An empirical study of environmental regulation on carbon emission efficiency in China

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Abstract

Based on the full-sample panel data from 23 provinces and cities in China from 2013 to 2020, this paper studies the influences of environmental regulations on regional carbon emission efficiency in China under the background of opening carbon emission trading after dividing the country into high, medium, and low emission areas with emission quantity as the classification standard and constructing a regression model. The experiment reveals that the environmental regulation strength and carbon dioxide emission efficiency are positively correlated with each other in the first place. Second, there exists a positive correlation between environmental regulation strength and carbon dioxide emission efficiency in different emission regions, while in terms of the impact of environmental regulation on carbon emission efficiency, it influences the medium emission areas most, followed by low emission areas, and the high emission areas to the least. Then, current domestic environmental regulation is effective and plays a positive role in improving carbon emission efficiency and promoting the development of a low-carbon economy in China.

KEYWORDS

carbon emission efficiency, certification emission reduction, environmental regulation

1 INTRODUCTION

CO\(_2\) emissions are increasing day by day with China’s accelerated industrialization and rising living standards. China’s carbon emissions will be 10.523 billion tons, accounting for 31% of global carbon emissions, up 5.2% year on year in 2021. The Chinese government attaches great importance to it, continuously increasing its environmental management efforts and formulating a series of environmental regulation policies to promote energy saving and emission reduction when faced with the ecological crisis caused by carbon emissions. Carbon emission behavior has a strong negative externality in the process of economic development, and there is a failure of the market mechanism in reducing carbon emissions and improving the efficiency of energy carbon emissions, which requires the government to carry out environmental regulation as a necessary supplement and an important means to compensate for the market failure. Since the carbon emission efficiency (CE) varies among regions in China, the impact of various environmental regulation tools on CE varies among regions in China. Therefore, this paper is a breakthrough from the existing studies that have mostly focused on the quantitative measurement, dynamic assessment, and influencing factors of CE, and also provides some reference for local governments in China.
to formulate targeted environmental policies, and has certain theoretical and practical significance for promoting high-quality development in various regions of China for theoretical and practical significance for promoting high-quality development in China through an empirical study of CE in China's high, medium, and low carbon emission regions from the perspective of environmental regulation.

2 | THE LITERATURE REVIEW

2.1 | A review of environmental regulation tools

The current research on environmental regulation is mainly studied on the selection and measurement of environmental regulation tools. Thomas finds no adverse effects of environmental regulation on output growth in the metalworking industry by examining the effects of air quality regulation on output growth in the industry. Greenstone and List reach the same conclusion. Ren and Qu explore how environmental regulation acts on interprovincial ecoefficiency from three perspectives and find that different environmental regulation tools have different effects on ecoefficiency in different regions. Li and Xiao study the China's A-share listed firms in the heavy pollution industry and found that different nature of environmental regulation tools has opposite effects on the results and on firms.

2.2 | A review of CE

There are two general approaches to measuring carbon efficiency: the single-factor perspective and the full-factor perspective. The single-factor perspective generally uses a single indicator to measure CE, and Kaya and Yokobori argue that CE can be expressed in terms of carbon productivity, that is, the economic value created per unit of carbon emission in a certain period of time. Wang and colleagues measure CE by the inverse of carbon dioxide emissions per unit of gross domestic product (GDP) as the emissions efficiency of countries along “the Belt and Road.” The total factor perspective generally uses data envelopment analysis (DEA) and stochastic frontier analysis, and Choi et al. and Cecchini Lucia et al. use the SBM-DEA model to measure CE.

2.3 | Environmental regulation and CE

On the impact of environmental regulation on energy carbon efficiency, there exist two views: “green paradox” and “forced emission reduction.” Sinn was the first to propose the concept of “green paradox,” arguing that as environmental regulations become more stringent, energy openers will accelerate the extraction of fossil energy, which will lead to a sharp increase in carbon emissions and is not conducive to the improvement of carbon efficiency. Wang and Li also support the “green paradox” in their empirical studies. Van der Ploeg and Withagen argue that the “green paradox” does not occur when the price of clean energy alternatives to fossil fuels is cheaper relative to marginal global warming losses. He and Zhang also show that environmental regulation is conducive to the improvement of CE, and the effect is very obvious. Facing the two mechanisms of environmental regulation on carbon efficiency, many scholars suggest that the effect is not a simple linear relationship. Zhang and Wei argue that environmental regulation has a “U-shaped” effect on carbon efficiency, that is, there is a threshold for the enhancement effect of environmental regulation, and the dominant force of the effect evolves from the “green paradox” effect to the “inverted paradox” effect as the intensity of environmental regulation increases. The empirical studies by Ma and Dong and Li and Ma confirm this view.

In order to explore the influencing factors of the CE, most of the existing literature focuses on the direct effect of environmental regulation and technological progress on energy efficiency, although there are abundant studies on the quantitative measurement. However, the literature has mostly analyzed the direct effects of environmental regulations and technological progress on energy carbon efficiency. There is also a lack of analysis of the indirect effect of environmental regulation on energy and carbon efficiency. In view of this, this paper incorporates environmental regulation, technological progress, and carbon efficiency into the same framework using indicators that also include economic growth, population factor investment, energy prices, and technological progress. The author clarifies the mechanisms of the three effects and proposes corresponding policy recommendations by investigating the direct effect of environmental regulation on carbon efficiency and the indirect effect of environmental regulation on carbon efficiency through the intermediary of technological progress.

3 | MECHANISM OF ENVIRONMENTAL REGULATION ON CE

The sum of the various direct and indirect effects determines the final effect results of environmental regulation on energy efficiency. In the process of
environmental regulation on energy efficiency, the formulation and implementation of environmental regulation policy tools play a vital role and its rational application is conducive to realizing the dual effect of environmental protection and energy efficiency improvement. Thus, the function mechanism of environmental regulation on energy efficiency through four indirect transmission channels of the environmental cost, technological innovation, industrial structure, and foreign direct investment is analyzed in detail in this thesis.

(a) From the aspect of the corporate environmental cost, environmental regulations will increase the short-term environmental costs of enterprises, which will occupy their total production cost, reduce resources available to improve energy efficiency, and lead to lower energy efficiency. However, considering in the long run, after the internalization of the external environmental cost, enterprises will introduce advanced production technologies and processes, orienting to ultimate energy efficiency improvement.

(b) From the view of technological innovation, on the one hand, intensifying environmental regulation will take up corporate research and development expenditure, thus affecting the investment in technological innovation and dying down energy efficiency. On the other hand, the augmentation of environmental governance costs will impel companies to make technological innovations the other way around, ameliorate the production process, and give energy efficiency a shot in the arm at the end.

(c) From the aspect of the industrial structure, environmental regulations affect the adjustment of industry structure from five aspects, namely, consumer demand, investment demand, industry entry barriers, enterprise exit mechanism, and industry shifts. Optimizing and upgrading industry structure empowers energy efficiency to advance ahead, which is true especially when the economic structure changes from the industry-led secondary industry to the service industry-led tertiary industry since the optimization of industrial structure can effectively promote the improvement of energy efficiency due to the overall high added value of the manufacturing and services industries of emerging technologies, low energy consumption and slight pollution degree.

(d) Considering the perspective of foreign direct investment, the influential results of environmental regulations on foreign direct investment are uncertain, which means fortifying environmental regulations may directly restrain foreign direct investment or may increase direct investment from environment-friendly foreign enterprises. The specific functions of foreign direct investment on energy utilization efficiency can be divided into the following aspects, improving energy efficiency with the help of technical effect and reducing it by virtue of structural effect. However, the final effect outcome depends on the sum of both technical and structural effects.

4 | DATA SOURCE, VARIABLE SELECTION, AND MODEL CONSTRUCTION

4.1 | Data source

The input and output data of 23 provinces in China from 2013 to 2020 are selected for measurement and calculation. Thereinto, $\text{CO}_2_{it}$ stands for the carbon dioxide emissions of Province $i$ in the $t$-year. Its logarithmic form is the explained variable measured in 10,000 tons, and the data are derived from “China Energy Statistical Yearbook.” $\text{ERS}_{it}$ refers to the environmental regulation variable and $\text{EP}_{it}$ indicates the relative price of energy, that is, the ratio of the raw material, fuel, and power purchase price index to the general price level. The data of $\text{ERS}_{it}$ and $\text{EP}_{it}$ also comes from “China Energy Statistical Yearbook.” $\text{L}_{it}$ shows the quantity of employment of Province $i$ in $t$-year, with data taken from “China Population & Employment Statistics Yearbook.” $\text{GDP}_{it}$ is the provincial income of Province $i$ in the $t$-year, $\text{IG}_{it}$ demonstrates the proportion of the secondary industry in the total value of GDP product, $\text{RD}_{it}$ is the proportion of the national R & D investment in GDP, $\text{TRADE}_{it}$ is the proportion of total exports in GDP, with data originating from “China Statistical Yearbook.” $\text{EY}_{it}$ is the proportion of total coal consumption in total energy consumption in the $t$-year of Province $i$, and the data are all derived from “China Energy Statistical Yearbook.”

4.2 | Variable definition and measure

4.2.1 | CE

In allusion to CE, relevant scholars usually adopt the input-output efficiency estimation method, which is mainly divided into single elements and multiple elements. Single factor indicators are mostly evaluated by single factors such as the ratio of carbon emission to energy consumption or GDP, while multifactor CE is widely used for fully considering the combined role of capital, energy, and labor in the process of economic activities. Related scholars mostly employ the stochastic frontier analysis (SFA) method, the DEA, and the...
improved model for the measurement. This thesis adopts the multielement measure method.

### 4.2.2 Environmental regulation strength (ERS)

There is no uniform standard of how to measure environmental regulation and measurement considerations vary across counties. A large number of scholars have also studied how to measure environmental regulation. Ederington and Miner\(^{16}\) measured environmental regulation through the proportion of investment costs in the total cost of an enterprise. Cole and Elliott\(^{17}\) considered the pollutant emission of different enterprises and believed that the strength and type of pollutant emission can be taken as the measurement standard of environmental regulation. Lu\(^{18}\) analyzed the environmental regulation factors based on the existing relevant indicators of CIESIN and obtained the relationship between them and the national income. Fu and Li\(^{19}\) conducted a field investigation to analyze the environmental pollution situation in different industries and obtained relevant data, and then used a weighted average analysis method for these data. The process is as follows:

At the very beginning, five kinds of pollutants needed for reference were determined and then the data in allusion to each pollutant were gathered and sorted out. The five pollutant indicators include industrial carbon dioxide emissions, industrial wastewater emissions, industrial sulfur dioxide emissions, industrial dust emissions, and industrial solid waste production. Then, the different index units of five pollutants made it difficult to be directly combined for application, the five pollutants were standardized and the formula is as follows:

\[
UE_{ij}^S = \frac{UE_{ij} - \min(E_j)}{\max(E_j) - \min(E_j)}.
\]

Thereinto, \(UE_{ij}\) is the actual emission value of Pollutant \(j\) in Province \(i\), \(\min(E_j)\) is the minimum emission value of Pollutant \(j\), \(\max(E_j)\) is the maximum emission value of Pollutant \(j\) and \(UE_{ij}^S\) is the linear normalized value of the Pollutant \(j\) obtained in Province \(i\).

Finally, the linear normalized values of the five pollutants were added and averaged (equal-weighted) to obtain the annual environmental regulation intensity \(ERS_{it}\) of each province.

Thus, the comprehensive index method of Fu and Li\(^{19}\) is used to describe the strength of environmental regulation in this paper.

4.2.3 Other control variables

Currently, scholars mainly focus on studying the energy intensity of Chinese energy, that is, total per-capita energy consumption divided by per-capita GDP. While many of them are convinced that the reduction of energy intensity is the result of multi-reasons such as the improvement of technology level and the transformation of energy structure, there are few scholars who take the effect of energy prices on energy intensity into consideration. With regard to the general relationship between energy intensity and carbon dioxide emissions, this thesis will consider the impact of Chinese energy prices on carbon dioxide into account, and since China has regulated the prices of coal, oil, and natural gas, the ratio of the energy price to the general price level is used as a proxy variable of the relative price of domestic energy\(^{20}\) in this thesis when studying energy prices. Thereinto, energy prices are usually replaced by the raw materials, fuel, and power purchase price index, and the price of this energy source is expressed as \(EP_{it}\).

Furthermore, the three decades of China’s reform and opening up have witnessed the rapid growth of China’s export trade corresponding to its high-speed economic growth. Although China has become the largest exporter in the world, a few researchers follow the impact of China’s export trade on carbon dioxide emissions. Some research in recent years illustrates that carbon dioxide emissions from goods produced by China and exported to other countries account for about one-third of its total carbon dioxide emissions.\(^{21}\) Yang et al.\(^{22}\) further show that China’s implied carbon dioxide emissions from its exports had increased by 11% from 2002 to 2007. What is more, in 2007, China’s implied carbon dioxide exports accounted for 50% of China’s domestic carbon dioxide emissions. Therefore, this thesis adds export as a factor affecting carbon dioxide to the measurement model, expressed by \(TRADE_{it}\).

In addition, since coal has higher carbon emissions factors than oil and natural gas, that is, 1.2 and 1.6 times that of oil and natural gas, respectively, it is necessary to consider the impact of energy consumption structure on carbon dioxide emissions, that is, the proportion of coal use in the total energy consumption, expressed in \(EY_{it}\) in this study.

4.2.4 Summary of the variables

The variables used in this paper are summarized in Table 2.
TABLE 1  Intensity of environmental regulations in the sample areas for the years 2015–2020

| Areas        | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  | 2020  |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Beijing      | 1.152 | 0.237 | 1.011 | 0.973 | 0.865 | 0.738 | 0.760 | 0.627 |
| Tianjin      | 2.224 | 2.321 | 2.976 | 2.435 | 2.344 | 2.877 | 2.488 | 2.080 |
| Hebei        | 3.332 | 2.321 | 3.110 | 3.222 | 4.120 | 4.251 | 4.219 | 4.411 |
| Shanxi       | 4.365 | 6.324 | 6.053 | 6.094 | 5.976 | 6.002 | 6.036 | 6.687 |
| Inner Mongolia | 2.121 | 2.336 | 2.215 | 2.326 | 2.558 | 2.910 | 3.447 | 4.320 |
| Liaoning     | 2.987 | 3.101 | 3.725 | 3.929 | 3.545 | 3.670 | 3.420 | 3.152 |
| Jilin        | 2.110 | 2.032 | 2.125 | 2.018 | 2.032 | 2.232 | 2.570 | 2.559 |
| Heilongjiang | 3.001 | 3.102 | 3.706 | 3.474 | 3.240 | 2.871 | 2.529 | 2.378 |
| Shanghai     | 2.012 | 2.410 | 2.536 | 2.250 | 1.869 | 1.646 | 1.474 | 1.255 |
| Jiangsu      | 3.214 | 3.115 | 3.657 | 3.775 | 3.575 | 3.898 | 3.684 | 3.220 |
| Zhejiang     | 3.021 | 3.004 | 3.042 | 3.062 | 2.789 | 2.891 | 2.580 | 2.424 |
| Anhui        | 5.073 | 5.032 | 5.962 | 6.219 | 5.588 | 5.444 | 5.454 | 5.089 |
| Fujian       | 2.541 | 2.014 | 2.581 | 3.503 | 3.682 | 3.884 | 3.831 | 3.664 |
| Jiangxi      | 3.224 | 3.024 | 3.437 | 4.354 | 4.737 | 4.316 | 4.777 | 4.483 |
| Shandong     | 3.241 | 3.057 | 3.638 | 3.645 | 3.352 | 3.393 | 3.552 | 3.302 |
| Henan        | 3.014 | 3.220 | 3.289 | 3.558 | 3.412 | 3.379 | 3.690 | 3.457 |
| Hubei        | 3.254 | 3.557 | 3.976 | 3.910 | 3.785 | 3.621 | 3.632 | 3.387 |
| Hunan        | 4.014 | 4.332 | 4.211 | 4.383 | 4.480 | 4.461 | 4.025 | 3.862 |
| Guangdong    | 1.235 | 1.201 | 1.442 | 1.371 | 1.395 | 1.424 | 1.631 | 1.642 |
| Guangxi      | 6.987 | 6.335 | 7.226 | 6.984 | 6.296 | 6.047 | 6.070 | 7.714 |
| Hainan       | 1.210 | 1.366 | 1.544 | 1.284 | 1.188 | 1.282 | 1.306 | 1.240 |
| Chongqing    | 5.340 | 5.237 | 5.678 | 5.718 | 5.473 | 5.522 | 5.208 | 4.584 |
| Sichuan      | 3.210 | 3.241 | 3.153 | 3.248 | 3.526 | 3.500486 | 3.223 | 3.068 |

TABLE 2  Summary of the variables

| Type of variables | Name of variables | Measure |
|-------------------|-------------------|---------|
| Explained variable | Carbon emission efficiency (CE) | Carbon emissions per unit of energy |
| Explanatory variable | Environmental regulation strength (ERS) | Government subsidy for secondary subjects of nonoperating income (take the logarithm) |
| Controlled variable | Energy price (EP) | The ratio of the raw material, fuel and power purchase price index to the general price level |
| Population L | Quantity of employment of Province \( i \) in the \( t \)-year |
| Economic level (RGDP) | Provincial income of Province \( i \) in the \( t \)-year |
| Industry structure IG | The proportion of the secondary industry in GDP |
| Technical level (RD) | The proportion of R & D investment in GDP |
| Export (TRADE) | The proportion of export in GDP of Province \( i \) in the \( t \)-year |
| Energy structure EY | The proportion of coal consumption in total energy consumption of Province \( i \) in the \( t \)-year |
| Whether to open up to carbon emissions trading | \( N = 0 \) before opening the carbon emission trading; \( N = 1 \) after opening the carbon emission trading |

Abbreviation: GDP, gross domestic product.
4.3 Model construction

The econometric model in this paper is as follows:

In this paper, a panel data regression model is selected for empirical analysis, which is mainly used to calculate the degree of influence of multiple variables on a single variable. Assuming that a dependent variable $Y$ is influenced by $k$ independent variables $x_1, x_2, ..., x_k$ with $n$ sets of observations $(Y, x_{1a}, x_{2a}, ..., x_{ka})$, $a = 1, 2, ..., n$, the expression of the model is:

$$Y = \alpha + \beta_1 X_{1a} + \beta_2 X_{2a} + \cdots + \beta_k X_{ka} + \mu. \quad (2)$$

where $\alpha$ is the intercept, $\beta$ is the coefficient, and $\mu$ the residuals. When $\alpha$ remains unchanged, a fixed effect model is used.

The following test model is constructed to analyze the effect of environmental regulation intensity on CE:

$$\ln CE_{it} = \beta_0 + \beta_1 ERS_{it} + \beta_2 \ln EP_{it} + \beta_3 \ln Lit + \beta_4 \ln GDP_{it} + \beta_5 \ln IG_{it} + \beta_6 \ln RD_{it} + \beta_7 \ln TRADE_{it} + \beta_8 EY_{it} + \varepsilon. \quad (3)$$

5 ANALYSIS OF EMPIRICAL RESULTS

5.1 Model analysis and testing

This section is to conduct relevant empirical evidence and elaborate and analyze the results. It is performed in four aspects: descriptive statistics, correlation analysis, panel data regression model, and robustness analysis.

### 5.1.1 Descriptive statistics analysis

In this paper, descriptive statistics are first presented in Table 3 for the overall sample to examine the overall national CE and environmental regulation intensity.

From the results of the descriptive statistics table of the overall sample in Table 3:

Firstly, the intensity of environmental regulation (ERS) is a relative concept, usually between $(-1,1)$, with its minimum value as $-0.6$, which can be illustrated as that the region not only ignores but also violates laws and regulations to stealthily emit; the maximum value is $0.84$, which can be explained as that the region environmental regulation is particularly strict, and the supporting legal system is perfect. The average is $0.0888$, indicating that the environmental regulation intensity has a good fit.

Second, the maximum value of CE is $1.26$, with the minimum value being $0$ and the average value being $0.0469$. It can be seen that there are large differences in CE levels, but the difference between the maximum and minimum values of environmental regulation intensity is close to the corresponding difference in CE. It can indicate that the CE investigated is mainly influenced by the intensity of environmental regulation.

Third, the standard deviations of the control variables such as EP, GDP, IG, RD, TRADE, EY are small, indicating that the distribution of the different degrees of the control variables is relatively balanced, without large abnormalities, and the influence of related factors can be excluded. The units of the above data are treated as standardized data with “1.”

### 5.1.2 Correlation analysis

To understand whether there is a correlation between the selected variables, the independent variables and the
dependent variables are first tested for correlation. According to the variable correlation matrix, the overall correlation coefficient of each variable is below 0.30, which indicates that the overall correlation between the selected independent variable and the dependent variable is relatively low, that is, the multicollinearity between the variables is not significant. Details are shown in Table 4.

### Table 4: Correlation analysis

|       | CE  | ERS   | EP   | L    | GDP  | IG   | RD   | TRADE | EY   |
|-------|-----|-------|------|------|------|------|------|-------|------|
| CE    | 1   |       |      |      |      |      |      |       |      |
| ERS   | 0.061** | 1     |      |      |      |      |      |       |      |
| EP    | 0.295        | 0.073** | 1     |      |      |      |      |       |      |
| L     | 0.109**      | 0.187** | 0.211 | 1     |      |      |      |       |      |
| GDP   | 0.183**      | 0.158** | 0.543** | 0.147 | 1     |      |      |       |      |
| IG    | 0.295**      | 0.073** | 0.14** | 0.077** | 0.233 | 1     |      |       |      |
| RD    | 0.159**      | 0.148   | 0.225 | 0.335 | 0.114 | 0.121 | 1     |       |      |
| TRADE | 0.294*       | 0.231   | 0.254 | 0.241 | 0.117 | 0.117 | 0.156 | 1     |      |
| EY    | 0.269**      | 0.010   | 0.004 | 0.154 | 0.321 | 0.146 | 0.132 | 0.211 | 1    |

*10% level of significance  
**5% level of significance  
***1% level of significance.

5.1.3 | Unit root test

Panel data can reflect the variation patterns and characteristics of variables in both cross-sectional and temporal two-dimensional space, and have the advantages that pure time-series data and pure cross-sectional data cannot match. Before processing panel data, a unit root test is required. If there are unit roots, there is a possibility of pseudoregression. Therefore, this paper uses the Levin, Lin, and Chu (LLC) test, a common method of panel unit root test, and the results are shown in Table 5.

From the results, it is clear that the $p$ value of the unit root test for all variables is less than 0.05. The hypothesis has been rejected, all variables are nonstationary, due to that all variables are $1(0)$ series and there is no unit root.

This paper performs correlation analysis on the selected variables. Table 6 uses the variance inflation factor (VIF) test to determine whether there is a problem of multicollinearity among the variables.

As shown in the above table, the correlation coefficients between the independent variables did not exceed 0.7 at the maximum, and the VIF values were all less than 10, so there was no serious problem of multicollinearity.

### Table 5: LLC unit root test results

| Variables | LLC inspection | $p$ Value | Results |
|-----------|----------------|-----------|---------|
| CE        | −4.8744        | 0.0012    | Stability |
| ERS       | −7.8687        | 0.0002    | Stability |
| EP        | −8.6655        | 0.0003    | Stability |
| L         | −9.8610        | 0.0007    | Stability |
| GDP       | −8.9458        | 0.0011    | Stability |
| IG        | −4.5705        | 0.0000    | Stability |
| RD        | −8.2691        | 0.0003    | Stability |
| TRADE     | −3.5574        | 0.0017    | Stability |
| EY        | −10.6850       | 0.0014    | stability |

Abbreviation: LLC, Levin, Lin, and Chu.

### Table 6: Results of VIF multicollinearity test

| Variables | VIF | 1/VIF |
|-----------|-----|-------|
| CE        | 3.09| 0.323317 |
| ERS       | 2.87| 0.348097 |
| EP        | 2.34| 0.426679 |
| L         | 2.14| 0.468057 |
| GDP       | 2.08| 0.480349 |
| IG        | 1.83| 0.546444 |
| RD        | 1.59| 0.566647 |
| TRADE     | 2.39| 0.6425654 |
| EY        | 1.4 | 0.71199 |

Mean VIF 3.11

Abbreviation: VIF, variance inflation factor.
5.2 | Regression and results

5.2.1 | Full-sample regression analysis before and after opening carbon emissions trading

The paper uses Equation (3) to conduct a panel data regression analysis of the environmental regulation intensity and CE obtained by the new energy enterprises before and after the opening of carbon emissions trading, so as to test the hypothesis. The corresponding results are shown in Table 7, and the linear regression results of environmental regulation intensity and CE are obtained.

Table 7 presents the results of the multiple regression of the data before and after the opening of carbon emissions trading. From the regression results in Table 6, it can be seen that in the regression analysis considering the dependent variable carbon emissions efficiency and related control variables, population and technology level are significantly and positively correlated with carbon emissions efficiency at the 5% and 10% levels, respectively. This indicates that both of them have significant effects on CE. In the regression of the sample, the regression coefficient of environmental regulation intensity (ERS) after the opening of carbon emissions trading is 0.2514785. It is a significant positive correlation at the 5% level. This shows that the higher the intensity of environmental regulation, the higher the efficiency of carbon emissions. This indicates that for the postopen carbon emissions trading sample, the intensity of environmental regulation has a positive relationship with carbon efficiency (i.e., it has a positive effect, and the intensity of environmental regulation improves carbon efficiency). In comparison, the ERS before the opening of carbon emissions trading is 0.01214748. Although the correlation is also significant at the 5% level, it is smaller than that after the opening of carbon emissions trading. It can be seen that the higher the intensity of environmental regulation, the higher the carbon emissions efficiency. It shows that for the sample after the opening of carbon emissions trading, the intensity of environmental regulation is positively correlated with carbon emissions efficiency, and the carbon emissions trading mechanism will promote this positive effect. (i.e., there is a positive effect, and the intensity of environmental regulation improves carbon emissions efficiency).

5.2.2 | Subsample regression analysis

By averaging the annual carbon dioxide data, they were divided into high carbon emission areas, medium carbon emission areas, and low carbon emission areas, and the results of the grouping were regressed. The boundaries of the division are as follows: if the annual average CO₂ emissions from 2002 to 2012 are less than 264,629,300 tons (2/3rd of the average annual CO₂ emissions of 30 provinces and cities), then it is a low carbon emission area, which is indicated by the number 0. If the annual average carbon dioxide emissions from 2002 to 2012 are greater than 264,629,300 tons and less than 529,258,600 tons (4/3rd of the average annual carbon dioxide emissions of 30 provinces and cities), then the region is a medium carbon emission region.
which is indicated by the number 1. If the annual average CO₂ emissions from 2002 to 2012 are greater than 529,258,600 tons, then it is a high carbon emission area, which is indicated by the number 2. Through this standard division, the 30 provinces and cities are divided into 8 high carbon emission regions, 8 medium carbon emission regions, and 14 low carbon emission regions. This paper uses EVIEWS for regression, and the results are shown in Table 8.

From the regression results in Table 8, it can be seen that the ERS is 0.372 for medium carbon emission regions, 0.218 for low carbon emission regions, and 0.122 for high carbon emission regions. Therefore, this proves that the impact of environmental regulations on carbon emission efficiency is the largest in medium emission regions; the second largest in low emission regions; and the smallest in high emission regions.

### 5.3 Robustness tests

#### 5.3.1 Full-sample robustness test before and after opening up carbon emissions trading

In this thesis, the explanatory variables are replaced with total CO₂ emissions for robustness testing. The corresponding results are shown in Table 9 to obtain the

| Variables | $N = 1$ Coefficient/$t$ value | $N = 0$ Coefficient/$t$ value |
|-----------|-----------------------------|-----------------------------|
| **Explanatory variables** | | |
| ERS | 0.0522144** (2.5536) | 0.032145** (1.9584) |
| | | |
| **Control variables** | | |
| EP | −0.0588** (−3.85696) | −0.03695** (−2.14785) |
| | | |
| L | 0.0118* (1.5625) | 0.0105* (2.33695) |
| | | |
| GDP | 0.0552*** (2.65112) | 0.028444*** (2.19584) |
| | | |
| IG | 0.189** (1.5569) | 0.526** (1.28411) |
| | | |
| RD | −0.0236* (−3.859) | −0.02011* (−4.2636) |
| | | |
| TRADE | 0.0557*** (1.89339) | 0.0596*** (11.6399) |
| | | |
| EY | 0.07866*** (1.2595864) | 0.09965*** (1.124174) |
| | | |
| Constants | 0.02245 (1.1566) | 0.02265 (0.2089) |
| | | |
| $R^2$ | 0.655 | 0.557 |
| | | |
| Prob($F$-statistic) | 0.0000 | 0.0019 |
| | | |
| $F$-test | 16.3312 | 15.669 |
| | | |
| | 0.0004 | 0.0009 |
| *10% level of significance | | |
| **5% level of significance | | |
| ***1% level of significance | | |
robustness test results of environmental regulation intensity and carbon emission efficiency.

Table 9 presents the results of the robustness tests for the full sample data before and after the opening of carbon emissions trading. From the robustness regression results in Table 9, it can be seen that the full sample regression results are robust.

5.3.2 | Subsample robustness test analysis

The same method was used to perform robustness tests on the subsample and the results are shown in Table 10. Table 10 presents the results of the robustness tests for the subsample data before and after the opening of carbon emissions trading. From the robustness regression results in Table 10, it can be seen that the subsample regression results are robust.

### Table 10: Linear regression results of environmental regulation intensity and carbon emission efficiency for subsamples

| Low carbon emission areas | Medium carbon emission region | High carbon emission areas |
|---------------------------|-------------------------------|-----------------------------|
| **ERS**                   | 0.199*** (0.0215)            | 0.224*** (0.0166)           | 0.177* (0.0559) |
| **EP**                    | 0.122 (0.474)                | −0.561 (0.553)              | −0.122 (0.300) |
| **L**                     | 0.599*** (0.255)             | 0.1177 (0.177)              | 0.0112 (0.335) |
| **GDP**                   | 0.487*** (0.044)             | 0.299*** (0.0569)           | 0.636*** (0.288) |
| **IG**                    | 0.178*** (0.0622)            | 0.263* (0.0511)             | 0.626 (0.188)  |
| **RD**                    | 0.131** (0.0266)             | 0.0522 (0.0695)             | 0.209 (0.0338) |
| **TRADE**                 | 0.0144* (0.0391)             | 0.263*** (0.0177)           | 0.258* (0.0228) |
| **EY**                    | 1.311*** (0.599)             | 1.559*** (0.339)            | −0.228 (0.296) |
| Constants                 | −0.224 (1.229)               | 0.395 (1.398)               | 2.188 (2.558)  |
| **R^2**                   | 0.998 (1.229)                | 0.895 (1.398)               | 0.906 (2.558)  |
| **F**                     | 199.5 (1.229)                | 312.2 (1.398)               | 200.6 (2.558)  |
| **p**                     | 0.0001 (0.0001)              | 0.0001 (0.0001)             | 0.0000 (0.0000) |

*10% level of significance  
**5% level of significance  
***1% level of significance.

6 | CONCLUSIONS AND ENLIGHTENMENT

6.1 | Test conclusions

This paper draws the following conclusions from the econometric model: first, environmental regulation reduces carbon dioxide emissions; second, the relative price of energy reduces provincial carbon dioxide emissions. The employment figure is related to the overall provincial carbon dioxide emissions. GDP growth positively affects carbon emissions, increasing the proportion of the R & D devotion by the Chinese government, and the provincial government in GDP reduces carbon emissions; technological progress greatly reduces carbon emissions, and exports augment increases in carbon emissions, which further illustrates that low value-added but high carbon emissions products are still dominant in exports, and the ascending proportion of coal consumption increases carbon emissions, which is in line with expectations.

6.2 | Enlightenment

6.2.1 | Implement differentiated environmental regulation policies

Because the formulation of an environmental regulatory system and the selection of policy tools have different effects on energy efficiency, they cannot be applied uniformly. Appropriate environmental regulation policy tools can assist in achieving the dual goals of regional ecological environment protection and improved energy efficiency. Because of China’s uneven economic development, the conditions of resource endowment, technical level, and natural environment vary greatly. To improve the effectiveness of environmental regulation policies, we should pay attention to policy flexibility, adjust measures to local conditions, and formulate differentiated environmental regulation policies based on the actual situation of environmental carrying capacity and energy resource endowment in different regions.

6.2.2 | The government should formulate appropriate environmental regulation tools according to local characteristics

How can high-polluting enterprise transition to clean and environmentally friendly production be solved? I believe it
is possible to use the “reverse mechanism” in moderation. In practice, the government should do everything possible to reduce examination and approval links and related procedures, implement the “streamline administration, delegate power, strengthen regulation, and improve services” reform, while also increasing technical investment in highly polluting enterprises and providing appropriate subsidies. When environmental pollution has harmed residents’ lives and the public demands that polluting enterprises compensate them, the government should step forward in a timely manner to provide the public with the necessary assistance and support, as well as to earnestly safeguard the public’s interests and attempt to internalize the external diseconomy of enterprises. The government should not formulate relevant policies blindly to maximize the role of environmental regulation tools. It should take into account the business environment and the affordability of enterprises, constantly improve and adjust, and the environmental regulation tools developed should correspond to the actual development of enterprises.

6.2.3 | Constantly improve China’s spot trading market system and establish a corresponding futures market

The futures market is a financial market that trades in accordance with the agreement and delivers on the agreed-upon date. As a result, by deriving a variety of carbon financial products and relying on the two basic carbon assets of carbon quotas and project emission reduction, we can develop various carbon financial instruments, improve market liquidity through diverse trading methods, and hedge the risk of future price fluctuations, thereby achieving hedging. Furthermore, we should build and improve financial infrastructure, increase financial market transparency, and work hard to solve the problem of asymmetric investment and financing information in the financial market. Furthermore, we should strengthen the requirements for corporate environmental information disclosure, create a public environmental data platform, analyze environmental risks, and implement a variety of measures to handle carbon trading in an open, fair, and just manner.

6.2.4 | National and local people’s congresses carry out the formulation of laws and regulations in the field of green investment to ensure that there are laws to follow in case of disputes

It is necessary to define the responsibilities and penalties that enterprises with unfavorable external environments must bear, to improve pollution discharge standards, and to develop waste charging standards in consumption links. The threshold for enterprises to become trading members should be lowered, reward and punishment mechanisms should coexist, and as many enterprises or units as possible should become trading members, resulting in a larger trading volume of the national carbon emission exchange and a more stable trading carbon price. The ultimate goal is for businesses to be able to profit from carbon trading while also reducing carbon emissions, increasing business enthusiasm for green production.

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