The Impact of Environmental Regulation on the Innovation and Diffusion of Low-Carbon Technology in Energy Sector

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Abstract: The issue of climate change caused by GHG is increasingly serious. As the main emission source, the energy sector has promising potential for emission reduction. In the context of low-carbon technology transition in China’s energy sector, this paper uses panel data of 30 provinces from 2000 to 2017, totally 297,721 patent data, and empirically examines how environmental regulation affects regional energy low-carbon technology innovation and diffusion under the framework of the "Porter Hypothesis". In addition, regional heterogeneity is also considered and the sub-samples of eastern, central and western regions were studied separately. The conclusions show significant heterogeneity in regions. The eastern region, which is less dependent on industries with high emissions and energy consumption, environmental regulation does not affect the innovation and diffusion of low-carbon technology in the energy sector. With the increasing intensity of environmental regulation, only the diffusion of low-carbon technology in the central region has been significantly improved, indicating that this region mainly adopts the introduction and learning of existing low-carbon technologies to meet the demand of emission reduction. Under the circumstances of high risk, uncertainty, sunk cost and opportunity cost brought by low-carbon energy technology, covered companies in western region are more inclined to relocate limited resources to schemes rather than low-carbon innovation.

1. Introduction

Due to rising global temperature caused by the emissions of greenhouse gas from human activities, the ecological environment has been increasingly threatened. The IPCC has put forward the limitation that the temperature should not increase by 2°C by the end of this century. However, the economic development heavily relies on fossil-based energy in long run, and technology is locked in the track of high-emission model. In the energy sector, low-carbon technology transition is particularly needed to realize its emission reduction potential. In order to eliminate the "externality" problem and reduce the uncertainty of innovation, the government needs timely intervention, though there is considerable controversy about whether and how it can affect innovation. Especially, the research about low-carbon technology is insufficient, which has hindered the evaluation of the inducing effect of environmental regulation on technology. Therefore, this article intends to analyze the differences in the impact of environmental regulation in different regions on the two perspectives of technological innovation and technological diffusion in the energy field.

2. Literature review
Studies on climate change and its socio-economic consequences point out that there is a close relationship between human production activities and the energy sector, and the use of fossil energy is a main source of GHGs. Therefore, only by redirecting the economic model based on fossil energy into clean technology can the adverse effects be effectively curbed, and low-carbon technology is an important and least cost tool to realize the scheme [1]. However, the serious “dual externality” has caused market failure in redirecting technology path, the intervention of environmental regulations is needed [2-3]. The “Porter Hypothesis” puts forward that the economic entities covered by environmental regulations can compensate for their costs by innovation, which has attracted close attention by following research [4-5]. However, there are some controversies, for example, Huang et. al. took the energy sector as the research subject and found that environmental regulations can effectively stimulate regional innovation, while Shi et. al. found that environmental regulations inhibited the innovative behavior of enterprises [6-7]. The reason for these contradictions may be failing to distinguish the heterogeneity of the technology, for example, the contents of green, low-carbon and clean technology are different [8]. It may also be the failure to distinguish the heterogeneity of technological activities in response to environmental regulations, for example, technological innovation, adoption or diffusion may be adopted [9]. It may also be the failure to distinguish regional differences, making the overall sample concealed regional structural differences [10]. Researchers believe that technological diffusion is as important as technological innovation, and the patent data is conducive to identifying these structural problems [11-12].

3. Empirical analysis

Due to the information advantages and availability of patent data, it is possible to separate low-carbon technologies in the energy field, and to distinguish the two processes of technological innovation and technological diffusion. This article selects the patent applications amount in the Y02E technology category under the framework of the Cooperative Patent Classification (CPC) to measure the level of low-carbon technologies in the energy sector. And the number of these patents citing is selected as the index for technological diffusion. This index describes the active technological diffusion process from the perspective of technology adoption and learning. It contains the historical reference of this technological innovation, and also implies the innovator’s mastery and learning degree of existing innovations. It is an ideal and reliable indicator to measure technological diffusion. The specific process for the two variables is as follows. Firstly, the bibliographic items of all CPC-Y02E patents applied by Chinese citizens in China from 2000 to 2017 are obtained through the Incopat patent database, and they are sorted by application date. Considering the availability of other data, patents of Tibet, Hong Kong, Macau and Taiwan are excluded, and the remaining patents are divided into 30 provinces. Secondly, considering the problems caused by repeated calculation of patents and patents with low value, the patent family is regarded as a single patent, and patents with less than three countries’ protection are also excluded. Finally, 297721 patents were obtained, and the citing number of these patents are collected either, with the total number of citations 775,165 times.

The explanatory variable is the intensity of environmental regulation which is usually measured by indicators such as pollution emission charges, related public investment and environmental pollution level among which the level of environmental pollution has obvious advantages. Generally, the higher the regional pollution level is, the stricter the environmental regulations are. Specifically, the index we use synthesizes the emission levels of various pollutants into a comprehensive indicator, containing more comprehensive information and less systematic errors introduced by variable selecting. At the same time, this indicator is closely related to the intensity of environmental regulation, but will not have a direct connection with the innovation activities, which reduces the endogenous problem to a certain extent. The specific data processing methods are as follows. Firstly, the emissions of the unit output value of the three important pollutants (sulfur dioxide, smoke, and wastewater) were obtained and treated with the linear standardization. Secondly, the relative importance of different pollutants in each region is considered, weighting by the proportion of regional emission to the total emissions in country during the same period. Finally, the comprehensive indicator of pollutant emission can be calculated by
weighted average, that is, the intensity of environmental regulations. The data mentioned above are all from the China Environmental Statistical Yearbook and the China Statistical Yearbook.

Furthermore, there are many factors influencing the activities related to low-carbon technology. This paper selects some important factors as control variables, including economic development (ED), research funding (RD), foreign direct investment (FDI) and industrial structure (IS). The specific processing as follows: ED is measured by GDP per capita; RD is measured by the stock of scientific research funding per capita, which is accounted by the perpetual inventory method to calculate the public R&D investment over the years as a stock, with a depreciation rate of 15%; FDI is the actual utilization amount of foreign direct investment, converted from USD to RMB according to the average exchange rate over years; IS is measured by the proportion of the output value of the tertiary industry to the secondary industry. At the same time, all the variables related to currency are deflated with the price index with 2000 as the base year. All the data sources from the China Statistical Yearbook, China City Statistical Yearbook, China Science and Technology Statistical Yearbook and the National Bureau of Statistics. Based on the data obtained from the above processing, this paper constructs the baseline econometric model as follows. Model (1) and Model (2) respectively take the amount of patent applications and citations of energy low-carbon technology as the explanatory variables to study the impact of environmental regulation intensity on low-carbon technology innovation and low-carbon technology diffusion.

\[
P_{Ai,t} = \alpha_0 + \alpha_1 \times ER_{i,t} + \beta \times CV_{i,t} + \epsilon_{i,t} \quad (1)
\]

\[
P_{Ci,t} = \alpha_0 + \alpha_1 \times ER_{i,t} + \beta \times CV_{i,t} + \epsilon_{i,t} \quad (2)
\]

In the formula, \(i\) and \(t\) are the numbers of province and year respectively, \(PA\) and \(PC\) represent energy low-carbon innovation and diffusion respectively, \(ER\) is the intensity of environmental regulation, \(\alpha_1\) is the coefficient of environmental regulation, \(CV\) is a vector composed of a selected set of control variables, \(\beta\) is the corresponding coefficient vector, \(\alpha_0\) is a constant term, and \(\epsilon\) is a residual term.

Based on the previous treatment of indicators and data, the empirical analysis uses model (1) and model (2) to study the impact of environmental regulations on energy low-carbon technology innovation and technology diffusion, in order to explore the effects of environmental regulations on technology more comprehensively, and provide more evidence for related research on the "Porter Hypothesis". The empirical results are reported in Table 1. At the same time, China’s regional heterogeneity is included in the analysis framework to further explore the spatial differences in the above-mentioned impacts. The empirical results based on the overall and regional sub-samples are reported in each column of the two tables. On the whole, the study of the "Porter Hypothesis" in this article focuses more on the discussion of structural influence, and attempts to provide preliminary ideas for subsequent in-depth research.

### Table 1. Empirical Results of the impact on low-carbon technology

|                  | Patent Application | Patent Citation |
|------------------|--------------------|-----------------|
|                  | (1)                | (2)            |
|                  | (3)                | (4)            |
|                  | (5)                | (6)            |
|                  | (7)                | (8)            |
| All              | 1.67***            | 0.50           | 0.77           | -1.42***        | -3.59*           | -5.41           | 6.17***         | -1.56**         |
| ED               | (1.68)             | (0.86)         | (0.53)         | (-3.27)         | (-1.71)         | (-0.34)         | (2.75)          | (-2.23)         |
| RD               | 0.11***            | 0.19***        | 0.20**         | 0.02**          | 0.23***         | 0.39***         | 0.24***         | 0.03**          |
| FDI              | (10.75)            | (8.91)         | (2.25)         | (2.26)          | (9.61)          | (7.39)          | (6.52)          | (2.12)          |
| IS               | 0.83***            | 0.54***        | 2.82***        | 0.53**          | 2.38****        | 1.21***         | 0.31            | 1.35*           | 0.81**          |
| (7.10)           | (2.59)             | (5.53)         | (2.38)         | (4.36)          | (0.59)          | (1.71)          | (2.24)          |
| FDI              | -0.84***           | -0.77***       | 0.09           | 0.35**          | -2.16***        | -2.12***        | -1.16*          | 0.83***         |
| (6.41)           | (-3.62)            | (0.24)         | (2.02)         | (-6.95)         | (-3.96)         | (-1.85)         | (2.96)          |
| IS               | 5.33***            | 8.20***        | 1.37*          | 4.40***         | 6.17***         | 18.85***        | -4.09           | -2.64           |
| (4.04)           | (2.85)             | (1.72)         | (4.41)         | (1.99)          | (2.62)          | (-1.03)         | (-1.64)         |
| Hausman          | Fixed              | Fixed          | Fixed          | Fixed           | Fixed           | Fixed           | Fixed           | Fixed           |
| N                | 540                | 198            | 144            | 198             | 540             | 198             | 144             | 198             |
| R²               | 0.588              | 0.663          | 0.666          | 0.465           | 0.445           | 0.509           | 0.713           | 0.430           |
According to the empirical results reported in Table 1, environmental regulations have a nationwide inhibitory effect on energy low-carbon technology innovation. The coefficient (-1.677) has passed the test on the 10% significance level, indicating that the increase in the intensity of environmental regulations may bring high-cost pressure to the covered subjects and they may not be able to quickly respond to the pressure of emission reduction through technological innovation. As a result, more resources are directed to non-R&D departments, thus suppressing the level of technological innovation. Furthermore, according to the analysis of samples in different regions, it can be found that the inhibitory effect embodied in the whole is mainly from the western region. Its corresponding parameter is significantly negative with the improved significance level, passing the 1% significance test. Neither the central nor eastern regions found any impact of environmental regulations on energy low-carbon technology innovation. In line with our research expectations, the difference in economic development makes regional heterogeneity more obvious. The western region is more dependent on the model of high energy consumption and emissions. The energy sector forms a large investment in fixed assets and faces high sunk costs and potential R&D risks, regional economic subjects have insufficient motivation to conduct R&D activities about low-carbon technologies. At the same time, the transformation of energy low-carbon technology means higher capital renewal investment, and the economic development status of the western region is difficult to give priority to support such a large-scale transformation task. In order to alleviate the pressure of environmental regulations, enterprises are more inclined to shift capital from low-carbon technology innovation with the lowest potential return rate to other directions. As for diffusion, environmental regulations show the same impacts across the country. The coefficient (-3.599) passed the test of 10% significance level, which is consistent with the results before. The results show that increasing the intensity of environmental regulations will not only inhibit the innovative behavior of enterprises, but also reduce their motivation to learn and adopt low-carbon technologies. However, the sub-regional samples gave very different results. Among them, the eastern region is still not found to have a significant impact, but the coefficient in the central region has passed the test of 1% significance level, which proves a strong promotion effect, while the western region still has a strong inhibitory effect. The above results indicate that in the face of the increase in the intensity of environmental regulations, the western region chose to reduce low-carbon technology innovation and seek other methods with the similar reasons with the previous analysis. While the central region chose to accelerate the learning and adoption of energy low-carbon technologies, which cannot be observed in the research on technological innovation.

4. Conclusion

Combined with the research background of low-carbon technology transformation in China's energy sector, this paper uses panel data from 30 provinces in China from 2000 to 2017, processing a total of 297,721 patent data and corresponding citation information, and empirically tests how environmental regulation affects regional energy low-carbon technology innovation and diffusion under the framework of the "Porter Hypothesis". Furthermore, taking full account of the heterogeneity of regional economic development, the eastern, central and western sub-samples are also studied separately. The research conclusions are as follows: (1) Due to the high level of economic development and industrial structure optimization in the eastern region, it has better R&D resource support and is adapted to the basic needs of low-carbon technology advancement in the energy sector. At the same time, the region’s dependence on high-emission and high-energy-consuming industries is low, and there is less resistance to low-carbon technology transformation. Therefore, environmental regulation is not the main factor affecting the innovation and diffusion of low-carbon technology in the energy sector in the region. (2) With the increase in the intensity of environmental regulations, the diffusion level of energy low-carbon technologies in the central region has been significantly improved, but the impact of the intensity of environmental regulations on its innovation level is not significant, indicating that the central region mainly adopts the introduction and learning of existing low-carbon technologies to deal with the pressure of environmental regulations. (3) The low-carbon technology R&D foundation in the western region is relatively weak, and it relies heavily on the development model of high emissions and high energy
consumption. In the case of high risk, high uncertainty, high sunk cost and high opportunity cost brought by energy low-carbon technology, regional economic entities are more inclined to transfer limited resources to other directions that can alleviate the pressure of environmental regulations.

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