Threshold Effect and Regional Differences of Environmental Regulation on Carbon Emission

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Abstract. The increasingly serious environmental and climate problems have attracted the attention of many countries in the world. As a country with a large amount of carbon emissions, with the economic growth, the pressure of carbon emission reduction is increasing. Starting from the basic issue of the impact of environmental regulation on carbon emissions, this paper takes energy intensity, industrial structure and FDI as threshold variables, environmental regulation as the core explanatory variables, and uses the panel threshold model to analyze the threshold effect of environmental regulation on carbon emissions in China and the regional differences in the East, middle and West.

1. Introduction
The increasingly serious climate problem has attracted the attention of all countries in the world. At the 2015 Paris climate conference, it is planned that the intensity of CO₂ emission will reach the peak by 2030. In order to realize the commitment, our government has formulated a series of environmental regulation measures to reduce CO₂ emissions. Therefore, the implementation of environmental regulation policies will not only not reduce CO₂ emissions, but also further increase CO₂ emissions, that is, the "green paradox" theory. How can environmental regulation promote or restrain carbon emission reduction? Is the impact of environmental regulation on carbon emissions the same in different regions? The answer to this question is of great significance to the formulation and implementation of China's environmental regulation policy.

At present, scholars at home and abroad have done a lot of research on the mechanism and effect of environmental regulation. Some scholars [1] think that environmental regulation can promote carbon emission, that is, "green paradox" effect. However, some scholars [2] think that environmental regulation has an inhibitory effect on carbon emissions, that is, backward forcing emission reduction. In addition, some scholars [3] have studied the impact of different regional environmental regulations on foreign direct investment (FDI). The results show that environmental regulations have negative effects on the introduction of foreign investment in different regions, and the impact of different regions is different. In the study of the path and effect of environmental regulation on carbon emission reduction, Xu Yingzhi [4] found that environmental regulation has a direct effect on CO₂ emissions, but also has an indirect effect through industrial structure adjustment. Therefore, three variables, energy intensity, industrial structure and FDI, are selected as threshold variables in this study. The panel threshold model of Hansen [5] is used to analyze the nonlinear relationship between environmental regulation and CO₂ emissions. At the same time, due to the vast territory of our country, there are great differences in resource endowment,
industrial structure and CO$_2$ emission in different regions. Therefore, it is necessary to consider
the regional heterogeneity of environmental regulations on carbon emissions, so as to formulate targeted
policies to achieve emission reduction goals.

2. Research methods

2.1. Threshold model construction

In the study of threshold effect, scholars often use Hansen[6] to put forward panel threshold model to
analyze the relationship between threshold variables and independent variables. In this study, panel
threshold model is used to analyze the impact of three threshold variables, energy intensity, industrial
structure and FDI, on CO$_2$ at different stages

Regression model:

$$
\ln CO_{2it} = \alpha + \beta_1 \ln P_{it} + \beta_2 \ln A_{it} + \beta_3 \ln URB_{it} + \rho_1 \ln ER_{it} \times I(th_{it} \leq \gamma_1) + \\
\rho_2 \ln ER_{it} \times I(\gamma_1 < th_{it} \leq \gamma_2) + \rho_3 \ln ER_{it} \times I(th_{it} > \gamma_2) + \epsilon_{it}
$$

(1)

In the formula, $i$ and $t$ respectively represent the region and time; CO$_{2it}$ is the carbon emission of each
province over the years, 10$^4$ T; $P_{it}$ is the population scale, 10$^4$ people; $A_{it}$ is the economic level, yuan;
URB$_{it}$ is the urbanization level of each province,%; Because this study mainly discusses the threshold
effect of environmental regulation on carbon emissions, ER$_{it}$ represents environmental regulation; $th_{it}$ is
the threshold variable; $\gamma_1$ and $\gamma_2$ are the threshold values; $I(\gamma_1 < th_{it} \leq \gamma_2)$ is the exponential function.

When the condition is true, the value is 1, otherwise it is 0; $\epsilon_{it}$ is the random error term; $\alpha I$ is the
constant term; $\rho I$ is the coefficient to be estimated

2.2. Variable selection and data source

Explained variable: carbon dioxide emissions (CO2), using the regional CO2 emissions over the years
as a measure of the scale of carbon emissions. The main source of carbon emission is the consumption
of fossil energy. The energy consumption of coal, oil and natural gas is converted into standard coal
consumption, and the corresponding carbon emission is calculated by carbon emission coefficient. Core
explanatory variable: Environmental Regulation (ER). Considering the availability of data, environmental
regulation is measured by the proportion of industrial pollution control investment in the industrial
added value of each province.

Other explanatory variables: population size (P), taking the total population of each province over
the years as the measurement index of population size; Economic level (A), select the per capital GDP
of each province as the index to measure the regional economic level; Urbanization level (URB) refers
to the proportion of urban population in the total population in each region.

Threshold variables: energy intensity (EI), which is expressed by the ratio of the consumption of coal,
oil and natural gas to the GDP, that is, the energy consumption per unit GDP; Industrial structure (IS). Because the secondary industry accounts for a large proportion and consumes a lot of energy, this study
uses the ratio of the output value of the secondary industry to GDP to measure the industrial structure;
FDI is measured by the amount of foreign direct investment actually used by each region.

2.3. Analysis of threshold regression results

According to the corresponding thresholds of the three threshold variables, the threshold model is
estimated with energy intensity, industrial structure and FDI as the threshold variables, in order to
explore the threshold effect of environmental regulation on carbon emissions and the differences among
the three regions.
3. Empirical results and analysis

3.1. Stability test of variables
The instability of series may lead to the existence of pseudo regression in panel data, while the threshold regression model requires the variables to be stable. Therefore, it is necessary to test the stability of data series before empirical regression. Considering the high data requirements of the alternative hypothesis of LLC test, IPS test and Fisher ADF test are selected to test the unit root of each variable in this study. The original hypothesis is that there is unit root in the data, and the alternative hypothesis is that there is no unit root. The test results are shown in Table 1. It is found that the test results of most of the original data cannot reject the original hypothesis that there is unit root, which is non-stationary. However, after taking the first-order difference, the original hypothesis is rejected at the significance level of 5%, and the data of the first-order difference can be considered as stable.

Table 1. Unit root test

| Unit root test | Variable | IPS | Fisher-ADF | Variable | IPS | Fisher-ADF |
|----------------|---------|-----|------------|---------|-----|------------|
|                | ln CO2  | -2.669*** | 96.145*** | ln CO2  | -4.642*** | 128.471*** |
| level          | ln P    | -1.219  | 98.357*** | ln P    | -4.458*** | 123.005**  |
|                | ln A    | -9.544*** | 187.663   | ln A    | -3.710*** | 112.564    |
|                | ln EI   | 8.170   | 19.443     | ln EI   | 7.009***  | 168.336*** |
|                | ln URB  | 1.188**  | 76.703*    | ln URB  | -8.252*** | 185.028*** |
|                | ln IS   | 0.452   | 77.423     | ln IS   | -7.554*** | 182.047*** |
|                | ln ER   | -0.864  | 68.579     | ln ER   | -9.830*** | 209.850*** |
|                | ln FDI  | -0.868  | 91.242***  | ln FDI  | -7.712*** | 161.871*** |

3.2. Analysis of threshold regression results
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3.3. Regression analysis of energy intensity
When the threshold variable is energy intensity, there is a double threshold effect in the east, central and west. As can be seen from table 3, the two thresholds for the impact of environmental regulations on carbon emissions in the east are 0.6325 and 1.1118 respectively. When the energy intensity is less than 0.6325, the elastic coefficient of environmental regulation is 0.081 and the significance level is 5%, indicating that environmental regulation plays a small role in increasing carbon emissions when the energy intensity is low. In the central region, when the energy intensity is less than 0.8146 and the significance level is 5%, the elasticity coefficient of environmental regulation is -0.0304. When the energy intensity is between 0.8146 and 1.3920, and when the significance level is 5%, the elasticity coefficient of environmental regulation is -0.063. When the energy intensity is greater than 1.3920, the elastic coefficient of environmental regulation is -0.100 and the significance level is 5%. The two thresholds of the impact of environmental regulation on carbon emissions in western China are 1.2008 and 2.1533 respectively. There is an inverted u-shaped relationship between environmental regulation and carbon emissions. When the energy intensity is greater than 2.1533, the elasticity coefficient of environmental regulation is negative and the significance level is 5%.
### Table 2. Threshold regression results

| Region | Energy intensity | Industrial Structure | FDI |
|--------|------------------|----------------------|-----|
|        | Parameter        | Estimation Results   |      | Variable        | Estimation Results   |      | Variable        | Estimation Results   |
| East   | ln P             | 0.743* (0.06)        |      | ln P            | 633*** (0.06)        |      | ln P            | 1.361* (0.08)        |
|        | ln A             | 1.057* (0.05)        |      | ln A            | 0.059 (0.08)         |      | ln A            | 0.177 (0.12)         |
|        | ln URB           | −1.609 (0.23)        |      | ln URB          | 2.079*** (0.25)      |      | ln URB          | 0.444 (0.30)         |
|        | ln ER, q1<0.205  | 0.081** (0.02)       |      | ln ER, q2=0.797 | 0.034 (0.02)         |      | ln ER, q3=14.958| 1.0 (0.03)           |
|        | ln ER, q2=0.205- | 0.039*** (0.02)      |      | ln ER, q3=14.958| 0.10 (0.02)          |      | ln ER, q3=14.958| 0.039** (0.04)       |
|        | ln ER, q3>0.749  | −0.100*** (0.02)     |      | ln ER, q3>0.749 | 0.444*** (0.06)      |      | ln ER, q3>0.749 | 0.321 (0.15)         |
|        | ln ER, q1>0.331  | 0.002** (0.02)       |      | ln ER, q1>0.331 | 0.001 (0.02)         |      | ln ER, q1>0.331 | 0.026** (0.04)       |
|        | ln ER, q1<0.331  | −8.806 (0.52)        |      | ln ER, q1<0.331 | −4.273*** (0.68)     |      | ln ER, q1<0.331 | −3.721 (1.03)        |
|        | ln P             | 0.619* (0.06)        |      | ln P            | 1.693*** (0.10)      |      | ln P            | 1.254 (0.19)         |
|        | ln A             | 0.815*** (0.05)      |      | ln A            | 0.410*** (0.06)      |      | ln A            | 0.897 (0.12)         |
|        | ln URB           | −0.708 (0.17)        |      | ln URB          | 0.382* (0.20)        |      | ln URB          | −2.028 (0.42)        |
| Central| ln ER, q1<0.205  | −0.0304** (0.02)     |      | ln ER, q1<0.205 | 0.015 (0.03)         |      | ln ER, q1<0.205 | 0.296** (0.04)       |
|        | ln ER, q2=0.797  | 0.063*** (0.02)      |      | ln ER, q2=0.797 | 0.032 (0.03)         |      | ln ER, q2=0.797 | 0.226** (0.04)       |
|        | ln ER, q3=14.958 | 0.100*** (0.02)      |      | ln ER, q3=14.958| 0.018*** (0.02)      |      | ln ER, q3=14.958| 0.169** (0.05)       |
|        | ln ER, q3>0.749  | −5.229 (0.56)        |      | ln ER, q3>0.749 | −0.064*** (0.63)     |      | ln ER, q3>0.749 | −10.485 (1.44)       |
|        | ln P             | 1.204 (0.18)         |      | ln P            | 1.156*** (0.05)      |      | ln P            | 0.540* (0.1)         |
|        | ln A             | 0.414 (0.11)         |      | ln A            | 0.367*** (0.08)      |      | ln A            | 0.232 (0.20)         |
|        | ln URB           | 1.801 (0.34)         |      | ln URB          | 0.910*** (0.27)      |      | ln URB          | 2.125 (0.57)         |
| West   | ln ER, q1<0.205  | 0.204** (0.02)       |      | ln ER, q1<0.205 | 0.118*** (0.02)      |      | ln ER, q1<0.205 | 0.136* (0.04)        |
|        | ln ER, q2=0.797  | 0.107*** (0.02)      |      | ln ER, q2=0.797 | 0.085*** (0.01)      |      | ln ER, q2=0.797 | 0.201** (0.04)       |
|        | ln ER, q3=14.958 | −0.024** (0.02)      |      | ln ER, q3=14.958| 0.051*** (0.02)      |      | ln ER, q3=14.958| 0.064** (0.04)       |
|        | ln URB           | −2.926 (1.37)        |      | ln URB          | −2.923*** (0.81)     |      | ln URB          | 4.692 (2.03)         |

### 3.4. Regression analysis of industrial structure

Taking industrial structure as threshold variable, we can find that there are double threshold effects in the eastern region. When the industrial structure is less than 0.2679, the impact of environmental regulation on carbon emissions is positive; when the industrial structure is greater than 0.5661, the impact coefficient of environmental regulation on carbon emissions becomes negative, which shows that the impact of environmental regulation on carbon emissions in the eastern region is inverted U-shaped curve. Economic growth will not only affect the scale effect of environmental quality, but also its compound effect.
3.5. Regression analysis of FDI

When FDI is taken as the threshold variable, there is a double threshold effect on carbon emissions in the East, middle and west regions, which is significant at the level of 5%. In the eastern region, when the actual use of FDI is less than 134.38 × 108 yuan, the elasticity coefficient of environmental supervision is 0.133; when the actual use of FDI between 134.38 × 108 yuan and 1159.40 × 108 yuan, the elasticity coefficient of environmental supervision is 0.039; when FDI is at a high level, it has a strong attraction to foreign investors. It can effectively absorb the advanced production technology and pollution control technology of foreign-funded enterprises, and FDI has a greater technology spillover effect. When the actual use of FDI in the central region is lower than 313.46 × 108 yuan, the elastic coefficient of environmental regulation is 0.296; when the actual use of FDI is between 313.46 × 108 yuan and 1371.50 × 108 yuan, the elastic coefficient of environmental regulation is 0.226; when the actual use of FDI is higher than 1371.50 × 108 yuan, the elastic coefficient of environmental regulation is 0.169. When the actual utilized foreign capital in the western region is less than 5.80 × 108 yuan, the elastic coefficient of environmental regulation is 0.136; when the actual utilized foreign capital is between 5.80 × 108 yuan and 287.63 × 108 yuan, the elastic coefficient of environmental regulation is 0.064; when it is greater than 287.63 × 108 yuan, the elastic coefficient of environmental regulation is 0.064.

4. Conclusions and suggestions

Due to the large regional differences in China, energy conservation and emission reduction strategies should be formulated according to local conditions, and appropriate environmental regulation level should be determined according to the actual situation of the region at present. Environmental regulation in the eastern region cannot promote carbon emission reduction in such aspects as energy intensity, industrial structure and medium and low threshold of FDI. It is necessary to improve the emission reduction potential through industrial restructuring, make use of existing advantages, further optimize the energy structure and vigorously develop renewable energy.

For the central region, under the influence of energy intensity, environmental regulation has an inhibitory effect on carbon emissions, while under the influence of industrial structure and FDI, environmental regulation has a promoting effect on carbon emissions.

In the western region, due to the influence of industrial structure and FDI, environmental regulation is difficult to play a role in carbon emission reduction.

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