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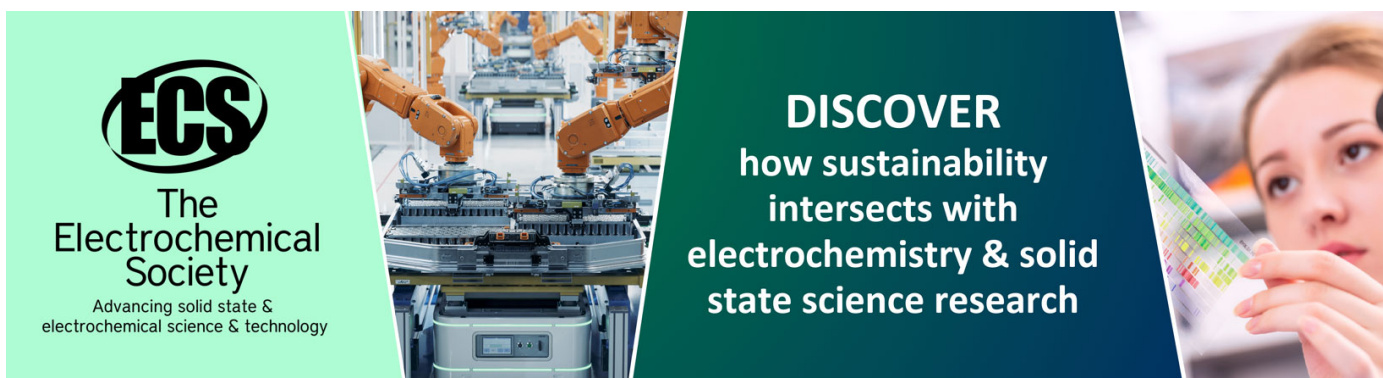
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The knowledge spillover effects of green technology innovation of low carbon regulation

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Abstract: The green technology spillover (*GTS*) is conducive to follower's innovation opportunities but harmful to pioneer's innovation advantages. Based on the knowledge production function and the panel data of cities in China, this paper discusses the effects of *GTS* on the relationship between the low carbon regulation (*LCR*) and the green technology innovation (*GTI*) by using the Spatial Durbin Model. We found that *LCR* makes a decrease-increase effect of the pioneer's *GTI* different from an increase-decrease effect of the follower's *GTI*.

1. Introduction

The environmental regulations are regarded as an important way to potentially directly reduce carbon emissions, and it also indirectly reduce carbon emissions through technical efficiency (Pei et al., 2019)^[1]. At the present time, the pandemic may significantly reduces global CO₂ emissions in 2020, which will probably rise again as governments and industries pause investments in clean energy and infrastructure (Zeke et al., 2020)^[2]. However, more enterprises, struggling hard to recover from the trauma of pandemic, have to rely on green technology knowledge spillover instead of green technology innovation to deal with the impact of environmental change.

The green technology spillovers are the unconscious knowledge fission, which can acquire some valuable knowledge base without paying for the knowledge creator (Ibrahim et al., 2005)^[3]. With the help of them, the followers who are indirectly affected by low carbon regulation, can reduce carbon emissions and improve green technical efficiency, which would get high returns with low input. But for the pioneer, their comparative advantage comes from the green innovation which will take a lot of time and cost, is directly affected by low carbon regulation, and weakened by the green technology spillovers.

Based on the above-mentioned analysis results, this study uses panel data of Chinese cities for spatial econometric regression to examine whether green technology spillovers can regulate the relationship between low carbon regulation and green technology innovation. This paper also discusses the effective path of coordinated development between the pioneer and the follower, which not only helps the enterprises to continuously acquire the advantage of green technology innovation but also promotes the extensive application of green technology knowledge.

2. Literature review

In essence, green technology innovation is a process of knowledge creation in which a series of



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knowledge elements are integrated and reconstructed. Since Joseph Schumpeter's innovation theory was put forward, many scholars have done a lot of empirical research on knowledge innovation by using input and output variables. After Nelson expounded the problem of optimal allocation of knowledge resources, Griliches put forward the concept of the knowledge production function. It is assumed that the output of innovative knowledge is a function of the input of capital and personnel in scientific research activities. On this basis, Jaffe further improved the knowledge spillover model, as the non-exclusiveness of technical knowledge is easy to be imitated, and the non-competition of technical knowledge leads to the knowledge spillover effect(Jaffe, 1993)^[4].

Green technological spillover is embodied in knowledge exchange, which drives enterprises to carry out green technology innovation and promotes Eco-efficiency (Storper et al., 2004). This paper studies the double-effect model of low carbon regulation, which takes into account both enterprise performance and Eco-efficiency (Hu et al., 2020)^[5]. On one hand, green technology spillover has gone through a series of stages of searching, acquiring, internalizing and applying green knowledge elements, which are embodied in the forms of green cooperation, green technology transformation, and green product flow, etc. (Bi et al., 2016). As the result expands the scope of green technology application, the followers pay a lower cost to use carbon reduction technology for production and operation, which is conducive to enterprise green innovation. The green technology tacit knowledge formed by the internalization of industrial clusters has the characteristics of environmental dependence and not easy to code, which lays the knowledge foundation of sustainable competitive advantage and increases the overall knowledge stock of industrial clusters, and also contributes to the accumulation of green innovation knowledge (Chen et al., 2020)^[6]. Wang (2015) found that knowledge spillovers play a positive role in regulating the relationship between innovation input and output, which can improve the level of innovation output and enhance regional innovation capability. According to Audretsch (2004), the clear division of tasks and clear cooperative relations among enterprises in industrial clusters can reduce transaction costs, increase the frequency of knowledge spillovers and stimulate the vitality of scientific and technological innovation. Therefore, the green technology spillover is beneficial to the green innovation of the regional industrial cluster, but the impact on the pioneer green innovation is still controversial.

On the other hand, green technology spillover promotes green efficiency growth, which is affected by external factors, including enterprise property rights, technology, talent, industry, and other structural heterogeneity factors (Liang et al., 2019). Inter-industry technological spillovers are beneficial to the growth of green total factor productivity, depending on the structural types of human capital and technological capital of enterprises. Pan et al. (2011) investigated inter-industry technological spillovers, have a significant positive impact on industrial labor productivity, whose productivity elasticity is higher than the industry direct research input. Wang et al. (2020) showed that inter-industry spillovers contribute to the growth of the manufacturing's green total factor productivity, with high tech relying on its own R&D stock and low-tech industries relying on technological advances in related industries. In other different views, green technology spillover which caused by unconsciousness, has a negative impact on the competitive characteristics of product markets. Peng et al. (2019) have found that the knowledge spillover of technologists can restrain the positive influence of product market competition on the technical efficiency.

From the perspective of regional industrial development, scholars have studied the knowledge spillover effect that contributes to the overall green efficiency. But they seldom consider the individual feelings of the pioneers. If the green technology knowledge overflow, which can delays the R&D return and makes the innovation compensation advantage disappear, is a double impact on the pioneer. How can we promote green innovation enthusiasm? And follower will easily develop the habit of "path dependence", if they take advantage of the technical knowledge base of "gains without pains" to reap more unexpected value and the requirement of carbon reduction by waiting for green knowledge spillover. Why they have to do green innovation? Not only that, but the asymmetry caused by green technology spillover may also lead to adverse selection problems. In the absence of low carbon regulation, enterprises are driven by external forces to restrain the stock of non-green technology

knowledge. Although it can stimulate the green technology innovation, it also stimulate the non-green technology innovation, Therefore, we should strengthen the guiding role of low carbon regulation policy and balance the uncoordinated benefits caused by green technology spillover.

3. Methodology and research design

3.1. Models

In previous related studies, based on the aforementioned theoretical analysis, and combining the inter-industry spillover effect (Jia et al., 2014) and the local-neighborhood effect of green technology (Dong et al., 2019)^[7], a spatial Dubin model was conducted by Tientao (2016)^[8] as follows:

$$\ln GTI_{it} = \alpha + \lambda W \ln GTI_{it} + \beta_1 \ln LCR_{it} + \beta_2 (\ln LCR_{it})^2 + \beta_3 GTS_{it} + \beta_4 \ln X_{it} + \delta_1 W \ln LCR_{it} + \delta_2 \ln W (\ln LCR_{it})^2 + \delta_3 W \ln GTS_{it} + \delta_4 W \ln X_{it} + \xi_{it} \quad (1)$$

Where GTI represents green technology innovation. In the equations, LCR and GTS represent the low carbon regulatory intensity and the green technological spillovers, respectively. There is a quadratic non-linear relationship between green technological innovation and the low carbon regulatory intensity in Eq. (1). X denotes control variables; W represents the space weight effect. i is the sample, and t indicates the year. ε indicates random disturbance terms.

3.2. Spatial weight matrix

In this paper, we use four spatial weight effects: $W1$, as the inverse distance matrix calculated by Arcgis to represent the spatial weight effect between cities; $W2$, as the diagonal matrix constructed by the difference of cities to represent the economic distance; $W3$, represents the distance of industrial agglomeration, constructing the diagonal matrix of the difference of industrial agglomeration of the cities which multiplying $W1$; $W4$, represents the distance of R&D capability, obtaining from the diagonal matrix of each city's financial expenditure on science and technology to multiply by $W1$.

3.3. Data sources and descriptive statistics

(1) The explained variable is the green technology innovation (GTI), taking into account the current state of green process output innovation, as measured CO₂ and SO₂ emissions by the ratio of urban industrial value-added. The lower the carbon emission per unit of output, indicating the higher the level of green technology innovation.

(2) The main explanatory variable is low carbon regulation (LCR). According to the research method of Dong et al. (2019), considering the effectiveness of CO₂ and SO₂ emissions, through the calculation of cities' emissions composite index to measure, the steps are as follows: first, using the proportion of the province where the city is located multiplied by the number CO₂ and SO₂ emissions; second, the maximum-minimum method is used to standardize the treatment; Third, the ratio of each pollutant emission to the average urban emission is used as a factor to adjust the standardized emission, take the average of the adjusted, and both emissions as the low-carbon regulatory intensity.

(3) The moderator variable is green technology spillover (GTS), considering the research of Dong et al. (2019), based on the World Intellectual Property Organization's Green Patent Code, use the patent inquiry website of the China Intellectual Property Office, by searching and matching the patent type, IPC classification code and the address of the patent applicant. We can get the green patent data of different cities based on the knowledge production function of Gilliches-Jaffe, the general measurement model of green technology spillovers is constructed:

$$\ln GTS_{it} = \alpha + \eta \ln H_{it} + \phi \ln RD_{it} + \varepsilon_{it} \quad (2)$$

In Eq. (2), GTS represents the green technological spillover; H is the human capital and RD denotes the scientific research input. R&D capital and labor were identified as input variables.

(4) Other variables: This study chose human capital (H) and information technology (IT) as the control variables. The human capital was measured by the product of Urban employments and average education. Information technology (IT) measured by the number of urban internet users. Additionally,

R&D investment (RD) measured by the full-time equivalent of urban personnel.

A set of data for the above variables is selected from the statistical yearbook of each city and province, about 2,052 valid samples from 171 cities in China as the basic data for the model test.

4. Empirical results and discussions

Firstly, we selected OLS to obtain the value of green technology spillovers by using Eq. (2). The number of green technology patents granted to represent the green technology progress as the explained variable, and the human capital (H) and the R&D investment (RD) as the main explanatory variable. The coefficients derived from the regression form the green technology spillover equation: $\ln GTS = 1.666 \times \ln H + 0.123 \times \ln RD - 22.906$. By this formula, the value of green technology spillover is estimated and replaced by Eq.(1) for spatial regression, and the empirical results are shown in Table 1.

In the present study, it was found that the regression results of Models (1)-(4) had indicated that the level of green technology innovation of the pioneers shows a trend of decreasing first and then increasing with the increase of low carbon regulation intensity. In the short term, due to the compliance cost of the "Porter Hypothesis", the environmental cost is pushed up, the enterprise profit level is declining, and the R&D personnel is lost, which makes the green technology knowledge spill out along the direction of diversification strategy. Thus, the pioneer's green technical barriers are disappearing, and the willingness of green technology innovation is also restrained, which shows that the green technological innovation level is declining. From the long-term practice, more enterprises are affected by low carbon regulation. The high-carbon enterprises are not only sensitive to regulation but also have good R&D ability and learning ability, they can adjust the development path of green technology innovation timely. When crossing a certain inflection point of low carbon regulation intensity, it can promote the green technological innovation level.

Table 1. Green technology spillover effects of low carbon regulation

Variables	Pioneering effects				Following effects			
	(1)W1	(2)W2	(3)W3	(4)W4	(5)W1	(6)W2	(7)W3	(8)W4
$\ln LCR$	5.6904*** (0.9159)	4.9747*** (0.9247)	5.2188*** (0.9110)	5.0494*** (0.9459)	-45.3025*** (9.4923)	-9.4560 (6.0288)	-19.1671*** (3.9890)	-2.5332 (7.0396)
$(\ln LCR)^2$	-0.9333*** (0.2080)	-0.8121*** (0.2121)	-0.8868*** (0.2088)	-0.7896*** (0.2182)	8.9253*** (2.3749)	1.5628 (1.0202)	2.4089*** (0.5734)	0.5063 (1.1901)
$\ln GTS$	22.3165*** (6.4066)	16.0363** (5.7598)	9.4886 (5.9562)	17.3797** (5.3198)	59.7213** (24.1592)	120.8445*** (31.8799)	108.5404*** (22.1220)	132.1001*** (37.8151)
$\ln H$	-34.8771** (10.7336)	-24.3755** (9.6610)	-13.4563 (9.9822)	-26.5260** (8.9427)	-93.9533** (41.2474)	-199.3152*** (53.4818)	-181.7714*** (37.2992)	-215.9419*** (63.1475)
$\ln ET$	-0.4869** (0.2231)	-0.5201** (0.2258)	-0.5086** (0.2218)	-0.5572** (0.2295)	-6.7370*** (1.5062)	-4.7468** (1.4616)	-3.1450*** (0.8655)	-4.2469** (1.4066)
$R-sq$	0.074	0.261	0.197	0.269	0.074	0.261	0.197	0.269

Notes: Standard error in parentheses; ***, **, * denote statistical significance levels at 1%, 5%, 10%, respectively.

For the follower, the effects in the empirical results are different from the pioneer effects. In the present study, based on the results obtained using Models (5)-(6), the green technology innovation level increases first and then decreases with the increase of the low carbon regulation intensity under the spatial distance Matrix and the industrial distance Matrix. In the short term, because of the technological neighborhood, the green technology knowledge of the pioneers spills over to the adjacent industries. The followers take advantage of the "preemptive advantage" and the spilled knowledge base, which getting twice the result with half the effort. However, this green technology follow-up strategy is not a long-term solution, they will soon fall into a passive situation without the support of the second green technology innovation. So that followers' green technology innovation

level would decline.

There is also a relationship between green technology spillovers and green technology innovation in Table 1. From the perspective of the pioneer effect, $W1$, $W2$, and $W4$ are significantly positive, indicating that knowledge spillovers make it difficult for the pioneer to obtain all the advantages of innovation. It could lose R&D costs to weaken the green innovation advantages of the pioneer. So, the pioneering effect needs external compensation for the green innovation toughness of enterprises. For the following effect, there are more opportunities for the enterprise's knowledge element fission, innovation, and sharing, and green technology knowledge spillover also significantly reduces the green technology innovation level, so the following effect needs to carry on the second green innovation to maintain the optimal effect.

5. Conclusions and implications

This paper examines the role of green technology spillovers in the relationship between low carbon regulation and green technology innovation, based on the knowledge production function and panel data of Chinese cities and listed companies. Based on the above empirical results, this study draws the following conclusions: The low carbon regulation has the pioneering effect of reducing first and increasing later and the following effect of increasing first and decreasing later on the innovation level of green technology. The forcing policy urges the pioneer to transfer investment from the high-carbon industry to the low-carbon industry, which reduces the innovation level of green technology. And the followers absorb the green technology knowledge overflow, will promote the level of green technology innovation.

The research of this paper shows that the knowledge gap of green technology can promote the carbon reduction effect of enterprises. Some useful policy recommendations were put forward as follows: First, we should know the dual nature of green technology spillovers, and develop cooperation among government, industry, universities and research institutions to enhance the ability of knowledge transfer, diffusion and absorption, and to avoid repeated investment and reduce the cost of carbon reduction. Second, we should also compensate enterprises for their resilience in green innovation, pay attention to the protection of green technology intellectual property rights, and promote enterprises to carry out green technology innovation activities continuously. Third, we should make use of the advantages of "internet plus" and technological talents to create a green technology knowledge-sharing platform. The financial funds, private equity funds, and other forms will be used to purchase green technology intellectual property rights and advocate the application of green technology. These changes will accelerate the application and dissemination of green carbon reduction technologies and guide more enterprises to make secondary green technology innovations through the sharing mechanism of intellectual property rights.

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