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# Impact of Environmental Regulations on Energy Efficiency: A Case Study of China's Air Pollution Prevention and Control Action Plan

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**Abstract:** Scientific environmental policies promote energy efficiency improvement by influencing the industrial structure and investment in R&D and innovation. In view of the insufficient impact of the Air Pollution Prevention and Control Action Plan (Action Plan for short) on energy efficiency, this paper takes 30 provinces and municipalities of the Chinese Mainland during 2004–2017 as samples and investigates the impact of China's Action Plan on energy efficiency as well as the impact path by means of the DID method. This paper finds a significant statistical relationship between the two. The following conclusions are drawn. Firstly, the Action Plan significantly promotes the improvement of provincial energy efficiency. Secondly, the Action Plan has heterogeneous impacts on the energy efficiency in different provinces. This heterogeneity is mainly reflected in the differences in resource endowments and the different intensities of environmental governance in different provinces. Thirdly, the upgrading and rationalization of the industrial structure and the investment in R&D and innovation have significantly different moderating effects on the Action Plan's impact on energy efficiency. The industrial structure rationalization and the investment in R&D and innovation will enhance the promotion effect of the Action Plan on energy efficiency, while the "quantity" of the industrial structure upgrading will weaken this promotion effect, and the moderating effect of the "quality" of the industrial structure upgrading is not significant.

**Keywords:** Air Pollution Prevention and Control Action Plan; energy efficiency; DID method; industrial structure upgrading; industrial structure rationalization; R&D and innovation investment

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## 1. Introduction

### *1.1. Research Background and Motivation*

Energy efficiency, as the core index that countries pay close attention to, has a significant and complex relationship with environmental regulations. Energy is not only an indispensable resource foundation for the social development of all countries but also a core driving force for rapid and stable economic progress. In recent years, with the continuous acceleration of industrialization in various countries, the dependence of mankind on energy has increased. Behind the rapid economic development is the overexploitation of energy resources and the continuous reduction in environmental quality, leading to the contradiction between energy supply and demand and causing resource conflicts and serious environmental pollution. In this context, it is particularly critical to study and improve energy efficiency in order to fully reduce energy consumption, protect the environment, and promote the comprehensive and coordinated development of economy, society, and ecology [1]. Improving energy efficiency can not only reduce excessive energy consumption but also curb the trend of environmental degradation from the source of pollution, and energy efficiency can effectively reflect the effects of energy-saving and emission-reduction measures in the environmental regulations of various countries [2].

"Energy efficiency" was first proposed by the World Energy Council in 1995. Subsequently, numerous scholars defined energy efficiency and gradually studied its real connotation. At present, energy efficiency is divided into single-factor energy efficiency and total-factor energy efficiency (TFEE). This paper focuses on the total-factor energy efficiency. The detailed meaning of TFEE is to create more expected outputs with less input and reduce environmental pollution and other undesirable outputs with a certain combination of input factors [3]. Therefore, energy efficiency not only emphasizes the relationship between a country's economic growth and energy consumption but also can effectively reflect a country's green development level. Environmental regulation is one of the powerful means adopted by the government to control environmental pollution. The "Porter hypothesis" holds that environmental regulation can improve the enterprise technological innovation level and energy utilization efficiency among industries, thus promoting the green development of the national economy [4]. The purpose of setting environmental regulations is to coordinate the relationship between economic development and environmental protection so as to form a new model of sustainable development. Therefore, there is an inseparable and complex relationship between environmental regulations and green development in all countries, which deserves in-depth study. As one of the largest energy consumers and carbon emitters, the Chinese government has adopted different environmental regulations in response to the increasing total energy consumption and carbon emissions. The Air Pollution Prevention and Control Action Plan is the most stringent one. The Action Plan has achieved remarkable results in recent years. On the one hand, from the industrial perspective of analysis, due to the requirements of energy conservation and emission reduction and the improvement of energy utilization efficiency, the average emissions of industrial waste water, fixed waste emissions, carbon dioxide, and other environmental pollutants have been effectively controlled. On the other hand, China's follow-up new actions are also based on the Action Plan, such as the Blue Sky Protection Campaign. Therefore, its impact on energy efficiency has important research value. The government can be inspired when formulating relevant policies and measures to solve environmental and energy problems. Therefore, we try to fully explore the relationship between environmental regulations and energy efficiency by taking China's Air Pollution Prevention and Control Action Plan as an example.

### *1.2. Literature Review*

The existing literature mainly studies the impact of environmental regulations on energy consumption, energy efficiency, and regional green development, focusing on the following two aspects.

The first is to study the impact of environmental regulations on energy efficiency, energy consumption, and energy structure, where scholars hold different opinions. Some scholars believe in a linear relationship between environmental regulations and energy efficiency. Yu and Shen [5] use a dynamic spatial panel model to explore the relationship between environmental regulations and industrial capacity utilization based on panel data of 30 provinces in the Chinese Mainland in 2004–2015. It is found that the relationship between the environmental regulation intensity and industrial capacity utilization varies among provinces, and it fluctuates and rises over time. In addition, environmental regulations significantly improve industrial capacity utilization, mainly through technological innovation. Based on China's industry panel data from 2004 to 2014, Zhang et al. [6] employed the panel-VAR model to analyze the impact of environmental regulations on energy efficiency, and they found that environmental regulations can improve energy efficiency through technological innovation only in the long term. Based on the regional panel data from 1997 to 2015, Liu et al. [7] adopted the generalized least square method to analyze the impact of different types of environmental regulations on energy consumption. The results show that economic and supervisory environmental regulations will inhibit energy consumption, while legal environmental regulations have no significant impact, and there are regional differences in the impact of different types of environmental regulations on energy consumption. Yuan and Xiong [8] used the panel data of China's manufacturing industry from 2003 to 2014 to test the impact of environmental regulations on industrial innovation and green development. The results show that environmental regulations can effectively improve the labor productivity, energy efficiency, and environmental efficiency of the manufacturing industry in the short term, but in the long run, they inhibit patent output and squeeze out R&D investment, only improving energy efficiency.

Some scholars found a nonlinear relationship between environmental regulations and energy efficiency, which can be divided into the following two aspects. On the one hand, based on the Chinese Mainland provincial panel data, scholars explore different models and estimation methods for energy efficiency, indicating that there is a U-shaped relationship between environmental regulation and energy efficiency from multiple perspectives [4,9,10]. On the other hand, other scholars use different empirical methods to study the relationship between environmental regulation and energy efficiency through the Chinese Mainland's provincial industry data. The results suggest that environmental regulation has a U-shaped relationship with energy efficiency in different industries of the Chinese Mainland [11,12].

The second is to study the impact of environmental regulations on energy efficiency and regional green development. Based on panel data of 30 provinces in China from 2000 to 2017, Chen et al. [13] used the DID method to explore the impact of carbon-emission trading pilot regulation on energy efficiency. The results show that the pilot regulation can significantly reduce carbon emissions to improve the single-factor and total-factor energy efficiency, and the mechanism test shows that the regulation can improve the energy efficiency by promoting technological innovation and the marketization of enterprises. Based on panel data of Chinese industrial enterprises from 1998 to 2007, Tang et al. [14] employed the DID method to analyze the impact of the "Two Control Zones" regulation on the enterprise TFP. The results show that the "Two Control Zones" regulation seriously hinders the growth of the enterprise TFP, and this negative impact is lagging and persistent. Based on the quasi-natural experiment of China's sulfur-dioxide emission trading pilot, Peng et al. [15] adopted panel data of Chinese industrial enterprises from 1998 to 2007 to analyze the impact of this environmental pilot regulation on productivity with the DID method. It is found that market-based environmental regulation can improve the productivity of industrial enterprises. Zhou and Tang [16] took the Action Plan as the quasi-natural experiment and used the DID method to explore the impact of environmental regulation on the green total-factor growth rate of China's industry. The results show that the Action Plan regulation can significantly promote the growth of green total-factor productivity by promoting the increase of R&D investment. Based on Chinese provincial panel data from 2007 to 2017, Zhang et al. [17] analyzed the effect of the Action Plan on the green TFP of the chemical industry by the DID method. The results show that the Action Plan can significantly improve green TFP, and the positive effect shows an inverted "U" shape in the dynamic effect analysis. Liu et al. [18] used the DID method to analyze the impact of China's carbon-emission trading pilot regulation on the TFEE. The results show that the regulation can improve the TFEE through industrial structure and technological innovation, which provides new evidence for Porter's hypothesis.

On balance, scholars pay more attention to the impact of environmental regulations on energy efficiency and green development among regions and industries, and provide great ideas and methods for theoretical and empirical analysis. However, few studies focus on the impact of the Action Plan on energy efficiency. Therefore, this paper combs the existing academic research and explores the relationship and impact path between the Action Plan and energy efficiency based on the panel data of 30 provinces (autonomous regions and municipalities) in the Chinese Mainland from 2004 to 2017. Compared with previous studies, the marginal contribution of this paper is threefold. First, this paper verifies the hypothesis that the Action Plan can promote energy efficiency using the DID method and the fixed effect model, enriching the research topics in this field and providing a solid demonstration that environmental regulations can effectively improve energy efficiency. The conclusion is helpful for different countries and regions to formulate environmental regulations to achieve the global carbon neutrality goal as soon as possible. Second, based on the difference in resource endowments and environmental investment intensity in the Chinese Mainland, this paper uses the method of sub-sample regression to verify the hypothesis that the Action Plan has heterogeneous effects on the energy efficiency of different regions. Third, as for the action mechanism of the Action Plan affecting provincial energy efficiency, this paper focuses on the moderating effects of the industrial structure upgrading, the industrial structure rationalization, and the investment intensity of R&D and innovation.

This paper is divided into five sections. Section 2 elaborates the research design. Section 3 carries out the empirical analysis. Section 4 extends the discussion further. Section 5 draws the conclusions.

## 2. Materials and Methods

### *2.1. Theoretical Analysis and Research Hypotheses*

Environmental policy is a kind of explicit environmental regulation, which mainly aims at protecting the environment and takes individuals and enterprises as the main objects. In the previous literature, the impact of environmental regulation on energy efficiency is mainly based on the cost effect and innovation compensation effect [4]. From the perspective of cost effect, the government sets pollution prevention targets for each region by issuing environmental regulations, which makes the regional authorities force local enterprises to spend corresponding funds for environmental pollution control, which will increase the production cost of enterprises and squeeze out their productive investment, resulting in a reduction in their output. In the case of constant input of energy resources, the reduction in enterprise output means the decline of energy efficiency. From the perspective of the innovation compensation effect, environmental regulations force enterprises in various regions to carry out transformation and upgrading, change the original production mode of high pollution and high emissions by improving the technological level of production process, improve energy efficiency, and thus form a new mode of green development. At the same time, the increase in environmental regulation intensity will make the new enterprises entering various industries have more advanced equipment and technology than the original enterprises for competitive advantage, so as to improve energy efficiency, achieve higher output and less pollution emissions, and occupy a strategic advantage in the product market under the same energy input level. Porter puts forward that when the innovation compensation effect exceeds the cost effect, the win-win situation of economic development and environmental governance can be realized. Based on this theoretical analysis, the Action Plan, as a strong environmental regulation, is expected to effectively drive enterprises to accelerate production technology transformation. Moreover, the Action Plan can help to eliminate enterprises with backward energy efficiency and serious pollution, thus ensuring that the energy conservation and pollutant emissions of various industries meet the standards [10]. Therefore, Hypothesis 1 is proposed as follows.

**Hypothesis 1.** *The Air Pollution Prevention and Control Action Plan can improve energy efficiency.*

There are obvious differences in the effect of environmental policies on energy efficiency and environmental governance in different regions. On the one hand, for regions with different resource endowments, the difficulty and effect of environmental policies will vary significantly in terms of the industrial structure, technological level, infrastructure construction, and foreign investment level [9]. The main focus of the Action Plan is the eastern coastal region, with high resource endowments. Compared with other regions, the eastern coastal region has obvious technological and financial advantages. It is easier for enterprises in this region to realize industrial transformation and upgrading, improve energy efficiency, and reduce the emission of pollutants in the production process so as to meet the environmental policy standards [6]. On the other hand, environmental regulations will have different effects on regions with different environmental governance intensities. Generally speaking, enterprises in the regions with relatively higher environmental governance intensity can invest capital in environmental governance so that the pollution emission in the production process is relatively less [7]. Therefore, environmental regulations will be stricter in areas with low environmental governance intensity, requiring local enterprises to improve their production technology and energy efficiency, so as to reduce pollution emissions and promote the green development of enterprises. Based on the above theoretical analysis, Hypothesis 2 is proposed as follows.

**Hypothesis 2.** *The promotion effect of the Action Plan on energy efficiency has regional heterogeneity.*

Environmental regulations can affect the transformation and upgrading of the industrial structure in various regions, thereby affecting energy efficiency and ultimately changing the scale and number of enterprises in the industry, thus eliminating high-pollution and low-energy-efficiency enterprises. On the one hand, environmental regulations will increase the production costs of industries in various regions, leading to the direct withdrawal of enterprises with low energy efficiency and production efficiency from the market, raising the environmental threshold of various industries, and thus achieving the effect of environmental governance. Based on this, environmental regulations can promote the rationalization of the industrial structure and accelerate enterprise technological innovation, thereby improving energy efficiency and promoting enterprises' green development [19]. On the other hand, the cost effect brought about by environmental regulations will prompt industries in various regions to move closer to high-output-value industries, forming a trend of industrial transfer. In upgrading the industrial structure, there will be a stage of shifting from the primary industry to the secondary industry with high pollution and high added value, and then to the tertiary industry with a high technological level. As the industrial structure of various regions is advanced to the secondary industry, local energy consumption and environmental pollution will increase simultaneously, and it is possible to face a situation of high added value and high pollution in the industry, which reduces energy efficiency. Based on this, the impact of environmental policy on energy utilization efficiency through industrial structure is twofold, which needs to be discussed and analyzed in combination with the actual situation of regional economic development [20]. Therefore, Hypothesis 3 and Hypothesis 4 are proposed as follows.

**Hypothesis 3.** *Industrial structure upgrading weakens the promotion effect of the Action Plan on energy efficiency.*

**Hypothesis 4.** *Industrial structure rationalization enhances the promotion effect of the Action Plan on energy efficiency.*

Environmental regulations will affect enterprises' R&D and innovation investment in various regions in different periods, changing the technological innovation level of enterprises, thereby affecting energy efficiency. In the short term, environmental regulations will lead to cost effects for companies. In order to maximize profits, enterprises reduce their investment in other areas, which affects energy efficiency and their total-factor productivity. However, from a long-term perspective, the implementation of effective environmental regulations can not only improve consumers' environmental awareness and regional environmental level, but also affect the R&D and innovation investment of enterprises. As the intensity of environmental regulations continues to increase, in order to maintain a competitive advantage in the product market, enterprises will increase their capital investment in R&D and innovation, thereby improving the production technology and innovation level and reducing energy consumption in the production process. Accordingly, energy efficiency will be effectively improved, with more green new products being produced, and a win-win situation at economic and environmental levels will be achieved [21]. Based on this, this paper proposes Hypothesis 5 as follows.

**Hypothesis 5.** *The intensity of R&D and innovation investment strengthens the promotion effect of the Action Plan on energy efficiency.*

*2.2. Research Models and Methods*

This study aims to explore the policy effect and impact path of environmental regulation on energy efficiency. Specifically, this paper analyzes the impact of the Action Plan on provincial energy efficiency through econometric methods. In addition, this paper further explores the moderating effect of the industrial structure and the R&D innovation investment on the impact. Firstly, this paper sets the target provinces of the Action Plan as the experimental group and the non-target provinces as the control group, assigning the value with the dummy variable treatment, i.e., the value of the experimental group is 1 and that of the control group is 0, so as to indicate whether the province is affected by the Action Plan. In addition, the dummy variable period is set according to the promulgation time of the Action Plan. Considering that the Action Plan was released on 13 September 2013, and the data in this paper are annual provincial panel data, it is difficult for the Action Plan to have a significant impact in the year of promulgation. Therefore, this paper sets 2014 as the year of policy implementation, and the period of each province is assigned 0 before 2014 and 1 after 2014 to reflect the time impact of the Action Plan.

Based on the data types of this paper and after passing the Hausmann test, it is found that the fixed effect model performs better than the random effect model. This paper adopts the difference-in-differences (DID) estimation method and the fixed effect model to study the impact of the Action Plan on provincial energy efficiency [22]. The DID method is limited to some extent and is only for panel data. However, as a mainstream method of policy effect evaluation, the DID method still has certain advantages. It can largely avoid the endogenous problems and estimate the policy effect more effectively.

In this paper, a variety of different statistical techniques and models are used to study the relationship between them. There may be some deficiencies in model selection. There are still some improvements to be made. In order to illustrate that the conclusions drawn from different estimation methods and models are more comprehensive and robust, this paper adopts different statistical techniques and models for energy efficiency in the analysis of the Action Plan. In this paper, Model (1) is taken as the benchmark model to test whether the impact of the Action Plan on energy efficiency is consistent with Hypotheses 1 and 2.

$$EE_{it} = \beta_0 + \beta_1 DID_{it} + \gamma_n X_{int} + \tau_t + \mu_i + \varepsilon_{it} \tag{1}$$

By referring to the research of other scholars, it can be seen that the premise of the DID method is that the experimental group and the control group meet the parallel trend assumption, i.e., before the implementation of the Action Plan, the changing trend of energy efficiency in each province is consistent. This paper proposes Model (2) to test whether it meets this basic assumption.

$$\begin{aligned} EE_{it} = \beta_0 + \beta_1 DID_{it} + \beta_2 Before1 + \beta_3 Before2 + \beta_4 Before3 + \beta_5 Current \\ + \beta_6 After1 + \beta_7 After2 + \gamma_n X_{int} + \tau_t + \mu_i + \varepsilon_{it} \end{aligned} \tag{2}$$

In the mechanism analysis, this paper uses the following Models (3)–(6) to explore the moderating effect of the industrial structure upgrading and rationalization as well as the R&D innovation investment intensity on the impact of the Action Plan on energy efficiency, so as to test Hypotheses 3–5.

$$EE_{it} = \beta_0 + \beta_1 DIS1_{it} + \beta_2 DID_{it} + \beta_3 IS1_{it} + \gamma_n X_{int} + \tau_t + \mu_i + \varepsilon_{it} \tag{3}$$

$$EE_{it} = \beta_0 + \beta_1 DIS2_{it} + \beta_2 DID_{it} + \beta_3 IS2_{it} + \gamma_n X_{int} + \tau_t + \mu_i + \varepsilon_{it} \tag{4}$$

$$EE_{it} = \beta_0 + \beta_1 DRIS_{it} + \beta_2 DID_{it} + \beta_3 RIS_{it} + \gamma_n X_{int} + \tau_t + \mu_i + \varepsilon_{it} \tag{5}$$

$$EE_{it} = \beta_0 + \beta_1 DRDL_{it} + \beta_2 DID_{it} + \beta_3 RDL_{it} + \gamma_n X_{int} + \tau_t + \mu_i + \varepsilon_{it} \quad (6)$$

In Formulas (1)–(6), $EE_{it}$ represents the energy efficiency of province $i$ in year $t$; $DID_{it} = treat_{it} \times period_{it}$ represents the impact of the Action Plan on each province; $Before1$, $Before2$, $Before$, $Current$, $After1$, $After2$, respectively, represent the policy effect variable of one year, two years, and three years before the implementation, as well as the implementation year, the next year, and the next two years; $DIS1_{it} = DID_{it} \times IS1_{it}$ represents the interaction term between the "quantity" of industrial structure upgrading and the Action Plan; $DIS2_{it} = DID_{it} \times IS2_{it}$ represents the interaction term between the "quality" of industrial structure upgrading and the Action Plan; $DRIS_{it} = DID_{it} \times RIS_{it}$ represents the interaction term between industrial structure rationalization and the Action Plan; $DRDL_{it} = DID_{it} \times RDL_{it}$ indicates the interaction term between R&D innovation investment intensity and the Action Plan; $X_{int}$ represents control variable $n$ of province $i$ in year $t$; $\tau_t$ represents the time effect; $\mu_i$ represents the individual effect, and $\varepsilon_{it}$ is a random interference item.

### *2.3. Variable Definition and Data Source*

#### 2.3.1. Variable Description and Measurement Method

The main explained variable in this paper is the provincial energy efficiency (EE), which represents the ratio of the input of certain energy factors to the total value of the products produced in each province. Most previous studies have considered the single-factor input–output form to measure energy efficiency, i.e., using the ratio of energy consumption to regional GDP to measure single-factor energy efficiency. Such measurement is simple and clear, but it cannot reflect the impact of other production factors and output pollutants on energy efficiency in the production process. In the whole economic system, the input of a certain amount of production factors, through production and processing, can obtain the expected output and undesired output [23–25]. Based on the total-factor input-output thought, this paper adopts the input-oriented DEA model with a constant return to scale (CCR-DEA) to measure the provincial energy efficiency. Although the DEA method only evaluates the relative efficiency of decision-making units, based on the total factor productivity theory, the CCR-DEA model can consider the effect of the interaction between various input elements in the economic system on the energy utilization efficiency, effectively solving the defects of the traditional single-factor energy efficiency research, which has strong universality [26]. To some extent, the model can objectively measure the energy efficiency of each province.

In terms of input factors, this paper selects labor and capital, which are commonly used in economic theory as well as energy consumption for energy efficiency measurement. These input indicators can effectively reflect the impact of the production factors on energy efficiency in the production process. The output indicators are mainly divided into expected output indicators and undesired output indicators. Regional GDP is selected as the expected output indicator since it can reflect the total value formed in the production process of the region, and it is also the core goal pursued in regional economic development. As for the undesired output indicators, this paper considers industrial wastewater, industrial fixed waste, industrial sulfur dioxide, and carbon dioxide emissions, which can effectively reflect the emission degree of pollutants and the allocation of energy resources [27,28]. The specific input–output indicators are shown in Table 1 below.

The indicators in Table 1 are all Chinese Mainland data of the 30 provinces and municipalities during 2004–2017. This is consistent with the temporal dimension of the data of the remaining variables in this paper.

The core explanatory variable of this paper is the proxy variable (DID) of the Action Plan, and the calculation method of DID is shown in the model [13]. The Action Plan, issued by China's State Council on 13 September 2013, sets out clear regulations on environmental pollution control in the Beijing–Tianjin–Hebei region, the Yangtze River Delta, and the Pearl River Delta. Based on this, the provinces in the above three regions are set as the experimental group and the other provinces as the control group. In other words, if the provinces are affected by the Action Plan after 2014, the DID value of the province is assigned as 1; otherwise, it is 0.

**Table 1.** Description of the input–output indicators of energy efficiency.

| Indicator Type | Indicator Name | Indicator Calculation Method |
|---|---|---|
| Input indicator | Labor | Measured by the number of employees at the end of the period in each province |
| | Capital | Calculated by the perpetual inventory method |
| | Energy consumption | Measured by the total energy consumption in each province |
| Expected output indicator | Regional GDP | Measured with regional GDP in the form of constant price |
| Undesired output indicator | Industrial wastewater discharge | Measured by industrial wastewater discharge in each province |
| | Industrial fixed waste | Measured by the output of industrial fixed waste in each province |
| | Industrial sulfur dioxide emissions | Measure with the industrial sulfur dioxide emissions of each province |
| | Carbon dioxide emissions | Measure with the carbon dioxide emissions of each province |

In this paper, the "quantity" and "quality" of the industrial structure upgrading, the industrial structure rationalization, and the R&D and innovation investment intensity are selected as the moderating variables in the mechanism analysis so as to explore the path of the Action Plan affecting the energy efficiency of each region [29–31].

The "quantity" of industrial structure upgrading (IS1) mainly refers to the transfer of key industries in the industrial structure and the degree of transfer of production factors and product forms successively, which are closely related to energy efficiency. The specific calculation formula is as follows:

$$IS1_{it} = \sum_{n=1}^{3} y_{int} \times N, N = 1,2,3 \tag{7}$$

The variable $IS1$ in the above formula can effectively reflect industrial structure transformation in Chinese Mainland provinces and municipalities. The variable's increasing value indicates that each region's dominant position has gradually shifted from the primary industry to the secondary and tertiary industries.

The "quality" of industrial structure upgrading ($IS2$) mainly refers to the situation in which high-value-added and high-tech industries are gradually deepened in the process of industrial structure transformation. Generally speaking, the increasing "quality" of industrial structure upgrading leads to the energy efficiency declining first and then rising. This paper uses the weighted sum of the product of the output share of each industry sector and labor production efficiency to measure the variable $IS2$. The specific calculation formula is as follows:

$$IS2_{it} = \sum_{n=1}^{3} y_{int} \times lp_{int} \tag{8}$$

$$lp_{int} = \frac{Y_{int}}{L_{int}} \tag{9}$$

The rationalization of industrial structure (RIS) can effectively reflect the relevance and coordination among the three industries and the extent of the rational allocation of resources. The greater the rationalization of the industrial structure, the higher the energy efficiency. The Theil Index can not only retain the characteristics of the deviation degree of the industrial structure, but also measure the deviation between the output value and the employment structure of different industries, effectively reflecting the economic status of various industries by weighting the output value. Therefore, this paper adopts the

Theil Index to measure the rationalization degree of industrial structure in each region. The specific calculation formula is as follows:

$$RIS_{it} = \sum_{n=1}^{3} (\frac{Y_{int}}{Y_{it}}) ln \frac{Y_{int}}{Y_{it}} / \frac{L_{int}}{L_{it}} = \sum_{n=1}^{3} y_{int} \times \ln (\frac{y_{int}}{l_{int}}) \quad (10)$$

R&D and innovation investment intensity (RDL) is the capital base of technological innovation in each region, which can effectively reflect the production innovation of each region. Increasing the investment in R&D and innovation by enterprises in each region can effectively improve the energy efficiency in the production process, develop more green products, and reduce environmental pollution. This paper uses the ratio of regional R&D investment to regional GDP to measure the investment intensity of R&D and innovation [32].

In Formulas (7)–(10) for measuring the moderating variables, $y_{int}$ represents the proportion of the added value of industry $n$ in province $i$ in the regional GDP in year $t$; $lp_{int}$ represents the labor production efficiency of industry $n$ in province $i$ in year $t$; $Y_{int}$ represents the added value of industry $n$ in province $i$ in year $t$; $Y_{it}$ represents the total added value of province $i$ in year $t$; $L_{int}$ represents the number of employees of industry $n$ in province $i$ at the end of year $t$; $L_{it}$ represents the total number of employees in province $i$ at the end of year $t$; $l_{int}$ indicates the proportion of the end-of-year employees in industry $n$ of province $i$ in year $t$ to the total end-of-year employees.

In order to control the impact of other influencing factors on energy efficiency, after referring to relevant research [22,33,34], this paper selects the urbanization level (UL), energy consumption structure (ECS), environmental governance level (ERL), and openness level (OL) as control variables from the perspectives of economy, environment, and foreign trade. Generally speaking, there is a negative correlation between energy consumption structure and energy efficiency; that is, the larger the value of energy consumption structure, the lower the energy efficiency. Regarding the energy consumption structure, this paper uses the ratio of the total coal consumption to the total energy consumption of each province for measurement. For the unit of this indicator to be consistent, this paper first multiplies the coal consumption by the standard coal conversion coefficient to convert the coal consumption into the standard coal unit. The urbanization level has an important impact on energy efficiency. The higher the level of urbanization in various regions, the more advanced the production technology of local enterprises, thus improving energy efficiency through technological innovation. This paper uses the built-up area of each province to measure the urbanization level. There is a complicated non-linear relationship between the environmental governance level and energy efficiency. Aiming at measuring the environmental governance level, this paper adopts the ratio of the investment in environmental pollution control of each province to the regional GDP. There is a complex relationship between the level of opening-up and energy efficiency. On the one hand, attracting foreign investment in various regions may bring advanced production technology to improve energy efficiency; on the other hand, foreign capital may choose to build production bases in regions with lower costs in order to transfer high-pollution and high-consumption industries, which reduces energy efficiency. This paper uses the ratio of foreign direct investment in each province to regional GDP to measure the level of opening-up. The abbreviation and characterization of all the variables in this paper are shown in Table 2.

**Table 2.** Variable characterization.

| Variable | Abbreviation | Characterization Variable |
|---|---|---|
| Energy efficiency | EE | The input-oriented DEA model with a constant return to scale to measure the provincial energy efficiency |
| Action Plan | DID | The proxy variable of the Action Plan |
| The "quantity" of industrial structure upgrading | IS1 | Calculation Formula (7) |
| The "quality" of industrial structure upgrading | IS2 | Calculation Formulas (8) and (9) |
| The rationalization of industrial structure | RIS | Calculation Formula (10) |
| R&D and innovation investment intensity | RDL | The ratio of regional R&D investment to regional GDP |
| Urbanization level | UL | The built-up area of each province |
| Energy consumption structure | ECS | The ratio of the total coal consumption to the total energy consumption of each province |
| Environmental governance level | ERL | The ratio of the investment in environmental pollution control of each province to the regional GDP |
| Openness level | OL | The ratio of foreign direct investment in each province to regional GDP |

Most of the control variables in Table 2 are in the relative number form, and the absolute number form of variables such as UL is taken in the log form, in order to reduce the data errors.

### 2.3.2. Descriptive Statistics of Variables and Data Sources

The descriptive statistics of variables are recorded in Table 3, which includes the full sample of the Chinese Mainland, the eastern coastal region with relatively high resource endowments in production technology and overseas trade, the inner central region with relatively high resource endowments in population, and the remote western region with relatively high policy and resource endowments. In order to eliminate data heteroscedasticity and other problems, this paper takes the natural logarithm of variables whose data are in the form of absolute numbers [35,36].

**Table 3.** Descriptive statistics of variables in various regions.

| | The Full Sample | | | The Eastern Coastal Region | | | The Inner Central Region | | | The Remote Western Region | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VarName | Obs | Mean | SD | Obs | Mean | SD | Obs | Mean | SD | Obs | Mean | SD |
| EE | 420 | 0.7154 | 0.1615 | 168 | 0.7952 | 0.1622 | 112 | 0.6786 | 0.1273 | 140 | 0.6493 | 0.1470 |
| ECS | 420 | 0.6847 | 0.2769 | 168 | 0.5210 | 0.1603 | 112 | 0.8329 | 0.2582 | 140 | 0.7666 | 0.3003 |
| lnUL | 420 | 6.9973 | 0.7722 | 168 | 7.2837 | 0.8102 | 112 | 7.2866 | 0.2922 | 140 | 6.4750 | 0.7142 |
| ERL | 420 | 1.3462 | 0.6675 | 168 | 1.2012 | 0.4852 | 112 | 1.2443 | 0.5924 | 140 | 1.6176 | 0.8133 |
| OL | 420 | 0.0330 | 0.0389 | 168 | 0.0298 | 0.0408 | 112 | 0.0228 | 0.0167 | 140 | 0.0431 | 0.0470 |

As shown in Table 3, the explained variable, energy efficiency, which this paper focuses on, varies obviously in different regions. According to the mean value, the energy efficiency of the eastern coastal region is better than that of the central and western regions, which may be due to regional differences in economic development level, production technology, R&D and innovation capacity, and industrial structure [37,38].

In view of data availability, this paper selects the annual panel data of 30 provinces (autonomous regions and municipalities) in the Chinese Mainland from 2004 to 2017 as research samples. Tibet was eventually deleted from the sample since it has serious missing variable data. In this paper, the interpolation method is used to supplement the missing data of some provinces. Data of all research variables in this paper come from the China Statistical Yearbook, China Regional Economic Statistical Yearbook, China

Energy Statistical Yearbook, China Science and Technology Statistical Yearbook, China City Statistical Yearbook, statistical yearbooks of provinces and cities, and the Economy Prediction System (EPS) database.

## 3. Empirical Results Analysis

### *3.1. Benchmark Model and Parallel Trend Test*

Based on the benchmark regression Model (1), this paper uses the panel OLS-DID estimation method and the fixed effect model to explore the impact of the Action Plan on energy efficiency. The specific regression results are shown in Table 3, in which Column (1) lists the parameter estimation results of the time and individual effects without adding control variables; Column (2) shows the parameter estimation results with control variables but with no time and individual effects; Columns (3) and (4) display the parameter estimation results under different estimation methods.

In order to ensure that the research in this paper satisfies the principle of the parallel trend assumption, this paper carries out specific tests through Model (2). Taking 2014 as the base year, this paper estimates the parameters consistent with the benchmark regression for the first three years and the second two years of the base year, i.e., the three years before and three years after the implementation of the Action Plan, so as to judge whether the energy efficiency of all provinces maintains a consistent changing trend before and after the implementation of the policy. The specific regression results are shown in Table 4, where Columns (5) and (6) are the parameter estimation results of the parallel trend test under different estimation methods.

**Table 4.** Empirical results of benchmark regression and parallel trend test.

| | OLS (1) | OLS (2) | OLS (3) | FE (4) | OLS (5) | FE (6) |
|---|---|---|---|---|---|---|
| | **EE** | **EE** | **EE** | **EE** | **EE** | **EE** |
| DID | 0.0617 ** | 0.0501 * | 0.0487 *** | 0.0487 *** | | |
| | (2.2913) | (1.8697) | (3.5266) | (3.7303) | | |
| Before3 | | | | | 0.0308 | 0.0308 |
| | | | | | (1.4188) | (1.3388) |
| Before2 | | | | | 0.0253 | 0.0253 |
| | | | | | (1.3570) | (1.0944) |
| Before1 | | | | | 0.0318 | 0.0318 |
| | | | | | (1.5213) | (1.3637) |
| Current | | | | | 0.0436 ** | 0.0436 * |
| | | | | | (1.9767) | (1.8648) |
| After1 | | | | | 0.0403 * | 0.0403 * |
| | | | | | (1.6500) | (1.7211) |
| After2 | | | | | 0.0436 * | 0.0438 * |
| | | | | | (1.7309) | (1.8685) |
| Control variables | NO | YES | YES | YES | YES | YES |
| Individual fixed effect | NO | NO | YES | YES | YES | YES |
| Time fixed effect | NO | NO | YES | YES | YES | YES |
| _cons | 0.7089 *** | 0.5687 *** | 1.5119 *** | 1.1512 *** | 1.5329 *** | 1.1452 *** |
| | (86.2034) | (7.0564) | (5.5183) | (4.5608) | (5.2261) | (4.3858) |
| N | 420 | 420 | 420 | 420 | 420 | 420 |

Note: t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

As can be seen from Table 4, the estimated regression coefficients of the policy proxy variable DID are significantly positive at the level of 10% in Columns (1)–(4), indicating that the Action Plan for air pollution prevention can effectively promote the improvement of provincial energy efficiency, which can be analyzed from the following dimensions [13]. First of all, from the micro level, the implementation of the Action Plan has a certain impact on the energy consumption of each region. Environmental policies can limit regional pollutant emissions; that is, the use of fossil energy such as coal, oil, and natural gas is restricted in various regions, affecting the demand for traditional energy. Energy consumption in each region will continue to decline compared to that before the implementation of the policy, and local industries will improve their production technology to ensure efficiency, thereby improving energy efficiency [19]. Secondly, from the meso-level analysis, environmental regulations can change the regional industrial structure to a certain extent, reduce the proportion of pollution-intensive industries, and make enterprises with low energy efficiency gradually withdraw from the market, thus promoting the improvement of energy efficiency. Finally, from the macro level, enterprises subject to environmental regulations will reduce the input of energy factors and increase labor and capital factors to reduce energy consumption and improve energy efficiency. The employment structure of each region will also be affected, which will gradually transfer the labor force from the high-pollution and high-emission secondary industry to the high-tech tertiary industry. The improvement of the employment structure will drive the improvement of the technological level and the increase in energy efficiency. It can be seen from different dimensions that the Action Plan can promote the improvement of provincial energy efficiency, and Hypothesis 1 of this paper is verified.

From the regression results listed in Columns (5) and (6) in Table 3, it can be seen that the estimated coefficients of the proxy variables for energy efficiency, Before3, Before2, and Before1, are not significant in the three years before the implementation of the Action Plan, while the estimated coefficients of the policy proxy variables, Current, After1, and After2, all passed the 10% significance test in the three years after the policy implementation, indicating that the energy efficiency of various provinces, autonomous regions, and municipalities remained relatively stable before the implementation of the Action Plan policy, and there is no obvious difference between the pilot area and the non-pilot area, i.e., the principle of the parallel trend assumption is satisfied. In addition, it can be seen from Figure 1 that, before and after the implementation of the Action Plan, the estimated coefficients of the policy proxy variables have a gradually increasing trend, and they are significantly positive after 2014, indicating that the Action Plan can promote the improvement of energy efficiency.

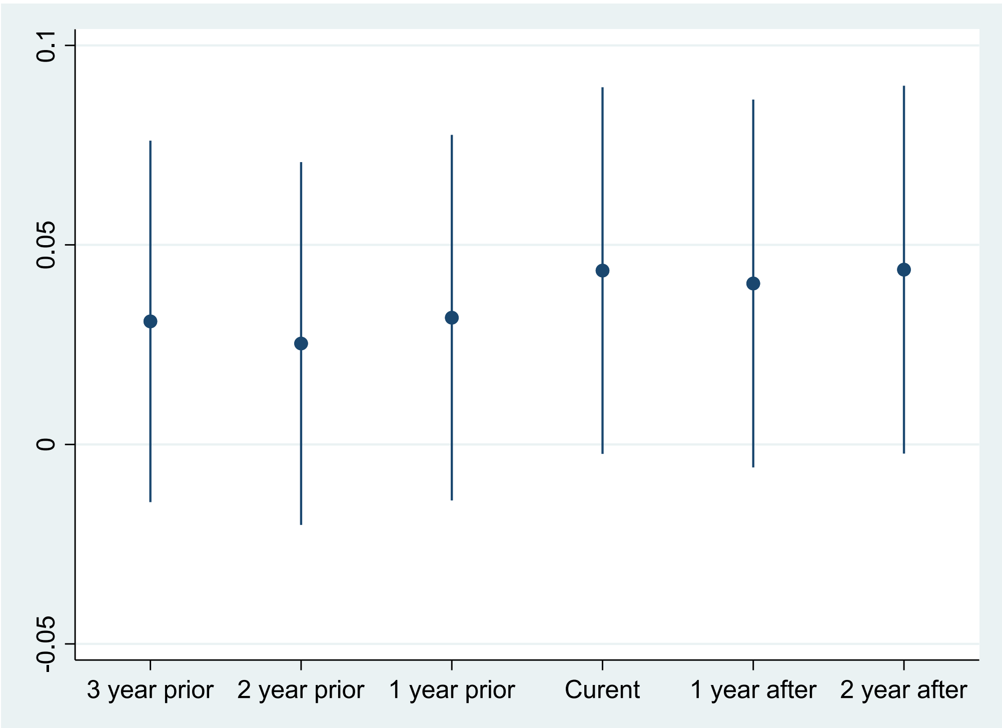


**Figure 1.** Box plot of parallel trend test analysis (based on FE (6) in Table 3).

### *3.2. Robustness Tests*

#### 3.2.1. Placebo Test

In order to ensure that the improvement of energy efficiency is caused by the implementation of the Action Plan policy, this paper conducts a placebo test to eliminate further the influence of other unknown factors on the selection of the policy pilot area [16]. The placebo test mainly refers to the procedure in which pilot provinces in the 30 provinces of the Chinese Mainland are randomly selected as the virtual experimental group, and then a certain number of regression tests are consistent with the benchmark regression. It can provide a robust guarantee for the research conclusions of this paper. The specific operation method is described as follows. Firstly, 19 provinces are selected randomly as the virtual experimental group from 30 provinces and municipalities in the Chinese Mainland, and the remaining 11 provinces are taken as the control group. Secondly, the regression consistent with the benchmark Model (1) is conducted to obtain a random sampling regression result. Finally, 10,000 repeated random sampling experiments are carried out, and the Kernel density distribution map is drawn according to the t values of the policy proxy variable of these random samplings. The specific empirical results are shown in Figures 2 and 3 below.

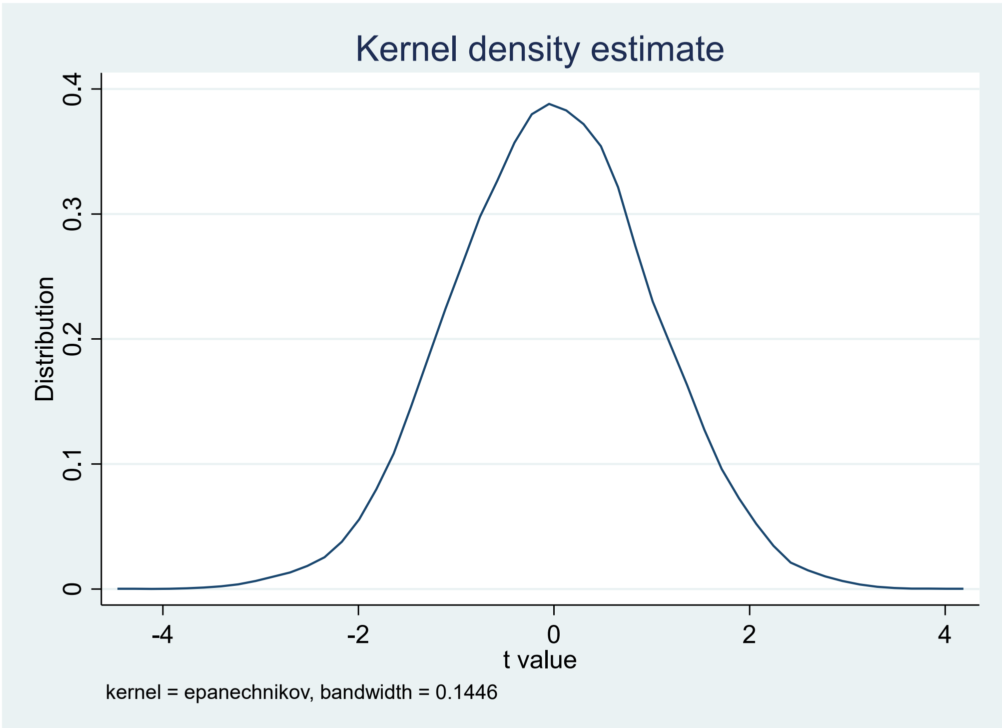


**Figure 2.** OLS estimation of the Kernel density with bandwidth of 0.1446.

As can be seen from Figures 2 and 3, the t values of the estimated coefficients of the policy proxy variable in most sampling estimates are between [−2, 2], and the corresponding *p* values are also above 0.1. This indicates that the Action Plan has no significant policy effect on the virtual experimental group in 10,000 random sampling experiments. Based on this, the placebo test shows that the conclusions are robust.

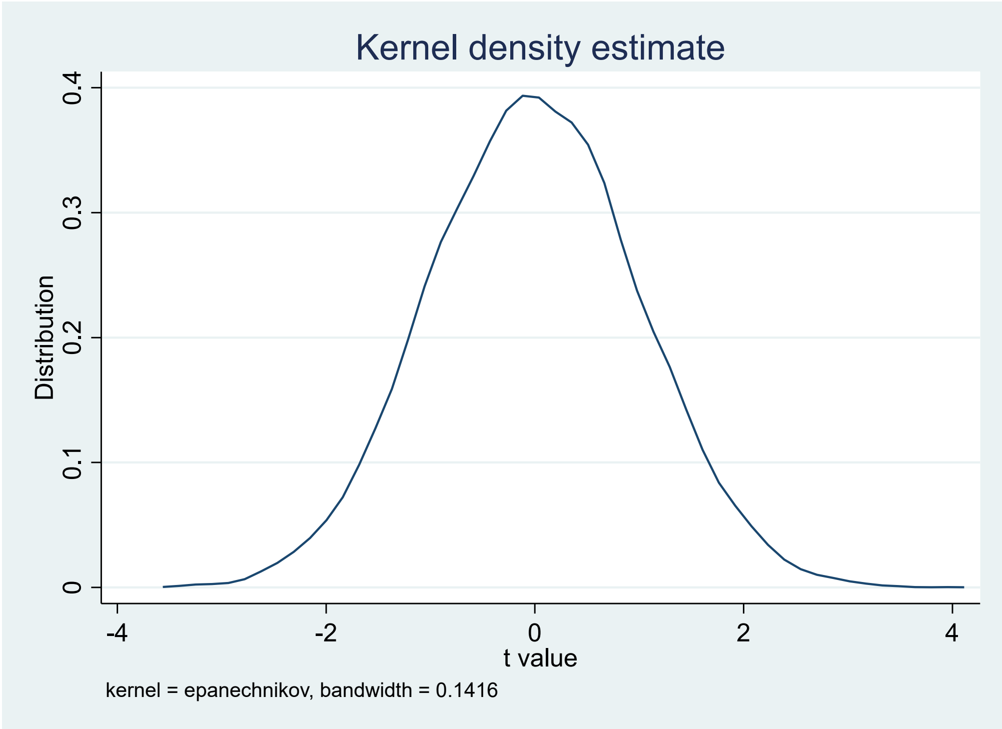


**Figure 3.** FE estimation of the Kernel density with bandwidth 0.1416.

### 3.2.2. PSM-DID Estimation and Replacement of the Explained Variable

As the DID estimation method cannot ensure that the policy pilot area and non-pilot area have the same individual characteristics before the policy implementation, and there are great differences in the economic development level, resource endowment, industrial structure, and technological innovation level among the 30 provinces in the Chinese Mainland, this paper adopts the propensity score matching (PSM) method to solve the problem of individual sample differences that may occur in the DID estimation [18,31]. Specifically, the control variables are taken as the identification features of sample points to match the pilot and the non-pilot areas, and then the regression consistent with the benchmark Model (1) is conducted for the matched data. Specific empirical results are shown in Columns (1) and (2) of Table 5.

**Table 5.** Regression results of robustness tests.

| | PSM-DID (1) | FE (2) | OLS (3) | FE (4) |
|---|---|---|---|---|
| | EE | EE | EE1 | EE1 |
| DID | 0.0476 *** | 0.0476 *** | 0.0837 *** | 0.0837 *** |
| | (3.2742) | (3.4962) | (2.8204) | (3.5277) |
| Control variables | YES | YES | YES | YES |
| Individual fixed effect | YES | YES | YES | YES |
| Time fixed effect | YES | YES | YES | YES |
| _cons | 1.2886 *** | 0.9622 *** | 3.2878 *** | 2.8383 *** |
| | (3.9543) | (3.0795) | (5.3168) | (6.1942) |
| N | 324 | 324 | 420 | 420 |

Note: t statistics are in parentheses; *** $p < 0.01$.

In order to further verify whether the conclusions of this paper are robust, this paper carries out a test by changing the explained variable. After referring to much relevant research, this paper adopts the ratio of total energy consumption to regional GDP to measure energy efficiency (EE1) according to the index structure of single-factor energy efficiency, and then a consistent regression with benchmark Model (1) is carried out. Specific empirical results are shown in Columns (3) and (4) of Table 5.

As can be seen from the regression results shown in Columns (1)–(4) of Table 5, under the two different robustness tests, the estimated coefficients of the policy proxy variable DID all pass the 1% level and are significantly positive. By comparing the above results with the empirical results in Table 4, the estimated coefficient of the policy proxy variable DID does not change much, all passing the 1% significance test, indicating that the Action Plan can effectively promote improved energy utilization efficiency. In a word, the conclusions of this paper are robust.

## 4. Discussion

### *4.1. Heterogeneity Analysis*

The econometric and robustness tests on the benchmark model indicate that the Action Plan can effectively promote the improvement of energy efficiency. In order to further analyze whether the Action Plan has heterogeneous impacts on the energy efficiency of different regions, so as to provide a reference for the government to implement applicable environmental regulations for different regions, this paper employs sub-sample regression to explore whether there are differences in the impact of the Action Plan on energy efficiency in different regions with different resource endowments and different environmental governance levels [39]. According to the differences in resource endowments in different provinces of the Chinese Mainland, this paper divides 30 provinces into the eastern coastal region with relatively high technology and innovation level, the central inland region with a rich population and natural resources, and the remote western region with large policy support and high development potential. In addition, according to the differences in environmental governance levels in different provinces, this paper divides the 30 provinces into the high-environmental-governance-level region and the low-environmental-governance-level region. After the Hausman test, this paper uses the fixed effect model to analyze the heterogeneity of the impact of the Action Plan on energy efficiency in different regions. The specific empirical results are shown in Table 6. Columns (1)–(4) in Table 6 display the empirical results of the whole sample, the eastern, the central, and the western region, respectively. Columns (5) and (6) list the empirical results of regions with high and low environmental governance levels.

**Table 6.** Empirical results of heterogeneity test.

| | FE (1) | FE (2) | FE (3) | FE (4) | FE (5) | FE (6) |
|---|---|---|---|---|---|---|
| | EE | EE | EE | EE | EE | EE |
| DID | 0.0487 *** | 0.1016 *** | 0.0117 | 0.0534 | 0.0096 | 0.0648 *** |
| | (3.7303) | (5.2669) | (0.6175) | (1.5921) | (0.5605) | (3.0472) |
| Control variables | YES | YES | YES | YES | YES | YES |
| Individual fixed effect | YES | YES | YES | YES | YES | YES |
| Time fixed effect | YES | YES | YES | YES | YES | YES |
| _cons | 1.1512 *** | 1.4417 *** | 0.5473 | 1.9248 *** | 1.2413 *** | 1.3729 *** |
| | (4.5608) | (3.7806) | (0.8654) | (4.6447) | (3.0485) | (3.9220) |
| N | 420 | 168 | 112 | 140 | 224 | 196 |

Note: t statistics in parentheses *** $p < 0.01$.

As can be seen from the regression results in Table 6, the estimated regression coefficients of the policy proxy variable DID are significantly positive at the 1% level in Columns (1) and (2) but fail to pass the significance test at the 10% level in Columns (3) and (4), indicating that the Action Plan has heterogeneous effects on the energy efficiency of regions with different resource endowments. This heterogeneity effect is embodied in the fact that the Action Plan can significantly promote the energy efficiency of the eastern coastal region with high resource endowments, while it has no significant impact on the energy efficiency of the central inland region and the remote western region. This may be explained by the following three aspects. First, the implementation intensity of environmental policies is based on the environmental situation that needs to be governed by different regions. The Action Plan mainly targets the eastern coastal provinces of the Chinese Mainland. It has implemented relatively more stringent monitoring measures and environmental objectives for these areas and promoted local industries to increase their investment in environmental governance and improve their production technology and R&D level, thus effectively improving energy efficiency and controlling excessive pollutant emissions in the production process of enterprises. Secondly, the eastern coastal region has a good resource endowment, and their infrastructure construction, foreign investment level, and technological innovation ability are stronger than those in the central and western regions. Based on these advantages, the Action Plan can promote industrial structure transformation and upgrading and drive the innovation and development of green technology in the eastern coastal region, so as to improve energy efficiency and realize the sustainable development of the regional economy [9]. Finally, due to different intensities of environmental governance, the Action Plan has little impact on the energy efficiency of the central and western regions and significantly improves the energy efficiency of the eastern coastal region. Therefore, when formulating environmental regulations, governments need to pay attention to the differences in economic development, infrastructure, and production technology among regions. They should formulate more reasonable environmental governance objectives, and achieve regional differentiated management and control, so as to reduce energy waste and improve the regional green production rate.

From the regression results in Table 6, we can see that the estimated regression coefficients of the policy proxy variable DID are all significantly positive at the 1% level in Column (6), but they fail the significance test in Column (5). This indicates that the Action Plan has different effects on the energy efficiency of regions with different environmental governance levels. This difference is manifested in the fact that the Action Plan has a significant role in promoting energy efficiency in provinces where the investment intensity of environmental governance is weak. However, it has less impact on the energy efficiency of areas where the investment in environmental governance is high. The reason may be that environmental regulations pay more attention to areas with less investment in environmental governance and severe pollution emissions, so stricter environmental regulations are imposed on these areas. Generally speaking, high-pollution and high-emission industries will give priority to areas with low pollutant emission costs and low environmental governance levels. Therefore, compared with areas with higher intensity of environmental governance, these areas with a lower environmental governance intensity will be subject to the key management and control of environmental regulations due to the high-pollution and high-emission industrial attributes [10]. The implementation of the Action Plan can raise environmental awareness in areas where the intensity of environmental governance is low, limit the excessive discharge of local high-pollution and high-emission industries, and increase the pollution control costs of these high-pollution industries, improving energy efficiency and reducing pollutant emissions in the production process. To this end, environmental regulations can effectively improve the industrial structure in areas where the investment intensity of environmental governance is low, promote the green development of the industrial structure, and improve energy efficiency.

Based on the above two different dimensions, it can be seen that the Action Plan has heterogeneous impacts on provincial energy efficiency. Hypothesis 2 is verified.

### 4.2. Impact Path Analysis

In order to further verify the ways through which the promotion effect of the Action Plan on energy efficiency is realized, combined with the theoretical analysis and research hypotheses in Section 2, this paper explores the impact mechanism of the Action Plan on provincial energy efficiency empirically. There is a complex correlation between industrial structure, R&D and innovation investment, and energy efficiency [8]. In this paper, the industrial structure upgrading, the industrial structure rationalization, and the investment intensity of R&D and innovation are introduced as moderating variables, and Models (3)–(6) are used to analyze their moderating effects on the impact of the Action Plan on energy efficiency. Based on the Hausman test, this paper adopts the fixed effect model to analyze the impact mechanism. The specific empirical results are shown in Table 7. Columns (1) and (2) in Table 7 are the empirical results of the moderating effect of the "quantity" and the "quality" of industrial structure upgrading; Column (3) lists the empirical results of the moderating effect of the industrial structure rationalization; Column (4) shows the empirical results of the moderating effect of the R&D and innovation investment intensity.

**Table 7.** Empirical results of the moderating effects.

| | FE (1) | FE (2) | FE (3) | FE (4) |
|---|---|---|---|---|
| | EE | EE | EE | EE |
| DIS1 | −0.2001 ** | | | |
| | (−2.1719) | | | |
| DIS2 | | 0.0087 | | |
| | | (0.2768) | | |
| DRIS | | | 0.2598 *** | |
| | | | (2.8558) | |
| DRDL | | | | 2.1190 *** |
| | | | | (2.6615) |
| DID | 0.5289 ** | 0.0450 ** | −0.0101 | −0.0189 |
| | (2.4068) | (2.0310) | (−0.4352) | (−0.7805) |
| Moderating variables | YES | YES | YES | YES |
| Control variables | YES | YES | YES | YES |
| Individual fixed effect | YES | YES | YES | YES |
| Time fixed effect | YES | YES | YES | YES |
| _cons | 0.4739 | 1.1166 *** | 1.2748 *** | 0.9307 *** |
| | (1.3811) | (4.3865) | (5.1272) | (3.6299) |
| N | 420 | 420 | 420 | 420 |

Note: t statistics in parentheses; ** $p < 0.05$, *** $p < 0.01$.

As can be seen from the regression results of Columns (1) and (2) in Table 7, on the one hand, the estimated regression coefficient of the interaction term DIS1 is significantly negative at the 5% level, indicating that the "quantity" of the industrial structure upgrading hinders the promotion effect of the Action Plan on provincial energy efficiency. On the other hand, the estimated regression coefficient of DIS2, the interaction term between the quality of the industrial structure upgrading and the policy proxy variable, fails to pass the significance test, indicating that the quality of the industrial structure upgrading has no significant moderating effect on the impact of the Action Plan on energy efficiency. From the perspective of industrial structure rationalization, it can be seen from the regression results of Column (3) in Table 6 that the estimated regression coefficient of DRIS, the interaction term between industrial structure rationalization and the policy proxy variable, is significantly positive at the 1% level, which indicates that industrial structure rationalization can increase the promoting effect of the Action Plan on energy efficiency.

It can be seen that different types of industrial structures have heterogeneous moderating effects on the impact of the Action Plan on energy efficiency. On the one hand, the Action Plan can effectively improve the environmental governance ability of industries in each region, strengthen the rational development of the industrial structure, enhance the degree of association and coordination among industries, and form industrial agglomeration. This will help to improve industrial concentration and promote enterprises to allocate and use resources rationally in environmental management, thus improving energy efficiency. On the other hand, the Action Plan can promote the transformation and upgrading of the regional industrial structure and accelerate the industrialization process of each region. In terms of the current level of provincial industrialization in the Chinese Mainland, most provinces are still in the early stage of industrialization, and high-tech industries in economic development dominate only a few provinces. This shows that the industrialization level in each region is still rising gradually. The industrial structure upgrading promotes economic development, but at the same time, it will bring more serious industrial pollution. With the rising of industrialization, the infrastructure and technical equipment of environmental governance cannot keep up with the speed of industrialization, which is likely to cause more serious industrial pollutant discharge problems and affect energy efficiency. Therefore, the industrial structure upgrading weakens the promotion effect of the Action Plan on energy efficiency [18,19]. To sum up, the difference in the focus of the industrial structure will lead to differences in the impact of the Action Plan on energy efficiency; thus, Hypotheses 3 and 4 are verified. Therefore, local governments should actively adjust the direction of industrial structure transformation and upgrading, and form a coordinated development linkage with environmental governance, so as to drive the development of green production technology and promote the improvement of energy efficiency.

From the regression results in Column (4) of Table 7, it can be seen that the estimated regression coefficient of the interaction term DRDL is significantly positive at the 1% level, indicating that the R&D and innovation investment intensity can significantly aggravate the promoting effect of the Action Plan on provincial energy efficiency. This is because, in order to meet the environmental governance standards of the Action Plan, industries need to increase the R&D investment in production technology and innovative green products so as to improve the development of green innovative technology and the energy efficiency of enterprises, thus achieving a win–win situation of energy conservation and emission reduction and economic development [16]. After the implementation of the Action Plan, enterprises in different provinces face stricter environmental regulations, and in order to maintain their competitive advantages and market shares in the product market, they need to increase their investment in R&D and innovation, reduce their energy consumption and resource waste in the production process, and further improve their energy efficiency. Based on this, the R&D innovation investment intensity can effectively increase the effect of the Action Plan on improving provincial energy efficiency, and Hypothesis 5 of this paper is verified. Technological innovation is not only the core factor to improve energy efficiency but also the key factor to drive regional green development. Therefore, in addition to implementing environmental regulations, governments should also introduce relevant policies to actively encourage local enterprises to implement technological innovation, increase investment in R&D and innovation, improve energy efficiency and total-factor productivity, and achieve green and sustainable development.

## 5. Conclusions

Based on the provincial panel data of 30 provinces and municipalities in the Chinese Mainland from 2004 to 2017, this paper explores the overall and regional heterogeneity of the impact of environmental regulations on provincial energy efficiency. Further, the impact mechanism is analyzed through moderating variables of the industrial structure upgrading, the rationalization of industrial structure, and the R&D and innovation investment intensity [11,40]. The basic conclusions are as follows.

Firstly, the Action Plan can promote the improvement of provincial energy efficiency, effectively improving the environmental governance capacity of the region.

Secondly, the Action Plan has heterogeneous effects on provincial energy efficiency. This heterogeneity is embodied in the differences in resource endowments and environmental governance in different regions. On the one hand, the Action Plan has a more significant role in promoting the energy efficiency of China's eastern coastal region, but it has no significant impact on the energy efficiency of Central and Western China. On the other hand, the Action Plan significantly promotes energy efficiency in the regions with a low level of environmental governance, while, for regions with high levels of environmental governance, its impact on energy efficiency is not significant.

Thirdly, there is also heterogeneity in the moderating effect of industrial structure and R&D and innovation input on the impact of the Action Plan on energy efficiency. On the one hand, the "quantity" of industrial structure upgrading weakens the promoting effect of the Action Plan on energy efficiency, and the "quality" of industrial structure upgrading does not have a significant moderating effect. In contrast, the rationalization of industrial structure can strengthen the promoting effect of the Action Plan on energy efficiency. On the other hand, the R&D and innovation investment intensity can significantly increase the promotion effect of the Action Plan on energy efficiency.

Based on the above research conclusions, this paper puts forward the following policy implications by referring to some studies [41,42].

Firstly, governments of all countries should implement targeted environmental policies and gradually strengthen environmental regulations so as to improve the level of production technology, promote energy efficiency, and achieve green and sustainable development.

Secondly, governments should implement regional differentiated environmental regulations to coordinate ecological development and economic development. Governments should consider the differences in the environmental governance capacity, industrial structure, economic development level, and resource endowments of different regions and implement differentiated environmental laws, regulations, and management policies in accordance with local conditions. In addition, governments should actively encourage regions with more experience in energy conservation and emission reduction, production technology, and innovation capacity to spread corresponding production equipment and technology, promoting the development of production technology and the improvement of energy efficiency in backward regions to realize the coordination and rational allocation of regional resources and promote the joint green development of all regions.

Thirdly, local governments should encourage enterprises to increase their investment and efficiency in R&D and innovation, promote the development of low-carbon technologies, and thus promote the rational transformation and upgrading of the industrial structure. In order to better achieve the win–win situation of environmental protection and economic development, enterprises should actively address their environmental protection responsibility and obligations, strengthen pollution information disclosure and promote green production ability, and actively introduce advanced energy conservation and environmental protection technology and management experience, so as to promote energy efficiency and realize the green development of energy conservation and emission reduction.

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