the authors measure the provincial total factor carbon emission efficiency in accordance with the directional distance function, and this model can satisfy the common desire of the public and policymakers to reduce inputs/undesirable outputs and increase desirable outputs simultaneously. The model allows the adjustment of the desirable outputs and inputs/undesirable outputs at different rates on the basis of different vector directions for input–output variables and provides a common framework for deriving the required models by changing the direction vectors (Meng *et al.*, 2016).

Consistent with the definition of environmental technology sets proposed, Chung and Fare assume that there are M countries (M decision-making Units, *DMU*s), and each country uses three kinds of inputs (X), namely, capital, labor and energy. The three inputs can produce one desirable output gross domestic production (Y^g) and one undesirable output CO_2 emissions (Y^b). The production technology set (T) is expressed as equation (1):

$$T = \left\{ \left(X, Y^g, Y^b\right) : x\, can \quad produce \quad \left(Y^g, Y^b\right) \right\} \tag{1}$$

On this basis, the directional distance function is defined as (Gomez *et al.*, 2014):

$$\vec{D}_T = \left(X, Y^g, Y^b; d\right) = \sup\left\{\delta : \left(Y^g + \delta d^g, Y^b - \delta d^b\right) \in p\left(X - \delta d^X\right)\right\} \tag{2}$$

where $d = (-d^x, d^g, -d^b)$. The value of δ measures the productive technical inefficiency and equation (2) seeks for the maximum attainable expansion of desirable outputs in the d^g direction and the largest feasible contraction of undesirable outputs and inputs in d^b and d^X directions. The directional distance function of equation (2) can be evaluated by the following optimization model (taking j_0 as a reference unit):

$$\max_{\delta,\lambda} \delta$$

$$s.t. \sum_{j=1}^{n} \lambda_j y^g_{rj} - \delta d^g_{rj_0} \geq y^g_{rj_0}, \quad r = 1, \ldots, q$$

$$\sum_{j=1}^{n} \lambda_j y_{kj}^b + \delta d_{kj_0}^b \leq y_{kj_0}^b, \quad k = 1, \ldots, l \tag{3}$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} + \delta d_{ij_0}^x \leq x_{ij_0}, \quad i = 1, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0, \quad j = 1, \ldots, n$$

In this study, the authors adopt a direction vector d=(0, d^g, $-d^b$) that allows for an expansion of desirable factors and a contraction of undesirable ones without increasing the inputs. The value δ measures the productive technical inefficiency and equation (2) seeks for the maximum attainable expansion of desirable outputs in the d^g direction and the largest feasible contraction of undesirable outputs in the -d^b direction. In addition, the aforementioned model separates the units to efficiency and non-efficiency, but can not rank the efficiency units. To avoid this defect, the authors introduced the super efficiency model proposed by Tone (2001), and the effective production units are ranked again.

3.2 Method for policy evaluation

The DID method has become widespread in estimating causal relationships since the work by Ashenfelter and Card (1985). On his basis, observations were collected for two groups and for two periods. As shown in Figure 1, the treatment group was exposed to the treatment in one period (t_0 to t_1) and the control group receives no treatment during both periods. The double differences, commonly known as DID method, removed biases in the second period comparison between the treatment group and the control group, which can be the result of permanent differences between those groups, as well as biases from comparison over time in the treatment group, which can be the result of time trends unrelated to the treatment (policy effect) (Abadie, 2005; Finkelstein, 2002; Card and Krueger, 1994).

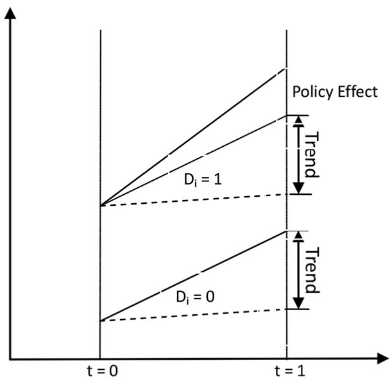

Figure 1.
DID method

Of note, the DID model strongly relied on the assumption that the treatment and control groups follow the same trend over time in the absence of the treatment (Meyer, 1995). However, the *national program* is a national test, and it is essential to determine the construction of the appropriate control group. To satisfy the conditions of the control and treatment groups close to nature, this study referred to the method of Ouyang and Huang (2013) and predicted the data after policy implementation on the basis of the data before environmental policy implementation. In the prediction process, we used the exponential smoothing method, which is a special kind of weighted moving average method and further strengthened the effect of recent observation on the predicted value (Ge *et al.*,2013). Furthermore, the predicted value was regarded as the group that is not affected by the policy.

On this basis, this study builds a dynamic model to judge the effect of environmental policy on total factor carbon emission efficiency.

$$CE_{i,t} = \alpha_0 + \alpha_1 CE_{i,t-1} + \beta_i X + \delta_1 d_{2007} + \delta_2 d_{promote} + \delta_3 d_{2007} * d_{promote} + e_{i,t} \tag{4}$$

where i and t represent the different regions and years, respectively, and $CE_{i,t}$ is the total factor carbon emission efficiency. Considering the lagging effect of the carbon emission efficiency, the authors added the lag item $CE_{i,t-1}$ to the right of the equation. Moreover, as the *national program* was implemented in 2007, the time variable was defined as d_{2007}; if the time denotes the year before 2007, d_{2007} equals zero; otherwise, d_{2007} equals one. $d_{promote}$ is the dummy variable of the groups; if $d_{promote}$ equals one, it represents the treatment group, and if $d_{promote}$ equals zero, it represents the control group. δ_3 is the key coefficient of regression to be estimated; the value of the coefficient directly reflects the effects of the policy. X represents the other factors that affect the carbon emission efficiency. The authors reviewed the literature on carbon emission efficiency influencing factors and selected the level of economic development (*RGDP*), industrial structure (*STR*) and energy intensity (*EI*) as control variables (Liu *et al.*, 2017; Goh *et al.*, 2018).

4. Data

According to geographical location and political classifications, China is divided into three parts (eastern, central and western)[1], including 30 provinces, autonomous regions, and municipalities in the mainland of China excluding Hong Kong, Macau, Taiwan and Tibet. The sample period is from 2000 to 2014 and all data are collected from *China Energy Statistics Yearbook*, *China Labor Statistics Yearbook* and *Data Compilation of Electric Power Statistics.*

(1) In the evaluation of the total factor carbon emission efficiency, the authors use the annual data of capital stock, labor and energy consumption as the three input variables, GDP as the desirable output, and CO_2 as the undesirable output. Specific variables are defined as follows:

- The capital stock. This study adopts the "perpetual inventory method" to calculate the actual annual capital stock of each province (Shan, 2008). The formula is $K_{i,t} = (1-\delta_{i,t})K_{i,t-1} + I_{i,t}$, where $K_{i,t}$ is the capital stock in the tth year of province i, $I_{i,t}$ is the investment in the t^{th} year of province i and $\delta_{i,t}$ is the depreciation rate in the t^{th} year of province i (9.6 per cent). Year of 2000 is used as the base period for the conversion of the actual data with unit of 100m *yuan*.

- Labor. In this study, the year-end employee number of each province is used to express Labor *L*, and the unit is 10,000 people.
- Total energy consumption (*E*). This study takes the annual total energy consumption of each province to describe the total energy consumption, and the unit is 10,000 *ton* standard coal.
- Desirable output. The actual GDP in the year 2000 is used as the base period, and the unit is 100m *yuan*.
- Undesirable output. There was no official statement that announced the annual carbon emission amount of all provinces in China. However, various statistical methods of carbon emissions have already been presented by other scholars (Kaya, 1989; Zhou and Zhou, 2007). Carbon emissions are mainly generated from the combustion of fossil energy. Therefore, carbon emissions from each energy input can be estimated through multiplying the consumption of individual fossil energy input by its carbon emission coefficient (Li and Hu, 2012). The details are as follows:

$$EC = \sum_{i=1}^{7} EC_i = \sum_{i=1}^{7} (E_i - RME_i \times CFR_i) \times CF_i \times CC_i \times COF_i \times 3.67 \qquad (5)$$

where *EC* represents carbon emissions(10^4 *ton*) of DMU_j (j = 1,2,. . ., n); 3.67 is the conversion coefficient between carbon and carbon dioxide; i is the index of different types of fossil energies (that is, i=coal, coke, petrol, kerosene, diesel oil, fuel oil and natural gas total of 7 species); E_i represents the consumption of fossil energy i measured by 10^4 *ton* of standard coal equivalent; RME_i is the amount of energy consumption used as raw material; CFR_i is the carbon fixation rate; CF_i is the calorific value; CC_i is the carbon content; and COF_i is the oxidation factor. The exact value was derived from *The 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

(2) Control Variables(X):

- The real GDP per capita (*RGDP*) is used to measure the regional economic development, and the unit is 10,000 *yuan*;
- The ratio of the tertiary industry and the secondary industry output (*STR*) is used to represent the industrial structure index and rating in per cent;
- The ratio of the energy consumption and real GDP (*EI*) is used to represent the energy consumption intensity and the unit is *ton* standard coal/ten thousand *yuan*. Table I shows the descriptive statistics for the aforementioned variables.

5. Empirical results

5.1 Measuring regional total factor carbon emission efficiency

This section calculates the total factor carbon emission efficiency of China's 30 provinces from 2000 to 2014 using MaxDEA software. The results are presented in Figures 2 and 3.

Table I.
Descriptive statistics of variables

Varibale (Unit)	Obs	Mean	Std.Dev.	Min	Max
CE (C)	450	0.766	0.207	0.118	1.208
RGDP (Ten thousand *yuan*)	450	1.891	1.397	0.265	7.890
STR (%)	450	0.899	0.418	0.494	3.658
EI (*ton* standard/ten thousand *yuan*)	450	1.753	1.070	0.608	5.753

The total factor carbon emission efficiency is different among different provinces. The lowest values are from Shanxi (0.28), Inner Mongolia (0.42), Liaoning (0.47) and Ningxia (0.49), and these values were less than half of the values in efficient units, such as those for Guangdong and Beijing, where the efficiency value was the highest with an average value of 1.01 and 1.04, respectively.

Figure 3 shows the trend of the carbon emission efficiency in three major regions and nationwide during the period 2000 to 2014. The level of the national carbon emission efficiency was fluctuant, and the average was about 0.77. In 2004, the national carbon emission efficiency reached the peak point (0.83), but during the period 2005 to 2008, the value of efficiency decreased by 6.8 per cent. After 2008, the carbon emission efficiency recovered, but the upward trend did not last for a long time; the carbon emission efficiency decreased slightly again after 2011. During the sample period, the average of the carbon emission efficiency in the eastern region was the highest, followed by the central and western regions. The reasons for this difference may be related to the geographical location and industrial structure. On the one hand, most provinces with higher carbon emission efficiency that located in the eastern coastal areas can get better support (Pan *et al.*, 2015), such as capital, technology and information, than the inland areas due to their geographic advantages. To a certain extent, the spatiotemporal distance between the inland and coastal regions hinders the entry of capital, technology and information, which makes the carbon emission efficiency in inland areas remain at a lower level. On the other hand, most regions with higher carbon emission efficiency have a higher level of industrial structure and better market development than other regions. Since the reform and opening up, the southeastern coastal areas, such as Guangdong, Zhejiang and Shanghai, have implemented the "walking out" strategy. With the development of an export-oriented economy, these regions realize the

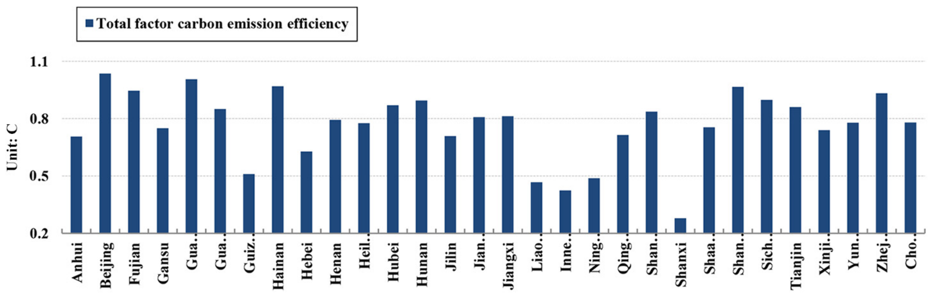

Figure 2. Average of total factor carbon emission efficiency by provinces, 2000-2014

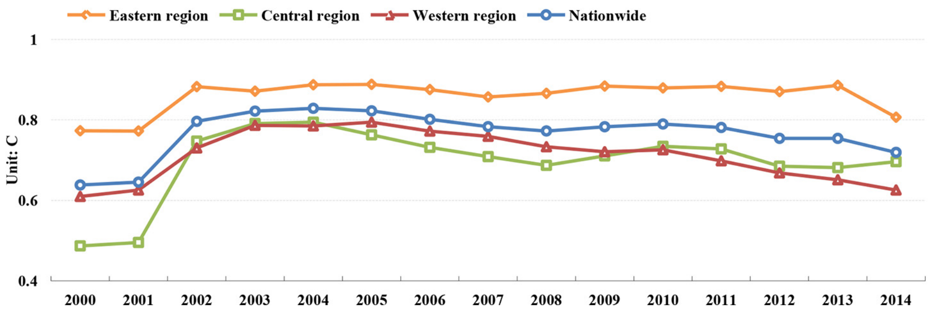

Figure 3. Tendency of regional and national carbon emission efficiency in China, 2000-2014

adjustment and optimization of the industrial structure. Relying on the highly standardized market economy, they transformed the model of extensive economic growth depending purely on the input of resources into intensive ones and developed an industrial structure mainly comprising the service and high-tech industries. However, the industrial development of the central and western regions is low, and the industrial structure is mainly composed of traditional resource-based industries (Zhang *et al.*, 2017).

A comparative analysis of the carbon emission efficiency average in the three major regions shows that the carbon emission efficiency in the central region follows an upward trend after 2007. In the eastern region, the level of upward trend is smaller than that of the central region, but in the western region, the carbon emission efficiency maintains a downward trend. Thus, the authors conducted a preliminary judgment. Considering the difference of economic development stage and economic structure among various regions, the effect of the *national program* implementation on the carbon emission efficiency may be distinct.

5.2 Effect evaluation of national program implementation

We empirically analyzed the effect of the *national program* on the carbon emission efficiency in accordance with the System Generalized Method of Moments estimator proposed by Arellano and Bover (1995) and Blundell and Bond (1998) using the software Stata 13.0. To distinguish the difference between different periods, the sample data are divided into two groups by the *Twelfth five-year planning*. One group is from 2000 to 2010, and the other group is from 2000 to 2014. Furthermore, the difference of the carbon emission efficiency among the three major regions in China is colossal. Meanwhile, the carbon emission efficiency in the eastern and central regions was improved in various degrees, but the upward trend in the western region is inapparent in the year 2007. Thus, we test the effect of environmental policy on the carbon emission efficiency in different regions. The results are shown in Table II.

(1) To illustrate that the system generalized method of moments (GMM) model constructed in this study is reasonable and advantageous, the authors present the regression results based on the traditional OLS model. As shown in the second column of Table II, the coefficients of $d_{2007}*d_{promote}$ do not pass the significance test, which implies that the traditional OLS model is not suitable to get an ideal result because of the existence of the carbon emission efficiency lag item.

(2) According to the AR and Hansen test results listed in the last three rows of Table II, the results of AR(2) prove that the null hypothesis is accepted at the 10 per cent significance level. Moreover, the values of the Hansen test are 1.000, which implies that the instrument variables are available. All regression coefficients of *L.CE* are in the interval [0 1], and pass the significance test at the 1 per cent level.

(3) The coefficients of $d_{2007}*d_{promote}$ directly reflect the effect of the *national program* on the carbon emission efficiency. The regression coefficients of $d_{2007}*d_{promote}$ in the two periods are greater than 0 and pass the significance test. Hence, the implementation of the *national program* has a significant positive effect on improving the carbon emission efficiency. Of note, the regression coefficient (0.264) in the 2000-2014 period is greater than that in 2000-2010 (0.127), which means that the regression result is steady in time dimension. Furthermore, the difference between the two regression coefficients reflects the fact that the implementation of the *national program* enhances the carbon emission efficiency effectively. However, the effect caused by the implementation of the *national program* is more

Table II. Estimation results

Variables	OLS	2000-2014	2000-2010	Eastern region	Central region	Western region
L.CE	0.780 (40.15)***	0.724 (14.05)***	0.740 (14.63)***	0.795 (10.09)***	0.672 (12.36)***	0.724 (44.30)***
RGDP	−0.001 (−0.23)	0.001 (0.17)	0.007 (0.92)	−0.001 (−0.18)	−0.015 (−0.79)	−0.028 (−2.79)***
EI	−0.026 (−6.85)***	−0.028 (−3.09)***	−0.025 (−3.31)***	−0.044 (−1.32)	−0.054 (−4.75)***	−0.028 (−8.66)***
STR	0.029 (3.79)***	0.036 (2.12)**	0.026 (1.59)	0.033 (3.24)***	0.019 (0.32)	−0.091 (−4.13)***
dpromote	5.37e − 17 (0.00)	−0.300 (−1.65)*	−0.156 (−1.86)*	−0.170 (−1.38)	−0.169 (−2.30)**	−0.010 (−4.13)
d2007	−0.039 (−4.26)***	−0.174 (−1.97)**	−0.100 (−2.78)***	−0.100 (−1.78)*	−0.113 (−2.45)**	−0.045 (−1.00)
d2007* dpromote	−0.003 (−0.25)	0.264 (1.62)*	0.127 (1.90)**	0.140 (1.32)	0.151 (2.22)**	0.013 (0.15)
c	0.221 (10.46)***	0.405 (3.65)***	0.318 (4.91)***	0.302 (2.78)***	0.457 (5.05)***	0.404 (8.51)***
Observations	840	840	600	336	252	252
AR (1)		−5.07 (0.000)	−5.02 (0.000)	−3.68 (0.000)	−2.99 (0.003)	−3.16 (0.002)
AR (2)		1.25 (0.210)	1.50 (0.134)	0.06 (0.954)	1.05 (0.295)	1.33 (0.184)
Hansen test		57.67 (1.000)	58.28 (1.000)	20.10 (1.000)	14.39 (1.000)	11.44 (1.000)

Notes: (1) The figures in parentheses close to the parameter estimates are t-statistics; (2) The figures in parentheses of AR test and Hansen test are probability; (3) ***, ** and * denote rejection of the null hypothesis at the 1, 5 and 10% levels, respectively outstanding in the long run. Therefore, to promote the process of energy saving and emission reduction through environmental policy, the government needs to take a long-term perspective.

(4) All the regression coefficients of $d_{2007} * d_{promote}$ in China's three major regions are greater than 0. However, the regression coefficients in the central region passed the significance test of the 5 per cent level, and those of the eastern region and western region do not. This result means that the effects of the *national program* on the carbon emission efficiency among different regions varied. After 2007, the *national program* has an obvious promotion effect on the carbon emission efficiency in the central region, but the upward trend in the western region is not. Furthermore, considering all factors, the carbon emission efficiency in the western region even shows a downward trend.

(5) The regression results of the control variables are also presented in Table II.

- The effect of economic development on the carbon emission efficiency is not significant on the national scale, but a 1 per cent improvement on the regional economic development will reduce the level of the carbon emission efficiency by 2.8 per cent in the western region.
- The adjustment of industrial structure has a positive impact on the carbon emission efficiency. The positive effect of adjusting the industrial structure on improving the carbon emission efficiency is significant in the eastern region. However, the pillar industry of the economic development has not been effectively established in the western region. The adjustment of industrial structure exerts an inhibiting effect on improving the carbon emission efficiency.
- Energy consumption is a main source of carbon emissions; thus, energy intensity dramatically inhibits the improvement of the carbon emission efficiency. In the central and western regions, a 1 per cent reduction of energy intensity will improve the carbon emission efficiency by 5.4 and 2.8 per cent, respectively.

5.3 Empirical test of the driving mechanism

To clarify the influence mechanism of environmental policy on the carbon emission efficiency, this section discusses the concept from the aspects of energy intensity, industrial restructuring, and economic development. The results are shown in Table III. Of note, the results were calculated using the actual average growth rate of each variable.

First, in terms of energy intensity, the DID result is −0.8 per cent. Specifically, the energy intensity in the two groups decreases after 2007, but the energy intensity in the treatment group decreased by 4.78 per cent, which is higher than control group. It can be concluded that the environmental policy has an effective decreasing effect on the energy intensity, thereby improving the carbon emission efficiency. On the basis of the existing conclusions about the effect of energy intensity on the carbon emission efficiency (Table II), the authors find that the effect of energy intensity on the carbon emission efficiency is the most

Table III.
DID estimate results of control variables

Variable	Treatment group 2000-2006	Treatment group 2007-2014	$\triangle I1$	Control group 2000-2006	Control group 2007-2014	$\triangle I2$	$\triangle I1 - \triangle I2$
EI	0.00022	−0.04782	−0.04805	0.00022	−0.03954	−0.03976	−0.00829
STR	−0.00228	0.02445	0.02674	−0.00228	0.01814	0.02043	0.00631
RGDP	0.11154	0.10305	−0.0085	0.11154	0.10368	−0.00786	−0.00063

significant in the central region, followed by the western region, whereas in the eastern region, it is statistically insignificant. Therefore, we point out that the environmental policy improves the carbon emission efficiency by lowering energy intensity in the central region, but the effect is relatively weak in the eastern region.

Second, from the perspective of industrial restructuring, the DID result is 0.6 per cent, which implies that the implementation of the *national program* has effectively sped up the progress in industrial restructuring, and the "Suppress the Second Industry and Develop the Third Industry" policy has improved the carbon emission efficiency effectively. On the basis of the effect of industrial structure adjustment on the carbon emission efficiency in the three regions, the authors can conclude that the implementation of the *national program* generates positive effects on improving the carbon emission efficiency through boosting the process of industrial structure adjustment in the eastern region, while it generates negative ones in the western region.

Finally, from the perspective of economic development, the implementation of the *national program* slows down economic growth. In particular, as China entered into a new normal age, the government concentrated on industrial structure adjustment and development with low carbon emission. However, the underdeveloped regions, such as the western regions, try to catch up with the better-developed regions based on the consumption of energy resources, thereby possibly expanding the gap of the carbon emission efficiency among different regions.

6. Conclusions

Improving the carbon emission efficiency by implementing environmental policy is helpful to build an ecologically civilized society when faced with energy and environmental constraints. The *national program* is one of the important guiding policies for easing carbon emission problem. The total factor carbon emission efficiency of 30 provinces from 2000 to 2014 was calculated using the directional distance function. A DID model was constructed to analyze the emission reduction effect since the implementation of the *national program* in 2007 objectively. The results are as follows:

First, the carbon emission efficiency was 0.766 on average, fluctuated in different years, and was significantly different among the three major regions in China. As the environmental policy was implemented in 2007, the carbon emission efficiency has been significantly improved, and the positive effect in different periods varied. Furthermore, improving the carbon emission efficiency caused by the implementation of the *national program* in the central region was essential, but the effects are insignificant in the eastern and western regions. Second, the environmental policy improves the carbon emission efficiency through the reduction of energy intensity and adjustment of the industrial structure, but the influence of economic growth rate on the carbon emission efficiency is relatively weak. On this basis, this study offers some useful policy recommendations.

(1) At present, the development of economy in China depends on the input of energy resources, and carbon emission will continue to grow in the future for a long period. Reducing energy intensity is an effective way of improving the carbon emission efficiency, and this strategy needs to be closely monitored by the government. In addition, renewable energy is essential to improve the carbon emission efficiency, but currently, the proportion is relatively small in China. Thus, the development of renewable energy should satisfy the new demand first, and the replacement of the fossil fuels will follow subsequently.

(2) In China, high-energy consuming industries still account for a major proportion, and the output of the second industries constitutes nearly 40 per cent of GDP. Economic development highly depends on energy consumption. In addition to

emphasizing on the economic reform on supply-side, the government should adopt an adjustment measure for industrial structure upgrading, eliminate parts of energy-intensive industries and fully control carbon emission on the demand side.

(3) The key to developing an ecological and low-carbon economy is to transform the government's development concepts. According to the development idea of "Green, Recyclable, and Low-carbon" implemented in the 18th National Congress of the Communist Party of China, the government at all levels should strike a balance between economic interests and environment degradation, change the energy consumption pattern and economic development mode and stress on the responsibility system of energy conservation and carbon emission reduction.

(4) Considering the different economic development stages, industrial structure, technology innovation and policy guidance in different regions, the challenges for different regions to reduce carbon emission are different under the drive of a unitary policy. Thus, the implementation of environmental policies is supposed to avoid the "one size fits all" phenomenon. The local governments should take their own economic foundations and advantages into consideration and adjust policy practices timely and effectively.

Note

1. Regional division: following the traditional method, China is divided into the East, Central and West regions. The East includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; The Central includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan; and the West includes Sichuan, Chongqing, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi and Inner Mongolia.

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