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Environmental regulation, outward foreign direct investment, and China's green total factor productivity

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Abstract
Increasing green total factor productivity (GTFP) is currently the primary goal of sustainable development worldwide. GTFP not only reflects the efficiency of economic expansion but also encompasses resource consumption and pollution. This research enhances the current understanding of GTFP by indicating that aside from reverse technology spillovers, labor mobility, and changes in industrial structure, additional factors, such as environmental regulations, exert a dynamic function in shaping the influence of outward foreign direct investment (OFDI) on the GTFP of the home nation. The empirical findings indicate that OFDI has a single threshold effect on GTFP, and the negative effect increases with the reinforcing of environmental control. The main impact comes from home country's changes in green technology (GTC) rather than changes in green efficiency. Additionally, environmental regulation has a positive moderating effect on OFDI, the moderating effect of environmental regulation in western regions is more pronounced in promoting the home country's GTC. It is imperative to take into account regional variations and devise distinct policies for eastern, central, and western regions.

Keywords Green total factor productivity · Environmental regulation · Outward foreign direct investment · Changes in green technology · Changes in green efficiency · Threshold effect

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Abbreviations

GTFP	Green Total Factor Productivity
OFDI	Outward Foreign Direct Investment
GTC	Changes in Green Technology
GEC	Changes in Green Efficiency
GDP	Gross Domestic Product
FDI	Foreign Direct Investment
FII	Foreign Institutional Investor
TE	Technical Efficiency
SE	Scale Efficiency
SBM-DDF	Slack-Based Measured Directional Distance Function
DEA	Data Envelopment Analysis
CCR	Charnes, Cooper, and Rhodes
GCC	Gulf Cooperation Council
Gov	Government fiscal strength
Tech	Technology innovation
Struc	Industrial structure
Edu	Education level
Trade	Trade openness

1 Introduction

The green revolution in economic growth is facilitated by environmental regulation. At the Paris Climate Change Conference, the Chinese government emphasized its commitment to actively respond to global changes through green economic development. A low-carbon economy, aggressive energy preservation, and emission decrease are essential to China's ability to fulfill its obligations as a major nation (Pan et al., 2018). China has pledged to achieving carbon neutrality by 2060 and a carbon peak by 2030, and has developed a number of environmental regulations and policies. At the same time, the Chinese government places a strong emphasis on the necessity of forming a new modern construction pattern that promotes harmonious development between human and nature, speeding up the green alteration of the development approach, and fostering the comprehensive social and economic development through a green transformation. The "Belt and Road" initiative introduced in 2014, significantly accelerated China's outward foreign direct investment (OFDI) growth (He & Cao, 2019). China's continuous expansion of OFDI is an important means of encouraging the shift towards a green development approach.

As of 2021, China ranked second globally with OFDI of $178.82 billion. China's foreign direct investment (OFDI) has exhibited a steady upward trajectory since the Ministry of Commerce started monitoring pertinent data in 2003. From 2002 to 2021, the average annual compound growth rate was 24.7%. The foremost three provinces in terms of the size of OFDI source investment are Guangdong, Zhejiang, and Shanghai, all of which have exceeded $10 billion in investment. With a stock of $2.50 trillion, or 89.7 percent, China's OFDI is primarily concentrated in developing nations. By the end of 2021, Hong Kong, the British Virgin Islands, the Cayman Islands, the United States, Singapore, Australia, the Netherlands, Indonesia, the United Kingdom, and Luxembourg ranked among the top ten nations or regions in terms of China's stock of OFDI.

Sustainable and green development, which is guided by resource conservation and environmental friendliness, has gained worldwide attention (Fang & Cao, 2022). An important aim of green development involves enhancing green total factor productivity (GTFP) as highlighted by Li and Chen (Li & Chen, 2021; Liu & Xin, 2019). Current research primarily focuses on strategies for enhancing GTFP through environmental regulation and decentralization (Wang et al., 2022b). Developing countries mainly conduct OFDI through the establishment of cross-border subsidiaries, approaching R&D resources in technologically advanced countries (Zhou et al., 2019), entering areas of advanced technology, and then enhancing their own technological capabilities through learning and imitation (Liu et al., 2020; Ren et al., 2012), thereby generating reverse technology spillover effects and enhancing GTFP level (Bourlès et al. 2013; Hamida, 2013; Salim & Bloch, 2009). This article primarily makes the following marginal contributions. First, we integrate the government's environmental regulation level, OFDI and GTFP into a common analytical framework which analyze the marginal effect between variables. Second, we confirm the nonlinear correlation between OFDI and the GTFP under varying environmental regulation levels using a panel threshold effect model. Lastly, we explore the moderating influence of environmental regulation, further observing the regional heterogeneity of the regression model.

This is how the paper organized: Sect. 2 offers a summary of literature, while Sect. 3 brings forth a theoretical assertion. Section 4 outlines the research methodology, consisting of model building, variable selection, and descriptive statistical analysis. Section 5 presents the analysis based on empirical evidence, followed by the conclusion in Sect. 6.

2 Literature review

Currently, there exist a couple of completely different perspectives on the impact of OFDI on domestic economic expansion. For example, Desai et al. (2005) used US time series data for empirical research and found that the growth of OFDI can effectively drive the investment within the nation, thereby promoting rapid economic growth in the home country. Hsiao and Hsiao (2006) selected panel data from 8 Southeast Asian economies and applied the Granger causality test in an empirical investigation to study the economic growth effect of OFDI, and the research conclusion shows that OFDI can effectively promote domestic economic development. Herzer (2010) used cross-sectional data from more than 50 countries to study the relationship between OFDI and economic growth, discovered that OFDI has a substantial promotion on domestic economic growth. However, Stevens et al. (1992) regarded that if the discharge of funds caused by OFDI is not matched by export increases or import reductions, the increase in OFDI will cause a decline in the economic growth of the home country. Certain researchers conducted empirical studies on Japan and South Korea's OFDI and discovered that such investments effectively facilitated the modernization of the domestic industrial structure and its related sectors (Advincula, 2000; Blomstrom et al., 2000; Hiley, 1999). However, the macroeconomic variables may have different impacts on economic performance. Verma and Bansal (2021) discern macroeconomic factors influencing stock market performance, observing that gross domestic product (GDP), Foreign Direct Investment (FDI), and Foreign Institutional Investment (FII) positively influence the stock markets of both developed and emerging economies, as the price of gold has an adverse effect.

Investigation into the host country environmental influence of OFDI is still in its early stages. Tang et al. (2022) examines the effects of two categories of environmental

regulations and discovers that OFDI notably enhances the development of GTFP. Liu et al. (2022) concludes that heightened environmental regulations within the country have raised the likelihood of firms engaging in OFDI. Dai et al. (2021) explore the nonlinear correlation between outward OFDI and GI within the context of environmental regulation. Feng et al. (2018) points out that green innovation's efficiency is severely harmed by the interaction between environmental governance and OFDI. Zhou and Pang (2013) conducted an empirical study of the environmental effects of China's OFDI from a regional perspective, and showed that the influence of OFDI on the domestic environment varies significantly among regions. Xu and Wang (2015) confirmed a notable positive correlation between domestic carbon emissions and OFDI in China. Nie and Liu (2015) discovered that carbon emission impacts of OFDI are limited by the threshold effect of urbanization.

The literature regarding the association between OFDI and GTFP can be categorized into three primary perspectives. The initial perspective asserts that OFDI yields a beneficial impact on GTFP (Kee, 2015; Zhu et al., 2019). The second view argues that OFDI does not bring about positive effects (Bitzer & Kerekes, 2008). The third view explains the inconsistent findings of the above studies by pointing out the importance of considering the economic environment of the parent company and whether it can gain advantages from the reverse technology spillovers facilitated by OFDI (Yin & Zhang, 2016). For example, having more high-level and highly skilled innovative talent is a prerequisite for enterprises to acquire, absorb, and digest advanced foreign technologies, and human capital is the most important economic value capital. OFDI's geographical agglomeration to some extent reflects the economic vitality of a region and is the main channel through which OFDI strengthens the introduction, absorption, and transformation of reverse technology (Sun & Liu, 2019).

Through summarizing and analyzing existing literature, it emerges that research on OFDI primarily concentrates on its effects on domestic economic expansion, including the effects on talent flow (Chen et al., 2019), industrial structure (Liao et al., 2021), and reverse technology spillover (Li et al., 2022a). Nevertheless, there exists a scarcity of investigation on connection between OFDI and environmentally sustainable economic growth within the home country, and the findings from studies regarding the relationship between OFDI and GTFP are inconclusive. While some studies suggest that environmental regulations affect OFDI, there is no systematic analysis of the mechanisms underlying the nonlinear correlation and how it affects GFTP. This paper contributes to existing studies on GTFP by illustrating that OFDI's impact on the GTFP is not solely shaped by factors such as personnel mobility, industrial structural adjustments and reverse technology spillovers, it is dynamically influenced by environmental regulations. This paper seeks to broaden the research scope of the existing literature in this regard.

3 Mechanism analysis

Generally, OFDI represents the relatively advanced productivity level of the home country, and enterprises with international technological leadership and competitive advantages will have greater motivation to seek foreign investment (Li et al., 2017). At present, China invests most of its foreign direct investment in developing nations with comparatively low levels of technology. Investment from China in the "Belt and Road" and other regions transferred some domestic enterprises with relatively advanced productivity levels to a certain extent, weakening the GTFP of the home country.

Simultaneously, as domestic environmental governance is reinforced, the enterprises of home country will have the incentive to relocate some high-polluting enterprises to the host country with lower requirements for environmental protection. The increase in an industry's technological bottom line and the expectations for stricter environmental regulation have led to the transfer of companies with higher technical levels to host countries with moderate regulation levels, resulting in a notable decline in the home country's GTFP.

Hypothesis 1: OFDI has an adverse influence on the GTFP of the home nation, and the environmental regulation exert a nonlinear influence on OFDI. When the intensity of government environmental regulation surpasses a specific threshold, OFDI's adverse impact on GTFP notably escalates.

According to calculation methods proposed by Odeck (2009) and Yörük and Zaim (2005), the GTFP index can be broken down into variations in green technology (GTC) and alterations in green efficiency (GEC), which respectively signify the advancement of sustainable production technology and the effectiveness of sustainable management techniques. China's current OFDI is primarily focused in developing countries, and the industries targeted for OFDI are mainly in the tertiary sector. The tertiary sector itself belongs to the industry with a relatively high GTC, and the industries in which China's OFDI is most prevalent, such as the service sector, negatively affect the home nation's GTFP. In addition, due to the concentration of China's OFDI primarily throughout the central and eastern areas, with less activity in the western region, the influence of OFDI on GFTP is notably pronounced in the provinces of the east and center. Conversely, the adverse effect of OFDI on GFTP in the western area is comparatively milder.

Hypothesis 2: The negative incluence of OFDI on GFTP mainly comes from GTC rather than GEC, and the weakening effect of OFDI on GTC is significantly greater throughout the central and eastern areas than in the regions of the west.

The government's environmental regulation serve to moderate the effect of OFDI on enhancing GTFP within the home nation (Guo & Wang, 2023). When government environmental regulations are lax, the share of corporate environmental compliance costs within the total costs remains minimal, thereby dampening enterprises' motivation to acquire advanced technology through overseas investments. At the same time, their own motivation for green technology innovation is insufficient. As environmental regulations tighten, the share of environmental costs within the total costs has gradually risen. To meet emission requirements, enterprises will consider shifting their OFDI toward high-tech, clean and environmentally friendly production in the long term. They will attach more importance to technology acquisition-type investment, enabling domestic enterprises to improve their green technology innovation through imitation, learning, and innovation, thereby maximizing the promoting effect on green development level. Therefore, the positive moderating effect between government environmental regulations and OFDI contributes to the growth of the home nation's GFTP through the transmission of advanced green technology via reverse spillovers. In the economically advanced coastal areas in the east, the correlation between OFDI and environmental regulation will exert a lesser influence on GFTP compared to the economically disadvantaged western and central areas, primarily due to higher levels of former GFTP.

Hypothesis 3: The government's environmental regulation exert a positive moderating effect on OFDI and GTFP in the home nation. In economically underdeveloped regions such as the western area, the moderating impact is more pronounced, primarily owing to the lower initial level of GTC.

4 Research methodology

4.1 Selection of variables

Explained variables Green Total Factor Productivity (GTFP). In previous studies, Kumar (2006) and Feng and Serletis (2014) utilized GDP as the anticipated output in GTFP calculations, incorporating factors like capital and labor inputs. Xie et al. (2021) added energy consumption to the input factors in the GTFP indicator system to calculate GTFP, taking into account the input of energy resources. Bansal (2019) employs the DEA-CCR model to compute the technical efficiency (TE), as well as the levels of pure technical efficiency and scale efficiency (SE) for companies within the Indian oil and gas sector. Zhang and Xu (2022) quantifies the Yellow River basin's carbon emission efficiency adopting the slack-based measured directional distance function (SBM-DDF) model. This paper employs the SBM-DDF method to evaluate GTFP. The SBM-DDF method, unlike the traditional DEA approach, incorporates unexpected outputs when assessing production efficiency, and integrates the Global Malmquist-Luenberger index to gauge GTFP. (Wang et al., 2019).

Explanatory variables First, the threshold of the regression model is represented by environmental regulation (Regu). Environmental regulations significantly influence foreign investment activities. Zhang et al. (2020) employ a threshold regression model to empirically examine how environmental regulations affect both the quantity and intensity of carbon emissions. Bansal and Singh (2021) assess the technical efficiency, pure technical efficiency, and scale efficiency scores of insurers in the Gulf Cooperation Council (GCC) by considering internal company variables as well as external environmental factors. In this study, the percentage of GDP that is allocated to controlling environmental pollutants has been chosen as the metric for assessing environmental regulation. A higher ratio signifies stronger environmental regulation. In 2021, the investment volume of capital in controlling pollution in China reached 1063.89 billion RMB, accounting for 1% of the GDP.

Second, outward foreign direct investment (OFDI). This paper regards outward foreign investment amount as the primary explanatory variable. It utilizes the OFDI stock of 30 provinces in China as the proxy variable. OFDI is an investment activity in which residents (natural persons and legal persons) invest in another country with certain production factors and accordingly obtain management rights. Multinational corporations are the primary entities engaged in OFDI. At the end of 2021, China's OFDI stock was 2.79 trillion US dollars, ranking among the top three in the world for five consecutive years.

Control variables Government fiscal strength (Gov) is a significant metric for assessing the degree of provincial economic advancement, and it is indicated by the ratio of each province's general fiscal budget expenditure to its GDP. The level of innovation in eco-friendly technology (Tech) is gauged by the quantity of innovations in environmentally friendly and sustainable technology across the 30 provinces of China. A higher count of applications for green technology patents grants reflects a stronger regional capacity for technological innovation. Industrial structure (Struc) is another crucial determinant influencing GTFP, with alterations in it correlating with shifts in productivity levels. This study

has opted to utilize the share of secondary industry in GDP as measurement of changes in industrial composition. Education level (Edu) has been employed to gauge the region's capacity for knowledge absorption. Per capita years of education, which is conducive to improving GTFP, is used to represent the level of education in the region. Trade openness (Trade) is denoted by the percentage of imports and exports to regional GDP. Greater trade openness can enhance resource allocation efficiency, consequently bolstering GTFP.

4.2 Model construction

Derived from the new economic growth theory and prior literature, this research extends the theoretical models based on Barro (1990) and Hulten et al. (2006). First, OFDI is incorporated into the GTFP function A(·), along with energy input and unexpected output (Wang et al., 2022a). Second, the study centers on examining how OFDI affects GTFP within specific environmental regulation frameworks, environmental regulation variable is added to A(·). In addition, this model includes some economic and technological variables that affect GTFP as control variables, including Gov, Tech, Struc, Edu, Trade, etc. Finally, utilizing the Hulten theoretical model as a foundation, we formulate the subsequent production function:

$$Y = A(\text{Regu},\ \text{OFDI},\ \text{Gov},\ \text{Tech},\ \text{Struc},\ \text{Edu},\ \text{Trade}, t) \cdot F(K, L) \tag{1}$$

where Y symbolizes output, A(·) represents the GTFP function, Regu represents the degree of environmental regulation, OFDI stands for outward foreign direct investment, Gov denotes the general budget expenditure of local finance, Tech signifies the count of patent authorizations, Struc indicates the level of industrial structure, Edu represents the average number of schooling years per person, and Trade corresponds to the total volume of imports and exports trade. Assuming that A(·) satisfies Hicks neutrality, we obtain:

$$\begin{aligned} &A(\text{Regu},\ \text{OFDI},\ \text{Gov},\ \text{Tech},\ \text{Struc},\ \text{Edu},\ \text{Trade}, t) \\ &= A_{i0}\text{Regu}_{it}^{a_i}\text{OFDI}_{it}^{\beta_i}\text{Gov}_{it}^{\gamma_i}\text{Tech}_{it}^{\delta_i}\text{Struc}_{it}^{\phi_i}\text{Edu}_{it}^{\eta_i}\text{Trade}_{it}^{\lambda_i}e^{\varepsilon_{it}} \end{aligned} \tag{2}$$

where i stands for the province, t signifies the year, A_{i0} is the initial productivity level, a_i,β_i,γ_i,δ_i,ϕ_i,η_i and λ_i are the influence parameters of Regu, OFDI, Gov, Tech, Struc, Edu, Trade and other factors on GTFP, respectively, and ε_{it} are technical exogenous variables. The above formula is substituted into Formula (1) to obtain:

$$\text{Y}_{it} = \text{A}_{i0}\text{Regu}_{it}^{a_i}OFDI_{it}^{\beta_i}Gov_{it}^{\gamma_i}\text{Tech}_{it}^{\delta_i}\text{Struc}_{it}^{\phi_i}\text{Edu}_{it}^{\eta_i}\text{Trade}_{it}^{\lambda_i}e^{\varepsilon_{it}} \cdot F(K_{it}, L_{it}) \tag{3}$$

Divide both sides of the formula by $F(K_{it}, L_{it})$, and obtain the expression of GTFP:

$$\text{GTFP}_{it} = Y_{it}/F(K_{it}, L_{it}) = A_{i0}\text{Regu}_{it}^{a_i}OFDI_{it}^{\beta_i}Gov_{it}^{\gamma_i}\text{Tech}_{it}^{\delta_i}\text{Struc}_{it}^{\phi_i}\text{Edu}_{it}^{\eta_i}\text{Trade}_{it}^{\lambda_i}e^{\varepsilon_{it}} \tag{4}$$

Taking the natural logarithm obtained as follows:

$$\begin{aligned} \ln \text{GTFP}_{it} = {} & \ln \text{A}_{i0} + a_i \ln \text{Regu}_{it} + \beta_i \ln OFDI_{it} + \gamma_i \ln Gov_{it} \\ & + \delta_i \ln \text{Tech}_{it} + \phi_i \ln \text{Struc}_{it} + \ln \text{Edu}_{it} + \lambda_i \ln \text{Trade}_{it} + \varepsilon_{it} \end{aligned} \tag{5}$$

Drawing from the analysis of the theoretical model, we formulated a fundamental empirical Model (5) to investigate the influence of environmental regulation on OFDI and GTFP. As the relationship among variables may be nonlinear, we developed a panel data

threshold regression model, an econometric model that is nonlinear and utilizes the environmental control level as a threshold to estimate the coefficient. The model includes single, double, and triple threshold models, so we established the following model:

$$\begin{aligned}\ln \mathrm{GTFP}_{it} = {} & \ln \mathrm{A}_{i0} + a_{i1} \ln OFDI_{it}(\ln \mathrm{Regu}_{it} \le \theta_1) \\ & + a_{i2} \ln OFDI_{it}(\theta_1 \le \ln \mathrm{Regu}_{it} \le \theta_2) + \cdots \\ & + a_{i3} \ln OFDI_{it}(\ln \mathrm{Regu}_{it} \ge \theta_q) + \beta_i \ln Gov_{it} + \gamma_i \ln \mathrm{Tech}_{it} \\ & + \delta_i \ln \mathrm{Struc}_{it} + \phi_i \ln \mathrm{Edu}_{it} + \lambda_i \ln \mathrm{Trade}_{it} + \varepsilon_{it}\end{aligned} \tag{6}$$

where GTFP_{it} symbolizes the dependent variable, which can be divided into changes in green efficiency GEC_{it} and changes in green technology GTC_{it}; i signifies the province, t represents the year, $\theta_1, \cdots \theta_q$ is the threshold parameter; $\ln \mathrm{A}_{i0}$ is the model intercept constant; a_i,β_i,γ_i,δ_i,ϕ_i and λ_i are the independent coefficients; and ε_{it} is the random error.

Moreover, considering the moderating effect of OFDI, we also verified the nonlinear relationship of the interaction term and constructed the following model:

$$\begin{aligned}\ln \mathrm{GTFP}_{it} = {} & \ln \mathrm{A}_{i0} + a_{i1} \ln OFDI_{it} \cdot \ln \mathrm{Regu}_{it}(\ln \mathrm{Regu}_{it} \le \theta_1) \\ & + a_{i2} \ln OFDI_{it} \cdot \ln \mathrm{Regu}_{it}(\theta_1 \le \ln \mathrm{Regu}_{it} \le \theta_2) \\ & + \cdots + a_{i3} \ln OFDI_{it} \cdot \ln \mathrm{Regu}_{it}(\ln \mathrm{Regu}_{it} \ge \theta_q) \\ & + \beta_i \ln Gov_{it} + \gamma_i \ln \mathrm{Tech}_{it} + \delta_i \ln \mathrm{Struc}_{it} + \phi_i \ln \mathrm{Edu}_{it} + \lambda_i \ln \mathrm{Trade}_{it} + \varepsilon_{it}\end{aligned} \tag{7}$$

4.3 Data sources and statistical summary

Samples from 30 provinces or regions (excluding Tibet, Hong Kong, Macao, and Taiwan) spanning from 2005 to 2021 have been employed to assess the influence of OFDI on GTFP of the home nation. The OFDI data subset are sourced from the Ministry of Commerce's "Statistical Bulletin on China's OFDI", energy consumption data subset are derived from the "China Energy Statistical Yearbook" environmental regulation data subset are from the "China Environmental Statistical Yearbook", while the remaining information originate from the China Statistical Yearbook on Science and Technology. The descriptive statistics of the samples are shown in Table 1.

Table 1 Descriptive statistics of the variables

Variable	sample size	Mean	SD	Min	Max
GTFP	510	1.531	0.771	0.608	7.826
GTC	510	1.530	0.580	0.887	7.150
GEC	510	0.988	0.198	0.190	2.118
Regu	510	0.0142	0.0091	0.0001	0.0936
OFDI	510	1724	3493	0.0001	23,970
Gov	510	3931	3020	151.2	18,247
Tech	510	9.207	13.50	0.134	90.80
Struc	510	0.424	0.0832	0.160	0.620
Edu	510	8.908	1.032	6.378	12.78
Trade	510	8002	14,592	21.44	101,800

Table 2 The F-test results and threshold values

Types	F value	*P* value	Threshold
Single	16.23	0.0400	−4.5037
Double	15.92	0.1050	−4.2161
Triple	15.61	0.1150	−4.2114

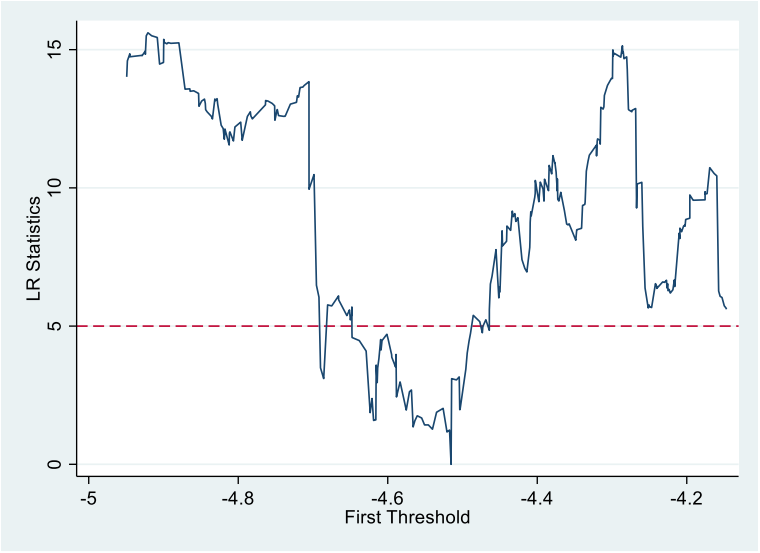

Fig. 1 The LR statistics of single threshold effect

5 Empirical analysis

5.1 Threshold regression of environmental regulation between OFDI and home country's GTFP

To examine how OFDI as a whole affects sustainable development in relation to governmental environmental regulations, this study employs environmental regulation as the threshold parameter and applies a panel regression model to explore the nonlinear influence of OFDI on GTFP. A test for the threshold effect indicated a single threshold effect, with a natural logarithmic value of the environmental regulation variable "Regu" at −4.5037, serving as the sole threshold, significant at a 5% level. The regression test outcomes are displayed in Table 2.

The double and triple threshold effects fail to meet the test criteria. This paper mainly focuses on the single threshold effect, which passed the significance test at a 5% level. The LR statistics of the single threshold effect are shown in Fig. 1.

As illustrated in Table 3, there exists a negative correlation between OFDI and GFTP in the home nation. When the strength of government environmental regulation (lnregu) falls below −4.5037, the influence of OFDI on China's GTFP is comparatively minor, with a coefficient of −0.0214, indicating that for every 1% rise in OFDI, the home country's

Table 3 Environmental regulation's threshold regression between OFDI and GTFP

Variable	Regression coeffificient	Standard error
ln OFDI (ln regu $\leq \theta_1$)	−0.0214**	0.0103
ln OFDI (ln regu $> \theta_1$)	−0.0310***	0.0101
ln gov	0.1180**	0.0518
ln tech	0.1406***	0.0303
ln struc	−0.3361***	0.0933
ln edu	0.3687	0.3412
ln trade	0.0791***	0.0296
_cons	−2.1641***	0.6818
R^2	0.696	
F	154.9203	

$P < 0.1$ for *, 0.05 for **, and 0.01 for ***

GTFP will decrease by 0.0214 percentage points. As environmental regulation intensifies, surpassing the threshold, the adverse effects of OFDI on GTFP increases significantly, with a coefficient of −0.0310, indicating that the home country's GTFP will decrease by 0.0310 percentage points with each 1% rise in OFDI.

China's OFDI predominantly focuses on countries along the "Belt and Road", with most nations having lower productivity levels. In 2022, Chinese enterprises carried out 118 merger and acquisition projects within nations engaged within the "Belt and Road" project, with a total transaction value of 5.52 billion US dollars. Among them, Argentina, Singapore, Zimbabwe, South Korea, Kazakhstan, and Indonesia attracted Chinese investment and acquisition projects with a scale exceeding 300 million US dollars. However, China's investments in "Belt and Road" countries do not necessarily contribute to the improvement of domestic productivity levels. Simultaneously, it has led to the transfer of some advanced productive enterprises, negatively impacting the nation's total factor productivity. The outcome of the single threshold effect corroborates this pattern, confirming Hypothesis 1.

Regarding the influence of control variables, factors such as government fiscal strength (Gov), green technology (Tech), education level (Edu), and trade openness (Trade) positively contribute to enhancing GTFP. This is attributed to the region's growing green innovation capability and escalating production levels. Industrial structure (Struc) is the sole variable that significantly adversely impacts GTFP. The ratio of secondary industry to GDP represents a country's industrial production capacity. The substantial presence of the manufacturing industry in China, characterized by a low level of green technology, has exerted a downward pressure on GTFP. In future economic development, high-polluting and low-efficiency manufacturing industries should be phased out at an accelerated pace, and clean energy should be widely adopted to reduce pollution emissions from the manufacturing industry.

5.2 Regression results of environmental regulation, OFDI on home country GTC

5.2.1 Full sample regression of the threshold effect on GTC

The calculated results of DEA method include efficiency change (EC) and technological change (TC). Correspondingly, the improvement or decline in GTFP is derived from changes in green technology (GTC) or changes in green efficiency (GEC). This paper

Table 4 The F-test results and threshold values

Types	F value	*P* value	Threshold
Single	10.0700	0.0233	−4.619

Table 5 Threshold value of environmental regulation on GTFP, GEC and GTC

Variable	lnGTFP	lnGTC	lnGEC
ln OFDI (ln regu ≤ θ_1)	−0.0214** (0.0103)	−0.0267*** (0.0074)	0.0112 (0.0090)
ln OFDI (ln regu > θ_1)	−0.0310*** (0.0101)	−0.0312*** (0.0072)	0.0051 (0.0089)
ln gov	0.1180** (0.0518)	0.1679*** (0.0367)	−0.0565 (0.0454)
ln tech	0.1406*** (0.0303)	0.1497*** (0.0215)	−0.0164 (0.0265)
ln struc	−0.3361*** (0.0933)	−0.5973*** (0.0658)	0.3145*** (0.0818)
ln edu	0.3687 (0.3412)	−0.3798 (0.2418)	0.7590** (0.2991)
ln trade	0.0791*** (0.0296)	0.0078 (0.0209)	0.0742*** (0.0260)
_cons	−2.1641*** (0.6818)	−0.5639 (0.4829)	−1.5939*** (0.5978)
N	510	510	510
R^2	0.696	0.806	0.090
F	154.9203	279.8717	6.6703

Standard deviations enclosed in parenthesis

P < 0.1 for *, 0.05 for **, and 0.01 for ***

further analyzes the origins of the adverse effects of OFDI and investigates the nonlinear effects of OFDI on GTC and GEC. The regression findings reveal that the influence of OFDI on GTC is notable, whereas its effect on GEC is not statistically significant. An assessment of the threshold regression of OFDI on GTC has indicated a notable effect, a single threshold value of −4.619, significant at 5%. The regression test outcomes are displayed in Table 4.

Governmental environmental regulation primarily encompasses the establishment of environmental permits and emission standards, the management of solid and hazardous waste, the promotion of clean production and energy conservation, as well as the execution of green finance and environmental incentives and penalties. In this article, the strength of environmental regulation in various regions is evaluated by the proportion of capital expenditure in controlling pollution. We found that economically less developed provinces, including Inner Mongolia, Ningxia, Xinjiang, Shanxi and Gansu, rank among the top five in terms of the stringency of environmental control. Although the overall capital expenditure in controlling pollution in these regions is not as high as in economically developed provinces, its proportion to GDP is relatively large. Due to the lagging green productivity and a shortage of talent in these regions, even with increased investment in green funds, it may not effectively elevate the degree of environmental efficiency. This results in the inefficiency of investment in ecological control of pollution and the squandering of resources for environmental protection. Thus, in regions with a higher degree of environmental governance, the adverse effect of OFDI predominantly stems from GTC in China.

According to the regression findings depicted in Table 5, there exists a notable adverse correlation between OFDI and GTC, whereas the regression coefficient for GEC is not statistically significant. When government regulation falls below the threshold −4.619, the regression coefficient of OFDI on GTC is −0.0267. This suggests that with each 1% rise

in OFDI, the home country's GTC will decrease by 0.0267 percentage points. As environmental regulation intensifies and surpasses the threshold value, the regression coefficient of OFDI on GTC reaches −0.0310, indicating that with each 1% increase in OFDI, the home country's GTC will decrease by 0.0312 percentage points. Under varying levels of government environmental regulation, OFDI negatively impacts GTC and demonstrates a single threshold effect, thereby partially confirming Hypothesis 2.

Meanwhile, the R^2 of OFDI's effect on the GTC reaches 0.806, greater than the R^2 value for the effect on GTFP, which is 0.696, strongly confirming that the influence of OFDI on GTFP primarily stems from the change in the level of GTC, rather than GEC. When formulating environmental regulation policies, China should consider protecting enterprises with high levels of green technology productivity, ensuring that stringent environmental regulations do not inadvertently prompt the relocation of certain high-tech firms overseas, thereby diminishing the nation's GTFP. At the same time, China should augment its investments in developed nations and foster the enhancement of green production technology level by reverse technology spillovers, thereby counterbalancing the adverse effects of intensified environmental regulation.

5.2.2 Regional heterogeneity of the threshold effect on GTC

China's thirty provinces are grouped into three regions: eastern, central, and western, each exhibiting notable distinctions in economic development, industrial structure, and green production technology levels. Regional variations in the strength of environmental regulation may result in substantial heterogeneity in the influence of OFDI on GTFP across different regions. The subsequent analysis delves into the interplay between variables at the sub-regional level.

The regression outcomes in Table 6 include threshold effects specific to the regions of the east, center, and west. The findings indicate that all three regions manifest threshold effects, albeit with varying significance levels. Specifically, the significance on GTC in the eastern region is 10%, which is lower compared to that in the western and central areas. Meanwhile, the regression coefficient in the western region is −0.0245, less than observed

Table 6 GTC threshold effect regional heterogeneity

Variable	Eastern	Central	Western
ln OFDI (ln regu $\leq \theta_1$)	−0.0369** (0.0162)	−0.0465*** (0.0143)	−0.0245*** (0.0079)
ln OFDI (ln regu $> \theta_1$)	−0.0413** (0.0160)	−0.0507*** (0.0134)	−0.0286*** (0.0078)
ln gov	−0.0380 (0.1036)	0.1335** (0.0664)	0.2293*** (0.0364)
ln tech	0.2724*** (0.0494)	0.1796*** (0.0415)	0.0905*** (0.0227)
ln struc	−1.0851*** (0.1536)	−0.2836*** (0.1033)	−0.3337*** (0.1029)
ln edu	−0.5952 (0.5589)	−0.1467 (0.4925)	−0.2767 (0.2328)
ln trade	0.1475* (0.0826)	0.0288 (0.0499)	−0.0006 (0.0171)
_cons	−0.3701 (1.2146)	−0.5242 (1.0321)	−0.8768* (0.4596)
N	187	136	187
R^2	0.816	0.816	0.887
F	107.0297	76.7975	190.4381

Standard deviations enclosed in parenthesis

$P < 0.1$ for *, 0.05 for **, and 0.01 for ***

Table 7 Threshold value of the cross-terms

Types	F value	*P* value	Threshold
Single	21.45	0.0200	−4.5037

Table 8 Results of the cross-terms' regression

Variable	Regression coeffificient	Standard error
ln OFDI*ln regu (ln regu $\leq \theta_1$)	0.0008	0.0014
ln OFDI*ln regu (ln regu $> \theta_1$)	0.0032**	0.0016
ln gov	0.0617	0.0460
ln tech	0.1506***	0.0302
ln struc	−0.3696***	0.0934
ln edu	0.3887	0.3443
ln trade	0.0779***	0.0301
_cons	−1.9813***	−0.6821
R^2	0.692	
F	151.7635	

$P < 0.1$ for *, 0.05 for **, and 0.01 for ***

in the regions of the east and center, indicating that the negative influence of OFDI on GTC is smaller in the western region, which confirms Hypothesis 2. This is because the western region has a smaller scale of OFDI and a lower starting point of green production technology level.

5.3 Analysis of the moderating effect of environmental regulation and OFDI

5.3.1 Full sample regression of the moderating effect

The moderating effects of OFDI and environmental regulation have been examined in this paper. In general, OFDI under environmental regulations also exerts a moderating influence on GTFP. The assessment of the cross-terms of environmental regulation and OFDI on GTFP confirmed the single threshold impact, significant at a 5% level. The regression test outcomes are depicted in Table 7.

As indicated in Table 8, the coefficient of the cross-terms is greater than zero. Environmental regulation promotes the improvement of GTFP by influencing OFDI. When the government's environmental governance strength falls below the threshold, the coefficient of the cross-term on GTFP is 0.0008; whereas, when surpasses the threshold, the coefficient is 0.0032. Regardless of the intensity of government regulation, the coefficient of the cross-term is non-negative number, partially validating Hypothesis 3. As the degree of environmental governance intensifies, the enhancing effect of the cross-term increase significantly. This is because environmental regulation serves as a "green driving force" on OFDI. To meet stringent environmental regulations, from a long-term perspective, companies will consider investments in high-tech, clean and environmentally friendly technologies and products, which will improve green technology innovation.

Table 9 Threshold value of the cross-terms

Types	F value	*P* value	Threshold
Eastern region	7.44	0.4475	−4.6876
Central region	10.72	0.0850*	−4.2393
Western region	10.07	0.0233 **	−4.6190

Standard errors in parentheses

$P < 0.1$ for *, 0.05 for **, and 0.01 for ***

Table 10 Regional heterogeneity of cross-terms on GTC

Variable	Eastern	Central	Western
ln OFDI*ln regu (ln regu $\leq \theta_1$)	0.0004 (0.0030)	0.0007 (0.0023)	0.0040** (0.0019)
ln OFDI*ln regu (ln regu $> \theta_1$)	0.0028 (0.0035)	0.0044 (0.0027)	0.0063*** (0.0022)
ln gov	−0.0940 (0.1317)	−0.0479 (0.0873)	0.1625*** (0.0517)
ln tech	0.2380*** (0.0686)	0.2097*** (0.0597)	0.0927** (0.0358)
ln struc	−1.0034*** (0.2196)	0.0564 (0.1442)	−0.1786 (0.1596)
ln edu	0.0845 (0.7947)	1.4676** (0.7181)	0.1977 (0.3634)
ln trade	0.0777 (0.1189)	0.0205 (0.0765)	0.1024*** (0.0272)
_cons	−1.0341 (1.7300)	−2.7833* (1.4824)	−1.9354*** (0.7158)
N	187	136	187
R^2	0.676	0.698	0.803
F	50.3662	40.0235	98.4325

Standard deviations enclosed in parenthesis

$P < 0.1$ for *, 0.05 for **, and 0.01 for ***

From the perspective of control variables, the findings are similar to those in Table 3, where only the regression coefficient of industrial structure exhibits a negative impact, substantially diminishing GTFP. This confirms the stability of the threshold regression model.

5.3.2 Variability in the moderating effect among regions

Regional heterogeneity is also observed in the moderating impact of environmental regulation and OFDI. Table 9 tests the threshold effect of the cross-terms in the regions to the east, center, and west. The regions to the west and center reach significance of 10% and 5%, respectively, while the P-value in the eastern is relatively high and fails to meet the significance level criterion.

The regression coefficients of 0.0040 and 0.0063 in the western region, as depicted in Table 10, surpass those in the regions of the east and center. This implies that the moderating impact of environmental regulation has a more pronounced stimulating influence on GTC in the western region, thus confirming Hypothesis 3. This is attributed to the limited scale of OFDI and the comparatively small initial green production technology in region of the west.

Table 11 Robustness test of threshold regression

Variable	lnGTFP	lnGTFP	lnGTC	lnGTC
ln OFDI(ln regu $\leq \theta_1$)	−0.0214** (0.0103)	−0.0019 (0.0091)	−0.0267*** (0.0074)	−0.0099** (0.0048)
ln OFDI (ln regu $> \theta_1$)	−0.0310*** (0.0101)	−0.0112 (0.0089)	−0.0312*** (0.0072)	−0.0129*** (0.0047)
lag_ln GTFP		0.9379*** (0.0729)		
lag_ln GTC				1.0312*** (0.0386)
_cons	−2.1641*** (0.6818)	−0.3030 (0.6102)	−0.5639 (0.4829)	0.9317*** (0.3221)
N	510	480	510	480
R^2	0.696	0.780	0.806	0.920
F	154.9203	196.0292	280.8242	635.2786

Standard deviations enclosed in parenthesis

$P < 0.1$ for *, 0.05 for **, and 0.01 for ***

5.4 Robustness test

5.4.1 The threshold regression with lag terms

This paper further verifies the robustness of the threshold effect model by conducting threshold regression analysis on panel data with a one-period lag of dependent variable. The outcomes presented in Table 11 indicate that, regardless of the level of government regulation, OFDI exhibits a detrimental impact on both GTFP and GTC, with the regression coefficient on GTC surpassing that on GFTP. At the same time, in the regression with a lag of one period, the goodness of fit R^2 reaches 0.780 and 0.920, respectively, indicating that the regression model results are robust.

5.4.2 Quantile regression of the the moderating effect

The quantile regression technique was employed to conduct regression analysis utilizing the 0.10, 0.50, and 0.90 quantiles of the dependent variables. The outcomes are depicted in Table 12. Environmental regulations and OFDI have a considerable moderating effect, with

Table 12 Quantile regression results of the lag terms of GTFP

Variable	Quantile 0.10	Quantile 0.50	Quantile 0.90
Ln OFDI*ln regu	0.0048** (0.023)	0.0042* (0.0024)	0.0083*** (0.0022)
ln gov	0.113*** (0.034)	0.1010*** (0.0321)	0.1647*** (0.0679)
ln tech	0.1308*** (0.0236)	0.1837*** (0.0239)	0.2060*** (0.0553)
ln struc	−0.0821 (0.0821)	−0.1760* (0.0978)	−0.2352* (0.1382)
ln edu	−0.2700 (0.1944)	0.4489** (0.1746)	1.456*** (0.4584)
ln trade	−0.0168 (0.0223)	−0.0898*** (0.0152)	−0.1164*** (0.0180)
_cons	−0.1269 (0.4218)	−0.9158** (0.4569)	−2.8962*** (0.9330)

Standard deviations enclosed in parenthesis

$P < 0.1$ for *, 0.05 for **, and 0.01 for ***

the coefficient of the cross-term being positive, consistent with the threshold regression coefficient. Regarding the coefficients' significance levels, there exist a notable increase across all control variables as the quantile increase.

Moreover, as the quantile increase, the cross-terms coefficient's absolute value demonstrates a pattern of initially decreasing and then increasing. This trend is also in line with the characteristics of the threshold regression coefficient.

6 Conclusions

OFDI is a major factor in propelling the domestic economy. Environmental governance guides economic progress toward a sustainable development framework that is green and low-carbon. The link between OFDI and GTFP under the threshold of environmental regulation is examined in this research. By conducting panel data analysis on 30 provinces in China, the study draws the following key conclusions. First, the OFDI in China exhibits a negative threshold effect on the GTFP, predominantly impacting the GTC rather than the GEC. At the same time, OFDI has a more pronounced adverse influence on GTC in the regions of the east and center compared to the west. Finally, environmental regulation positively moderates OFDI, acting as a catalyst or "green driving force" for green technology enhancement and encouraging enterprises to elevate their green technology standards. In the western region, the moderating effect has a notably greater promoting impact on the home country's GTC.

6.1 Theoretical implication

This paper holds several theoretical implications. Firstly, it contributes to existing studies on GTFP by demonstrating that the influence of OFDI on GTFP in home nation is not solely determined by factors like personnel mobility (Gu and Qiu 2017), industrial structural adjustments (Gondim et al. 2018), and reverse technology spillovers (Li et al., 2022b), but is also dynamically influenced by environmental regulations. Empirical research indicates that OFDI exhibits a singular threshold effect on GTFP in the home country, and the adverse impact intensifies with the reinforcement of environmental regulations.

Secondly, the paper introduces a comprehensive theoretical framework for analyzing the connection between GTFP and OFDI under the threshold of environmental regulation. Numerous research have focused on examining the influence of OFID in environment decentralization (Fang & Cao, 2022), while insufficient attention has been given to the relationships and impact mechanisms among the three factors. The innovative application of threshold regression models validates the dynamic nature of the connection between OFDI and GTFP. Meanwhile, this study has identified the main pathway through which environmental regulations affect the home country's GTFP: the primary impact arises from changes in the home country's green technology (GTC) rather than alterations in green efficiency (GEC).

Moreover, the study validates the moderating influence of environmental regulation on OFDI. Environmental regulation positively moderates OFDI, particularly in bolstering the GTFP in China, especially in the western regions. The findings of this paper provides a scientific reference for China's outward investment policy.

6.2 Policy implications

Drawing from the empirical findings, this paper suggests the subsequent policy suggestions. First, China should adhere to the principle of sustainable development in outward investment and give further attention to the green technology levels of invested enterprises. When engaging in investments along the "Belt and Road", it's essential to consider not only the scale but also the environmental technology level of the enterprises involved. Second, OFDI should consider regional differences and develop distinct environmental regulatory policies tailored to the specific needs and conditions of the regions in the east, center, and west. While in the eastern and western regions, less stringent environmental regulations should be devised, reducing the expected increase in environmental regulation and giving critical domestic enterprises time and space to improve their green technology levels. In the western region, more targeted environmental regulation policies should be formulated, providing targeted assistance in selecting investment targets and encouraging the development of green technology. Third, as China's OFDI continues to expand, its influence on the host country's GTFP will evolve accordingly. Focusing on the consequences of alterations in environmental regulation policies on OFDI and leveraging the moderate effect of environmental regulation to promote GTFP are encouraged steps.

6.3 Restrictions and upcoming research

This paper explores the correlation between OFDI and GTFP under the threshold of environmental regulation provincial level in China, without accounting for variations in economic growth status, green technology, and industrial composition across different countries. The empirical data mainly comes from the authoritative report from the government department. While the sample carries a certain level of authority, it's important to acknowledge that the context-specific nature of the study may undermine the generalization of the findings and the framework of the study. Significant differences exist in industrial characteristics and demographic factors among these countries, and varying research backgrounds may potentially influence the model.

In future research, India and Europe can be studied as research objects to further deepen the model and obtain more general conclusions. These entities are at various stages of economic growth compared to China. The European Union serves as a focal point for major developed countries, with foreign direct investment reaching 142 billion euros in 2021, ranking second globally. India is one of the largest developing nations globally and shares many similarities with China in terms of population and economic status. These two regions exhibit significant differences in environmental regulatory policies. Investigating how their OFDI influences GTFP can further corroborate the theoretical model's scientific validity.

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Declarations

Conflict of interest The authors declare no competing interests.

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