The Impact of OFDI on Green Technology Innovation in China

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Abstract. Green technology innovation is one of the important driving forces to promote green development of China’s economy. Based on the panel data of 29 provinces, municipalities and autonomous regions in China and the mechanism of Outward Foreign Direct Investment (OFDI) on green technology innovation, this paper introduced different spatial weights and established a Spatial Durbin Model (SDM) to study the impact of OFDI on China’s green technology innovation according to the hypothesis proposed in this paper. It is found that OFDI can significantly promote China’s green technology innovation, which is under the influence of different spatial weights, and presents a significant spatial spillover effect. However, there are obvious regional differences in the spatial impact of OFDI on green technology innovation, and the spatial spillover effect in some regions is not significant enough. Then the change of international investment environment will affect the spatial spillover effect of OFDI on China’s green technology innovation. Moreover, OFDI has significant nonlinear characteristics in its impact on green technology innovation. After crossing the threshold, OFDI has significantly increased its impact on green technology innovation, which further confirms that OFDI can effectively promote China’s green technology innovation and it can promote China’s green economic development. Keywords: Investments, International trade, Environmental technology, Spatial distribution, Nonlinear equations.

1 Introduction

Since the initiation of reform and opening up, the pressure of environmental pollution in China has gradually increased with the rapid development of the economy. With the advancement of sustainable development concepts and ecological civilization construction, China has proposed and implemented a new development concept of “innovation, coordination, green, open, and shared.” At the same time, China adheres to the strategy of “going out” and “bringing in” and emphasizes high-level opening up to the outside world. Outward foreign direct investment (OFDI) is not only an important manifestation of “going out,” but it also enables China to acquire advanced technology, provide better support and inspiration for domestic enterprises’ research and development and innovation, and enhance the international competitiveness of enterprises (Buckley et al., 2007) [1]. On the other hand, green technology

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innovation is one of the important driving forces for the country’s economic green transformation and the realization of green development. Therefore, under the new development pattern, how China can make use of the green technology innovation spillover effect brought by OFDI to better assist enterprise green technology innovation, promote the green transformation and development of enterprises, and further contribute to the green development of the Chinese economy is a significant issue worthy of research.

In the following chapters, after reviewing the literature of related foundational issues, this paper will conduct a detailed analysis of the impact of OFDI on green technology innovation in China and potential variations in such impact. Subsequently, this paper will establish a spatial Durbin model and a threshold model, utilizing provincial panel data to empirically analyze the spatial and threshold effects of OFDI on green technology innovation in China, and conduct heterogeneity, endogeneity and stability tests. Finally, this paper will present corresponding recommendations.

2 Literature Review

Currently, research on the relationship between the development of OFDI and green technology innovation, as well as its reverse green technology spillover effect, has sparked much discussion among scholars.

Research has found that OFDI has a significant promoting effect on the technological progress of the home country (Kogut and Chang, 1991; Huang and Wang, 2009) [2], [3], and there is a significant spatial spillover effect of OFDI on the technological progress of the home country (Huang and Yan, 2020) [4]. Further examination has led some scholars to believe that foreign direct investment can have a positive impact on the home country’s green technology innovation through reverse green technology spillover (Albornoz et al., 2009) [5], as the interaction between host country firms and foreign investors leads to the transfer of knowledge and skills, the import of advanced technology and equipment, and the adoption of best practices and standards by home country firms (Kim and Adilov, 2012) [6]. As multinational corporations are exposed to new advanced green technologies and processes, they can not only help themselves achieve green transformation, but also stimulate green technology innovation in the home country (Maksimov et al., 2022) [7]. Additionally, the impact of OFDI on green technology innovation in the home country is also affected by the home country’s technological absorption capability, and there is significant regional heterogeneity (Qin et al., 2022) [8]. Literature also suggests that the impact of OFDI on green technology innovation in the home country is also influenced by factors such as the level of environmental regulations and policies in the home country (Dai et al., 2021) [9], and under certain conditions, there are significant non-linear characteristics (Liu et al., 2021) [10].

However, the aforementioned literature indicates that OFDI can play a positive role in promoting the transfer of green technologies and practices to the home country, but the specific impact of OFDI on green technology innovation in China remains worthy of further research. Additionally, there is limited discussion on the impact of changes in the international economic environment on reverse spillover effects on green technology innovation in the home country.

Therefore, this paper seeks to further study the impact of OFDI on green technology innovation in the home country, building upon existing research, and make its own marginal contribution to the field. The main issues considered in this paper are: What is the impact of OFDI on green technology innovation in China? Is there a spatial spillover effect? How does the regional spatial distribution and changes in the international economic environment affect the spatial effect of OFDI on green technology innovation in China? Are there threshold
effects on the impact of OFDI on green technology innovation in the home country during the study period.

3 Theoretical Analysis and Research Hypothesis

Overall, technology-oriented OFDI primarily involves investment by large and medium-sized enterprises in the industry. This type of OFDI involves learning advanced technologies in the host country through means such as technology research and development cooperation, horizontal competition, and mergers and acquisitions, and transferring foreign advanced green technologies to the home country (Kim and Adilov, 2012) [6]. Additionally, OFDI also aims to track and imitate green technologies in the production and research and development of enterprises in the host country, cultivate relevant technical personnel within the company, and subsequently bring advanced green technologies back to the parent company through internal personnel exchange, as a way to prepare for the upgrading of green technologies of enterprises and the technological upgrading of the whole industry. However, it’s worth noting that technological innovation requires significant investments in capital, infrastructure, talent reserve and other elements, and tends to flow from low economic level regions to high economic level regions (Han et al., 2012) [11]. As China continues to promote high-level opening-up, enterprises in areas with higher economic level can access advanced green technologies through OFDI to promote the green technology upgrading of local enterprises. These efforts can not only improve the industrial technology level of the region, but also produce a spatial spillover effect of technological innovation, radiating to the surrounding areas.

Based on this, we propose the Hypothesis 1:

Hypothesis 1. OFDI in China has a positive impact on the advancement of green technology innovation, and it’s expected to have a spatial spillover effect on the progress of green technology.

From a regional perspective, economic differences in China have undergone a process of "first small increase and then sustained decline" since 2000, and intra-provincial differences are greater than regional differences (Feng et al., 2015) [12]. During this period, green innovation has had a positive spatial spillover effect (Peng et al., 2021) [13] and there is a spatial concentration of technological innovation level differences among regions (Song and Zhao, 2018) [14]. The eastern region has better economic level, infrastructure and human resources than the western region, with an innate advantage in technological innovation, and in addition, high-tech industries develop faster in the eastern region, and also leads the country in implementing green development and sustainable development. However, the spatial distribution of regional differences will make it necessary to further study the spatial impact of OFDI on green technology innovation. Based on this, we propose the Hypothesis 2.

Hypothesis 2. The spatial spillover effect of OFDI on green technology innovation in China exhibits regional variations

Generally speaking, international capital flows allow savings to flow to countries with more productive investment opportunities, and allow countries subjected to different shocks to better share macroeconomic risks (Milesi-Ferretti and Tille, 2011) [15]. After the reform and opening up, China’s industrial production and production technology have been rapidly improved after accepting many investments from developed countries. However, the two global crises in 2008 and 2012 made developed countries aware of the hollowing out of the manufacturing industry and controlled the transfer of high technology. In addition, in recent years, the US-China trade friction has increased the difficulty for Chinese companies to invest and learn advanced technology in the United States. Therefore, the change of the international capital flow environment will to some extent affect the spatial effects of OFDI on China’s green technology innovation. Furthermore, OFDI has significant nonlinear characteristics
and threshold effects on China’s technology progress (Piao and Yu, 2022) [16]. As part of technological innovation, OFDI also has threshold effects when it comes to influencing green technology innovation (Liu et al., 2021) [10]. However, with the extension of the observation period, whether the nonlinear effects of OFDI on China’s green technology innovation are still significant deserves further discussion. Based on this, we propose the Hypothesis 3 and Hypothesis 4.

Hypothesis 3. The spatial effect of OFDI on green technology innovation will be affected by changes in the international economic environment.

Hypothesis 4. OFDI has a nonlinear impact on green technology innovation, with a threshold effect.

4 Data and Methods

4.1 Data and Variables

Through an examination of the action mechanisms and in light of prior research, the key factors that impact the impact of China’s OFDI on green technology innovation have been identified.

In this study, the number of green utility model patents obtained in a given year is utilized as the dependent variable to represent advancements in green technology (lnGreen). Despite the fact that some researchers argue that green total factor productivity (Peng et al., 2021; Xie and Thompson, 2022) [13], [17] or the number of green patent licenses (Yang and Liu, 2021) [18] can better indicate China’s green technology innovation. However, we think it is posited that the practical green patents obtained by different regions in the same year are more easily implemented, can accelerate the efficiency of technology conversion, and have stronger timeliness and practical application in enhancing the level of green technology in a specific region. The green patent data is logarithmized in this research to reduce potential inaccuracies.

The OFDI stock is used to be the explanatory variable (lnofdi). Then we use OFDI flow data as a substitute in the robustness test (lnofdi2) and test the stability of the model by lagging the variables by one period (lnofdi_1). In order to avoid potential biases in the estimation process, the OFDI variables data is also quantized in the empirical analysis.

Also, we include a variety of control variables that have been shown elsewhere to be significant determinants of green technology innovation. The following variables are used: (1) Export effect (ex), represented by the ratio of total exports to total imports and exports of domestic destinations and goods sources. (2) Openness to the outside world (fdi), measured by the ratio of actual foreign capital utilization to GDP. (3) Human resource reserve (Hr), reflected by the proportion of individuals with higher education in the total working population. (4) Economic development level (lnrjgdp), expressed by GDP per capita to indicate the wealth of the region, which is also logarithmized to reduce potential bias.

We apply provincial panel data from 29 provinces, cities, autonomous regions, and municipalities in China (excluding Hainan Province, Tibet Autonomous Region, Hong Kong, Macao and Taiwan) from 2004 to 2019. Among them, the data of green patents is taken from the “Chinese Research Data Services (CNRDS)”, and the data of the OFDI is from the “Statistical Bulletin of China’s Foreign Direct Investment”. The data of control variables were from the “China Statistical Yearbook on Science and Technology”, “Educational Statistics Yearbook of China” and the “Official website of National Bureau of Statistics”. In addition, the variables related to economic factors in the above variables have been adjusted (with 2004 as the base period), and some missing values are supplemented by the moving average method with trends.
Table 1. Descriptive statistics of key variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>lnGreen</td>
<td>464</td>
<td>6.406</td>
<td>1.642</td>
<td>0.693</td>
<td>10.163</td>
</tr>
<tr>
<td>lnofdi</td>
<td>464</td>
<td>11.499</td>
<td>2.233</td>
<td>4.625</td>
<td>16.474</td>
</tr>
<tr>
<td>lnofdi2</td>
<td>464</td>
<td>2.972</td>
<td>1.696</td>
<td>0.000</td>
<td>7.054</td>
</tr>
<tr>
<td>lnofdi_1</td>
<td>435</td>
<td>11.363</td>
<td>2.216</td>
<td>4.625</td>
<td>16.474</td>
</tr>
<tr>
<td>ex</td>
<td>464</td>
<td>0.243</td>
<td>0.467</td>
<td>0.000</td>
<td>2.903</td>
</tr>
<tr>
<td>fdi</td>
<td>464</td>
<td>0.058</td>
<td>0.735</td>
<td>0.000</td>
<td>15.858</td>
</tr>
<tr>
<td>Hr</td>
<td>464</td>
<td>0.113</td>
<td>0.072</td>
<td>0.027</td>
<td>0.505</td>
</tr>
<tr>
<td>lnrjgdp</td>
<td>464</td>
<td>10.198</td>
<td>0.618</td>
<td>8.353</td>
<td>11.624</td>
</tr>
</tbody>
</table>

Table 2. Moran’s I index and its significance

<table>
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<tr>
<th>Year weights</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>W0</td>
<td>0.273***</td>
<td>0.285***</td>
<td>0.306***</td>
<td>0.309***</td>
<td>0.308***</td>
<td>0.381***</td>
<td>0.364***</td>
<td>0.383***</td>
</tr>
<tr>
<td>W1</td>
<td>0.257***</td>
<td>0.238***</td>
<td>0.257***</td>
<td>0.271***</td>
<td>0.263***</td>
<td>0.312***</td>
<td>0.301***</td>
<td>0.314***</td>
</tr>
<tr>
<td>W2</td>
<td>0.235***</td>
<td>0.219***</td>
<td>0.236***</td>
<td>0.249***</td>
<td>0.248***</td>
<td>0.286***</td>
<td>0.278***</td>
<td>0.287***</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>W0</td>
<td>0.419***</td>
<td>0.402***</td>
<td>0.405***</td>
<td>0.463***</td>
<td>0.470***</td>
<td>0.456***</td>
<td>0.467***</td>
<td>0.488***</td>
</tr>
<tr>
<td>W1</td>
<td>0.317***</td>
<td>0.317***</td>
<td>0.337***</td>
<td>0.355***</td>
<td>0.343***</td>
<td>0.329***</td>
<td>0.324***</td>
<td>0.332***</td>
</tr>
<tr>
<td>W2</td>
<td>0.293***</td>
<td>0.288***</td>
<td>0.303***</td>
<td>0.310***</td>
<td>0.300***</td>
<td>0.296***</td>
<td>0.304***</td>
<td></td>
</tr>
</tbody>
</table>

Note: ***, **, and * show the significance levels of 1%, 5%, and 10%.

4.2 Models

1. Spatial autocorrelation analysis

In order to analyze the spatial autocorrelation of green technology innovation, we employ the use of Moran’s I index. The index ranges from -1 to 1, with a positive value indicating positive autocorrelation, a negative value indicating negative autocorrelation, and a value close to zero indicating a random spatial distribution with no autocorrelation. The results of the Moran’s I test can be found in Table 2.

In addition, to evaluate the spatial correlation of green technology innovation in China, this study utilizes three different spatial weight matrices. The first is the adjacency matrix (W0), which is based on the proximity of regions to one another. The second is a geographic matrix (W1), which is calculated using the reciprocal of the direct distance between regions. The third is an economic matrix(W2), which combines the per capita GDP with the geographic matrix. The formula used for this calculation is as follows:

\[ W_2 = W_1 \times \text{diag}(\bar{Y}_1^2) \]

In Eq. (1), \( \bar{Y}_i = \frac{1}{n_{i-1}} \sum_{i=1}^{n} Y_{ii} \cdot \bar{Y} = \frac{1}{n} \sum_{i=1}^{n} \bar{Y}_i \), \( \bar{Y}_i \) is the average value of the adjusted real GDP per capita of region i from 2004 to 2019, denotes the average of for all regions.

As observed in Table 2, the global spatial correlation of China’s green technology progress is highly significant under the influence of various spatial weight matrices. Specifically, when using the spatial adjacency weight (W0), the Moran’s I index increases over time, indicating that the spatial correlation of green technology progress is becoming stronger.

Additionally, by analyzing the local spatial correlation changes of green technology innovation, as seen in figure 1 and figure 2, it is clear that in 2019 the distribution of provinces
and cities is more concentrated than it was in 2004, with a reduction of provinces and cities in the second and fourth quadrants, and a significant increase in the distribution of regions in the third quadrant in 2019 compared to 2004. This suggests that the gap between regions has widened. It can be inferred that after more than a decade of development in China, the differences in the spatial distribution of green technology innovation have further deepened, characterized by a “High-High” and “Low-Low” agglomeration pattern.

2. Spatial Dubin Model

Based on the findings of previous studies and the practicality of technology, this paper constructs a Spatial Durbin Model (SDM) to examine the influence of OFDI on the green technology innovation.

\[
\ln \text{Green}_{it} = \rho W \times \ln \text{Green}_{it} + \beta_1 \ln \text{OFDI}_{it} + \beta_2 \text{ex}_{it} + \beta_3 \text{fdi}_{it} \\
+ \beta_4 \text{Hr}_{it} + \beta_5 \ln \text{rgdp}_{it} + \sigma W \times \text{X}_{it} + \alpha_t + \nu_i + \epsilon_{it}
\] (2)
Table 3. Result of Lratio test

<table>
<thead>
<tr>
<th></th>
<th>W₀</th>
<th>W₁</th>
<th>W₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likelihood-ratio test</td>
<td>LR chi²(6) = 16.77</td>
<td>LR chi²(6) = 20.29</td>
<td>LR chi²(6) = 16.01</td>
</tr>
<tr>
<td>(Assumption: sar nested in sdm)</td>
<td>Prob &gt; chi² = 0.01</td>
<td>Prob &gt; chi² = 0.00</td>
<td>Prob &gt; chi² = 0.01</td>
</tr>
<tr>
<td>Likelihood-ratio test</td>
<td>LR chi²(6) = 13.76</td>
<td>LR chi²(6) = 28.81</td>
<td>LR chi²(6) = 23.64</td>
</tr>
<tr>
<td>(Assumption: sem nested in sdm)</td>
<td>Prob &gt; chi² = 0.01</td>
<td>Prob &gt; chi² = 0.00</td>
<td>Prob &gt; chi² = 0.00</td>
</tr>
</tbody>
</table>

In Eq. (2), where i denotes region and t years. lnGreenₜᵢ denotes the effect of green technology innovation of province t in year i. lnofdiₜᵢ represents the OFDI stock of province t in year i. exports denotes export benefits of province t in year i. fdiₜᵢ denotes international capital inflows of province t in year i. Human resource reserve of province t in year i can be denoted with Hᵣᵢ. And the economic development level of province t in year i can be represented with ln GDPₜᵢ in this paper. β¹−⁵ are the parameters to be estimated. W represents the spatial weight matrix of 29 * 29. αᵢ denotes the individual effects and νᵣ represent the time effects. ρ and σ correspond to the spatial correlation coefficient in the model respectively. Xᵢ is the set of control variable vectors. εᵢ is a residual error term capturing all other effects.

To ensure the precision of the model chosen in this paper, LM inspection was performed, as well as Wald and Lratio tests on the SDM model. The results of the Lratio test, represented in Table 3, reveal that the P-value for various spatial matrices is less than 0.05, indicating that the SDM model is suitable for analyzing the spatial impact of OFDI on green technology innovation. Additionally, a Hausman test was conducted and confirmed that the spatial panel model used in this paper should be a fixed-effect model with two-way fixed effects.

3. Panel threshold model This research builds upon the static panel threshold model proposed by Hansen (1999) [19], and delves deeper into the non-linear impact of OFDI on green technology innovation by utilizing OFDI as the threshold variable. The specific model is illustrated as follows:

\[
\text{lnGreen}_t = \mu_t + \beta_1 \text{lnofdi}_t \times I(\text{lnofdi}_t \leq \gamma) + \\
\beta_2 \text{lnofdi}_t \times I(\text{lnofdi}_t > \gamma) + \beta_n \sum_{k=1}^{4} \text{Controls}_{i,k,1} + e_t
\]

In Eq. (3), lnGreenₜᵢ the and lnofdiₜᵢ maintain the same signification as in Eq.(2). μᵢ denotes constants, β₁−ₙ represents regression coefficients(n=6),I(·) is indicator function. γ denotes threshold value, and the threshold variable shows as lnofdiₜᵢ. Controlsₜᵢ,k,1 stand for control variable set. eₜᵢ follows an independent and identically distributed distribution.

5 Empirical Results and Analyses

5.1 Spatial Overall Regression

Table 4 presents the spatial spillover effect of OFDI on China’s green technology innovation under different spatial weighting methods. The results indicate that the direct, indirect and total effects of OFDI (lnofdi) on green technology innovation (lnGreen) are all positively significant at the 1% significance level under the influence of three spatial weight matrices. It can be observed that the indirect spillover effect of OFDI on green technology innovation is greater than the direct effect under the influence of different spatial weight matrices. This indicates that OFDI can significantly promote green technology innovation in China from the perspective of spatial correlation, and OFDI in surrounding regions also plays a positive role in promoting green technology innovation in the region. Furthermore, the spatial spillover
Table 4. Regression results of the spatial Durbin model

<table>
<thead>
<tr>
<th>Spatial effect</th>
<th>Spatial weights</th>
<th>Variables</th>
<th>lnofdi</th>
<th>fdi</th>
<th>ex</th>
<th>Hr</th>
<th>lnrgdp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct effect</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W0</td>
<td>0.1662***</td>
<td>-0.0245*</td>
<td>-0.1046</td>
<td>-1.2666*</td>
<td>0.3543***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(5.90)</td>
<td>(-1.65)</td>
<td>(-0.92)</td>
<td>(-1.92)</td>
<td>(3.49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1</td>
<td>0.1385***</td>
<td>-0.0063</td>
<td>-0.0383</td>
<td>-1.3045*</td>
<td>0.2477**</td>
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</tr>
<tr>
<td></td>
<td>(4.90)</td>
<td>(-0.43)</td>
<td>(-0.35)</td>
<td>(-1.90)</td>
<td>(2.49)</td>
<td></td>
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</tr>
<tr>
<td>W2</td>
<td>0.1348***</td>
<td>-0.0096</td>
<td>-0.0858</td>
<td>-1.0769</td>
<td>0.2894***</td>
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<tr>
<td></td>
<td>(4.67)</td>
<td>(-0.64)</td>
<td>(-0.77)</td>
<td>(-1.52)</td>
<td>(2.86)</td>
<td></td>
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<tr>
<td><strong>Indirect effect</strong></td>
<td></td>
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</tr>
<tr>
<td>W0</td>
<td>0.2101**</td>
<td>-0.0658*</td>
<td>0.1946</td>
<td>-3.2051</td>
<td>-0.7396***</td>
<td></td>
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<tr>
<td></td>
<td>(2.35)</td>
<td>(-1.67)</td>
<td>(0.68)</td>
<td>(-1.56)</td>
<td>(-2.93)</td>
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<tr>
<td>W1</td>
<td>0.3622***</td>
<td>-0.0437</td>
<td>-0.8823**</td>
<td>5.0344**</td>
<td>0.5112</td>
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<tr>
<td></td>
<td>(3.11)</td>
<td>(-1.13)</td>
<td>(-1.98)</td>
<td>(2.15)</td>
<td>(1.31)</td>
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</tr>
<tr>
<td>W2</td>
<td>0.2609**</td>
<td>-0.0532</td>
<td>-1.0988***</td>
<td>3.6409*</td>
<td>0.7047*</td>
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<td></td>
<td>(2.08)</td>
<td>(-1.16)</td>
<td>(-2.82)</td>
<td>(1.75)</td>
<td>(1.79)</td>
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<tr>
<td><strong>Total effect</strong></td>
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<tr>
<td>W0</td>
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<td>-0.0903*</td>
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<td></td>
<td>(3.50)</td>
<td>(-1.87)</td>
<td>(0.29)</td>
<td>(-1.93)</td>
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<tr>
<td>W1</td>
<td>0.5007***</td>
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<td>3.7299</td>
<td>0.7589*</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(3.76)</td>
<td>(-1.05)</td>
<td>(-1.94)</td>
<td>(1.44)</td>
<td>(1.82)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W2</td>
<td>0.3957***</td>
<td>-0.0628</td>
<td>-1.1847***</td>
<td>2.564</td>
<td>0.9941**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.78)</td>
<td>(-1.15)</td>
<td>(-2.84)</td>
<td>(1.08)</td>
<td>(2.33)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: * p < 0.10, ** p < 0.05, *** p < 0.01, t statistics in parentheses

effect and total effect of OFDI on green technology innovation are optimal under the influence of spatial geographical weights (W1), indicating that the spatial effect of OFDI on green technology innovation cannot be fully explained simply from the perspective of regional adjacency and the impact of geographical distance should be taken into account in research. In conclusion, this result supports Hypothesis 1.

5.2 Regional Heterogeneity

Based on Hypothesis 2, this study uses a spatial geographic matrix (W1) to examine the regional variations in the spatial impact of OFDI on green technology innovation in China. The results, presented in Table 5, reveal that there are significant regional differences in the spatial impact of OFDI on green technology innovation. Specifically, OFDI in the central, western, and northeastern regions has a significant positive impact on green technology innovation, but this is not the case in the eastern region. From a spatial perspective, OFDI in the central and northeastern regions can significantly boost green technology innovation, while OFDI in the western region only effectively drives local green technology innovation. However, during the study period, OFDI in the eastern region had no significant spatial impact on green technology innovation, and its spatial effect was even negative. This implies that currently, green technology innovation in the eastern region is not stimulated by OFDI from a spatial point of view, whereas other regions can utilize OFDI to drive local green technology innovation.

5.3 Time Interval Regression and Further Test

1.Time interval regression

OFDI is susceptible to fluctuations in the global investment climate, particularly after the two global economic crises in 2012. As a result, this study divided the observation period into two stages (2004-2012 and 2013-2019), and conducted regression analysis to observe
Table 5. Space panel data regression results of different regions.

<table>
<thead>
<tr>
<th>Spatial effect</th>
<th>variables</th>
<th>Eastern</th>
<th>Central</th>
<th>Western</th>
<th>North-eastern</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Direct effect</td>
<td>lnofdi</td>
<td>-0.0063</td>
<td>0.0577</td>
<td>0.1120***</td>
<td>0.1129</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.12)</td>
<td>(1.00)</td>
<td>(2.96)</td>
<td>(1.44)</td>
</tr>
<tr>
<td>Indirect effect</td>
<td>lnofdi</td>
<td>-0.0430</td>
<td>0.1076</td>
<td>-0.0704</td>
<td>0.3492**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.41)</td>
<td>(1.19)</td>
<td>(-0.93)</td>
<td>(2.02)</td>
</tr>
<tr>
<td>Total effect</td>
<td>lnofdi</td>
<td>-0.0494</td>
<td>0.1653*</td>
<td>0.0416</td>
<td>0.4621**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.35)</td>
<td>(1.66)</td>
<td>(0.42)</td>
<td>(2.57)</td>
</tr>
<tr>
<td>control variables</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Spatial rho</td>
<td></td>
<td>0.0209</td>
<td>-1.1183***</td>
<td>-0.2718**</td>
<td>-0.6594***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.18)</td>
<td>(-7.24)</td>
<td>(-2.17)</td>
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</tr>
<tr>
<td>Variance sigma2_e</td>
<td></td>
<td>0.0220***</td>
<td>0.0159***</td>
<td>0.0279***</td>
<td>0.0033***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(8.48)</td>
<td>(5.65)</td>
<td>(9.31)</td>
<td>(4.16)</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>144</td>
<td>96</td>
<td>176</td>
<td>42</td>
</tr>
</tbody>
</table>

Note: * p < 0.10, ** p < 0.05, *** p < 0.01, t statistics in parentheses

the changes in OFDI’s spatial effects on green technology innovation at different stages. The results of models (1) and (2) (see Table 6) indicate that OFDI had a significant spatial effect on green technology innovation from 2004 to 2012, but the spatial correlation coefficient of the model was not significant after 2012. This may be attributed to the impact of the Durbin term on the model during the latter stage (Lee and Yu, 2016) [20]. Furthermore, it also suggests that China’s development of OFDI is affected by changes in the global investment environment, which in turn alters the spatial spillover effect of OFDI on green technology innovation. The radiation effect of green technology innovation may be reduced due to changes in the global investment environment. Hence, to enhance domestic green technology innovation, attention should be paid to changes in the global investment environment.

2. Further test

In this study, we employed the logarithm of OFDI flow (lnofdi2) as a replacement for the key explanatory variable (lnofdi) to test the stability of the model. Additionally, the logarithmized OFDI stock with a lag of one period (lnofdi_1) was used as the instrumental variable to conduct the endogenous test. The regression results are presented in Table 6 Models (3) and (4). Both the stability test and endogenous test are significant, indicating that OFDI can steadily promote green technology innovation from a spatial perspective, and OFDI can have a positive impact on green technology innovation over time, which can continue to generate beneficial spatial spillover effects.

5.4 Threshold Effect Test

The shifts in the global investment environment can impact China’s OFDI and subsequently, China’s green technology innovation. As seen in Table 7, OFDI exhibits a single threshold effect, which is significant at the 1% significance level. Table 8 indicates that the threshold value of OFDI (lnofdi) is 12.4137, and its value range is [12.3705,12.4342]. When the OFDI value is less than 12.4137, its regression coefficient is 0.2796; when the OFDI value is greater than 12.4137, its regression coefficient is 0.3050, which are both significant at the 1% significance level. This demonstrates that foreign direct investment can effectively promote China’s green technology innovation and has a significant nonlinear impact on green technology innovation. This validates the hypothesis H4 proposed in this study. As OFDI continues to
Table 6. Time interval regression and Further test

<table>
<thead>
<tr>
<th>Spatial effect variables</th>
<th>Model(1)</th>
<th>Model(2)</th>
<th>Model(3)</th>
<th>Model(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct effect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnofdi</td>
<td>0.0531*</td>
<td>0.2400***</td>
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</tr>
<tr>
<td>lnofdi</td>
<td>(1.75)</td>
<td>(4.72)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnofdi_1</td>
<td></td>
<td></td>
<td>0.1253***</td>
<td></td>
</tr>
<tr>
<td>lnofdi_1</td>
<td></td>
<td></td>
<td>(4.31)</td>
<td></td>
</tr>
<tr>
<td>lnofdi2</td>
<td>0.0467**</td>
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<td></td>
<td></td>
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<tr>
<td>lnofdi2</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>lnofdi_1</td>
<td>0.1253***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnofdi_1</td>
<td>(4.31)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect effect</td>
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<td></td>
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<td></td>
</tr>
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<td>lnofdi_1</td>
<td>0.2035*</td>
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<tr>
<td>lnofdi2</td>
<td>0.1587**</td>
<td></td>
<td></td>
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<tr>
<td>lnofdi2</td>
<td>(2.27)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>lnofdi_1</td>
<td></td>
<td>0.2035*</td>
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<td></td>
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<tr>
<td>lnofdi_1</td>
<td></td>
<td>(1.67)</td>
<td></td>
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</tr>
<tr>
<td>Total effect</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>lnofdi</td>
<td>0.4480***</td>
<td>0.2172</td>
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<td>(1.29)</td>
<td></td>
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</tr>
<tr>
<td>lnofdi2</td>
<td>0.2054***</td>
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<tr>
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<td>(2.63)</td>
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<tr>
<td>lnofdi_1</td>
<td>0.3289**</td>
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<td>lnofdi_1</td>
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</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial rho</td>
<td>0.3561***</td>
<td>0.1658</td>
<td>0.4401***</td>
<td>0.4306***</td>
</tr>
<tr>
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<td>(3.86)</td>
<td>(1.40)</td>
<td>(6.74)</td>
<td>(6.29)</td>
</tr>
<tr>
<td>Variance sigma2_e</td>
<td>0.0277***</td>
<td>0.0207***</td>
<td>0.0453***</td>
<td>0.0422***</td>
</tr>
<tr>
<td>lnofdi</td>
<td>(11.29)</td>
<td>(10.05)</td>
<td>(14.97)</td>
<td>(14.50)</td>
</tr>
<tr>
<td>N</td>
<td>261</td>
<td>203</td>
<td>464</td>
<td>435</td>
</tr>
</tbody>
</table>

Note: * p < 0.10, ** p < 0.05, *** p < 0.01, t statistics in parentheses

Table 7. Threshold effect test

<table>
<thead>
<tr>
<th>Threshold variable</th>
<th>Threshold effect test</th>
<th>Fstat</th>
<th>p-value</th>
<th>Critical Value of F</th>
<th>RSS</th>
<th>MSE</th>
<th>Bootstrap</th>
</tr>
</thead>
<tbody>
<tr>
<td>lnofdi</td>
<td>Single</td>
<td>54.80</td>
<td>0.0033</td>
<td>24.4710</td>
<td>26.8657</td>
<td>40.7911</td>
<td>36.9368</td>
</tr>
<tr>
<td></td>
<td>Double</td>
<td>11.79</td>
<td>0.4433</td>
<td>21.0588</td>
<td>24.628</td>
<td>31.5687</td>
<td>35.9897</td>
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</tbody>
</table>

Table 8. Threshold-value estimation

<table>
<thead>
<tr>
<th>Threshold variable</th>
<th>Threshold value</th>
<th>95% confidence interval</th>
<th>Regression coefficient</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>lnofdi</td>
<td>12.4137</td>
<td>[12.3705,12.4342]</td>
<td>0.2796</td>
<td>9.68</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>lnofdi ≤ 12.4137</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>lnofdi ≥ 12.4137</td>
<td>10.63</td>
<td>0.00</td>
</tr>
</tbody>
</table>

increase, when the value of regional OFDI surpasses the threshold value, the role of OFDI in promoting green technology innovation will be further amplified. This further confirms that OFDI’s technology spillover is beneficial to the development of green technology innovation in China.

6 Conclusions and Recommendations

This study proposes four well-supported hypotheses through an examination of the theories and mechanisms of OFDI’s influence on green technology innovation. Utilizing spatial panel
models and panel threshold models, and analyzing panel data from 29 provinces, cities, and autonomous regions in China from 2004 to 2019, this research investigates the impact of OFDI on China’s green technology innovation from a spatial perspective, delving deeper into the non-linear impact of OFDI on China’s green technology innovation.

This study finds that: (1) OFDI has a significant positive impact on China’s green technology innovation from a spatial perspective, with a notable spatial spillover effect. (2) The spatial impact of OFDI on green technology innovation varies by region, with significant correlations in central, western, and northeastern regions, but not in the eastern region. OFDI in central and northeastern regions can greatly enhance green technology innovation, while OFDI in the western region only impacts local innovation. (3) During the observation period, the spatial correlation between OFDI and green technology innovation is not significant after 2012, indicating that changes in the international trade environment will affect the radiation effect of OFDI on China’s green technology innovation. (4) OFDI has a nonlinear relationship with green technology innovation, which can significantly boost innovation after crossing a certain threshold.

In light of the above findings, this paper suggests the following: First, policymakers should harness the positive spillover effect of OFDI on green technology innovation to enhance the country’s ability to innovate independently and boost its overall green technology capabilities. Second, efforts should be made to break down regional barriers and promote coordination among different regions. Third, as China shifts towards a new development pattern, it should continue to pursue high-level opening up and actively participate in international cooperation while also paying attention to the security of international capital flows.

References

[17] R. Xie, T.S. Teo, Technological Forecasting and Social Change 184, 122020 (2022)