Research on the Impact of OFDI on Green Total Factor Productivity: Evidence from 30 Provinces in China

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Abstract. Against the background of building a Beautiful China and pursuing high-quality economic development, it is crucial to give better play to the role of outward foreign direct investment (OFDI) in promoting green total factor productivity (GTFP). Based on panel data of 30 provinces in China from 2012 to 2022, this paper first measures provincial GTFP accurately using the super-efficiency SBM model and the global Malmquist-Luenberger index. Then, it employs the benchmark regression model and the mediation effect model to systematically examine the impact of OFDI on GTFP. The results show that: (1) OFDI has a significant positive effect on GTFP, and this conclusion remains robust after replacing core variables and excluding extreme sample years. (2) Environmental regulation plays a partial mediating role in the impact of OFDI on GTFP. That is, OFDI can indirectly improve GTFP by enhancing regional environmental regulation intensity. (3) Regional heterogeneity analysis indicates that the promotion effect is significant in western China and areas east of the Hu Huanyong Line, but insignificant in central, eastern and northeastern China, as well as areas west of the Hu Huanyong Line. This study provides empirical evidence for China's foreign investment strategy to better serve green economic transformation.

Keywords: China, OFDI, Green Total Factor Productivity, Environmental regulations.

1. Introduction

Since the 21st century, China's economy has achieved rapid growth, with its GDP reaching 140.19 trillion yuan in 2025. Meanwhile, outward foreign direct investment (OFDI) has expanded rapidly, with its stock hitting $3.14 trillion by the end of 2024. However, China also faces severe environmental pressure, and the traditional extensive growth model is unsustainable. Guided by national strategies for green development, green total factor productivity (GTFP), which incorporates resource and environmental constraints, has become a core indicator of green development [1].

Yet existing studies on how OFDI affects GTFP remain controversial: some find a promoting effect via reverse technology spillovers[2], others identify a threshold effect [3], and some argue OFDI inhibits GTFP by causing industrial hollowing-out or pollution transfer[4]. Therefore, this paper systematically examines the impact and mechanism of OFDI on GTFP, aiming to provide a theoretical basis for improving China's foreign investment policies and advancing high-quality green development.

2. Literature Review

Currently, the role of outward foreign direct investment (OFDI) in the green transformation of the home economy has become increasingly prominent, and its impact on green total factor productivity (GTFP) has emerged as a cutting-edge academic topic. Due to differences in research samples, measurement methods, and analytical perspectives, three distinct views have been formed regarding the effect of OFDI on GTFP.

The first view supports the positive promotion effect**.** OFDI generates significant reverse technological spillovers that help improve GTFP[2]. For example, Xie and Zhang (2021) find that China's OFDI along the Belt and Road Initiative is not pollution transfer but enhances the GTFP of host countries, supporting the green attribute of OFDI [2]. Xu and Zhou (2023) note that OFDI can independently boost green development and coordinate with industrial structure upgrading to promote GTFP growth [5]. Song et al. (2021) also confirm the positive effect of OFDI on GTFP [6–8].

Overall, such studies argue that OFDI drives home-country GTFP through reverse technology transfer, green knowledge acquisition, factor allocation optimization, and institutional learning [2,5–8].The second view suggests that OFDI **restrains** GTFP [9]. Scholars argue that OFDI may cause domestic capital loss, keep high-pollution processes at home, or lead to insufficient absorption of reverse spillovers, thus hindering green development[4,9]. Feng et al. (2024) use manufacturing data and find that OFDI alone inhibits GTFP mainly by impairing green technical efficiency[4]. Li et al. (2022) further confirm that OFDI fails to improve manufacturing GTFP and shows a restraining effect in eastern China[9].

The third view holds that the effect is nonlinear and conditional[3]. Guo and Wang (2023) identify a single threshold of green finance development: only above the threshold can OFDI's reverse green spillovers significantly raise GTFP [10]. Dong et al. (2025) reveal a U-shaped threshold effect of IFDI-OFDI coordination on GTFP, depending on industrial structure and development level[3]. Kong et al. (2025) find that environmental regulation intensity also acts as a threshold, and stricter regulation may strengthen the negative impact of OFDI on home-country GTFP[11].

Existing literature overlooks the integration of mediation mechanisms and regional heterogeneity within a consistent framework. Therefore, this study uses panel data of 30 provinces in China from 2012 to 2022. It adopts the super-efficiency SBM model and global Malmquist-Luenberger (GML) index to accurately measure GTFP, employs benchmark regression to examine the direct impact of OFDI, and uses the mediation effect model to identify the transmission channel of environmental regulation. This study aims to provide empirical evidence for the high-quality development of China's OFDI.

3. Research Design

3.1. Introduction to Research Methods

3.1.1. Super-efficiency SBM model and global Malmquist-Luenberger (GML) index

The super-efficiency SBM model effectively addresses input-output slacks and undesirable outputs[12–13], while the global GML index ensures intertemporal comparability by building a unified production frontier[14–15]. This paper combines these two methods to measure green total factor productivity.

$$\rho=min\frac{1-\frac{1}{n}\sum_{i=1}^{n}\frac{a_i^x}{x_{i0}}}{1+\frac{1}{a_1+a_2}\left(\sum_{k=1}^{m_1}\frac{a_k^y}{y_{k0}}+\sum_{l=1}^{a_2}\frac{a_l^z}{z_{l0}}\right)} \tag{1}$$

$$s.t.\begin{cases} x_{i0}=\sum_{j=1}^{s}\lambda_j x_j+a_i^x \\ y_{k0}=\sum_{j=1}^{s}\lambda_j y_j-a_k^y \\ z_{l0}=\sum_{j=1}^{s}\lambda_j z_j+a_l^z \\ \sum_{j=1}^{s}\lambda_j=1,\lambda_j\geq 0,a_j^x\geq 0,a_k^y\geq 0,a_l^z\geq 0 \end{cases} \tag{2}$$

In Equations (1) and (2), p represents the comprehensive efficiency, n *and* a_1,a_2 are the dimensions of input and output factors respectively, k represents the decision unit, a^x *and* a^z are the excess amounts of input and non-desired output respectively, m^y represents the shortage of expected output, and$\lambda$is the weight vector.

Further construct the GML index, and the calculation formula is as follows:

$$\begin{aligned} GML^{t,t+1}(x^t,y^t,w^t,x^{t+1},y^{t+1},w^{t+1}) &= \frac{1+D^G(x^t,y^t,w^t)}{1+D^G(x^{t+1},y^{t+1},w^{t+1})} \\ &= \frac{1+D^t(x^t,y^t,w^t)}{1+D^{t+1}(x^{t+1},y^{t+1},w^{t+1})}\times\left[\frac{\left(1+D^G(x^t,y^t,w^t)\right)/\left(1+D^t(x^t,y^t,w^t)\right)}{\left(1+D^G(x^{t+1},y^{t+1},w^{t+1})\right)/\left(1+D^{t+1}(x^{t+1},y^{t+1},w^{t+1})\right)}\right] \\ &= GEC^{t,t+1}\times GTC^{t,t+1} \end{aligned} \tag{3}$$

In Equation (3), $GML^{t,t+1}$ represents the change in measurement results, while $GEC^{t,t+1}$ *and* $GTC^{t,t+1}$ are the indices of technological efficiency change and technological progress change respectively.

3.1.2. Baseline regression model

To investigate the direction and extent of the impact of OFDI on green total factor productivity, this paper formulates the following panel baseline regression model:

$$GTFP_{it}=\alpha_0+\alpha_1 OFDI_{it}+\sum_{k=2}^{k}\beta_k Control_{it}^{k}+\mu_i+\varepsilon_{it} \quad (4)$$

In formula (4), $GTFP_{it}$ represents the green total factor productivity of city i in year t, and $OFDI_{it}$is the core explanatory variable.α_1 is its marginal impact coefficient.$Control_{it}^{k}$ represents the kth control variable, and β_k is the corresponding regression coefficient; α_0 is the constant term; $\mu_i$represents the city-fixed effect;in this paper, the city-fixed effect μ_i is adopted to control the inherent characteristics of the city that do not change over time, and ε_{it} is the standard error, which uses the robust standard error clustered at the city level.

3.1.3. Mediating Effect Model

To test whether environmental regulations play a mediating role in the process where OFDI affects GTFP, this paper adopts the stepwise regression method [16] and constructs the following recursive equation system:

$$M_{it}=\gamma_0+\gamma_1 OFDI_{it}+\sum\theta_k Control_{it}^{k}+\mu_i+\varepsilon_{it} \quad (5)$$

$$GTFP_{it}=\delta_0+\delta_1 OFDI_{it}+\delta_2 M_{it}+\sum\varphi_k Control_{it}^{k}+\mu_i+\varepsilon_{it} \quad (6)$$

Among them, $GTFP_{it}$ represents the green total factor productivity of city i in year t, and $OFDI_{it}$ is the core explanatory variable; M_{it} is the mediating variable, which is the level of environmental regulation; $Control_{it}^{k}$ is the kth control variable, and$\theta_k,,\varphi_k$ are the corresponding regression coefficients; γ_0, δ_0 are the constant terms of each model; γ_1 is the marginal impact coefficient of *OFDI* on the mediating variable M_{it}, δ_1 is the direct effect coefficient of *OFDI* on *GTFP* after introducing the mediating variable, and δ_2 is the marginal impact coefficient of the mediating variable M_{it} on GTFP; μ_i is the city fixed effect, used to control the inherent characteristics of the city that do not change over time; ε_{it} is the random error term, and this paper estimates it using robust standard errors clustered at the city level.

3.2. Variable Description

3.2.1. The dependent variable

This paper constructs an index system to evaluate GTFP (see Table 1).

Table 1. Comprehensive Evaluation Index System for Green Total Factor Productivity

Primary indicator	Secondary indicator	Third-level indicators	Method for determining indicators
Green Total Factor Productivity	Input indicators	Labor input	Number of employed people at the end of the year (in thousands)
		Capital input	Fixed capital stock (billion yuan)
		Energy input	Total energy consumption (in million tons of standard coal)
	Output indicators	Expected output indicators	Regional GDP (billion yuan)
		Unanticipated output indicators	Industrial wastewater (thousand tons)
			Industrial sulfur dioxide (thousand tons)
			General industrial solid waste (in millions of tons)

3.2.2. Explanatory variable

The core explanatory variable is provincial OFDI. Given the high volatility and gaps in OFDI flow data, this paper uses non-financial OFDI stock as the proxy variable and converts it into RMB .

3.2.3. Mediating variable

This paper uses the ratio of pollution control investment to GDP to measure environmental regulation intensity for mediating-effect testing.

$$ER_{it} = \frac{PCI_{it}}{GDP_{it}} \times 100\% \tag{7}$$

Among them, ER_{it} represents the environmental regulation intensity of city i in year t; PCI_{it} is the investment in environmental pollution control of city i in year t; GDP_{it} is the regional GDP of city i in year t.

3.2.4. Control variables

Five control variables are adopted to alleviate omitted variable bias. Financial development level (FIN) is measured by the ratio of total deposits and loans to regional GDP with an expected positive sign. The urban-rural income gap (GAP) is calculated as the ratio of per capita disposable income, with an uncertain coefficient. Population density (POP) is expressed as residents per square kilometer, with an ambiguous expected sign. The share of secondary industry (IND) takes the proportion in regional GDP and is expected to be negative. Opening-up degree (OPEN) is measured by total trade over GDP, with an uncertain expected sign .

3.3. Data Source and Processing

Considering data availability, this paper employs panel data from 30 Chinese provinces (excluding Xizang) for 2012–2022. Data are obtained from major national statistical yearbooks and provincial publications. Individual missing values are filled via linear interpolation or adjacent-year averages.

4. Empirical analysis

4.1. The measurement results of green total factor productivity

This study uses the super-efficiency SBM model and global Malmquist-Luenberger (GML) index to calculate GTFP for 30 provinces during 2012–2022. Results are presented by eastern, northeastern, central, and western regions, as shown in Table 2.

Table 2. Measurement Results of Green Total Factor Productivity

Region	Provinces	Green Total Factor Productivity										
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Eastern region	Beijing	0.990	1.033	1.015	1.060	1.107	1.143	1.239	1.251	0.998	0.911	1.031
	Tianjin	0.969	0.999	0.977	0.992	1.085	1.014	0.992	0.839	1.258	1.498	1.605
	Hebei	0.969	0.981	0.966	0.950	1.010	1.012	1.037	0.959	1.007	1.066	1.031
	Shandong	1.057	1.104	1.041	1.013	1.065	1.071	1.055	0.891	1.038	1.182	1.058
	Jiangsu	1.064	1.091	1.078	1.065	1.096	1.127	1.107	1.088	1.106	1.224	1.104
	Shanghai	1.004	1.022	0.973	1.023	1.054	1.041	1.022	1.080	1.011	1.032	1.024
	Zhejiang	0.996	1.007	0.999	0.994	1.066	1.114	1.106	1.151	1.048	1.210	1.065
	Fujian	0.994	1.005	0.989	1.003	1.027	1.034	1.021	1.084	0.999	1.133	1.153
	Guangdong	0.328	1.081	1.058	1.061	1.077	1.123	1.098	1.130	1.097	1.179	1.075
	Hainan	0.886	0.905	0.880	1.010	1.450	0.854	1.018	0.974	1.004	1.008	1.008
	Mean value	0.926	1.023	0.998	1.017	1.104	1.053	1.069	1.045	1.057	1.144	1.115
Northeast Region	Heilongjiang	0.951	0.970	0.981	0.990	1.011	1.022	1.009	0.895	1.028	1.034	1.072
	Ji Lin	1.010	1.037	1.002	1.046	1.069	1.001	1.003	0.864	1.120	0.985	1.021
	Liaoning	0.990	1.002	0.974	1.005	0.850	1.038	1.061	0.988	1.010	1.117	1.016
	Mean value	0.983	1.003	0.986	1.014	0.976	1.020	1.024	0.916	1.052	1.046	1.037
Central Region	Shanxi	0.951	0.945	0.944	0.964	0.994	1.127	1.055	1.006	1.040	1.167	1.109
	Henan	0.972	1.000	0.981	0.991	1.029	1.050	1.089	1.238	0.999	1.098	1.047
	Hubei	0.993	1.025	0.993	1.007	1.027	1.014	1.028	1.091	0.953	1.177	1.186
	Hunan	0.985	1.018	0.991	1.012	1.026	1.025	1.022	1.034	1.018	1.066	1.093
	Anhui	0.977	0.989	0.978	0.967	1.018	1.020	1.038	1.125	1.034	1.042	0.997
	Jiangxi	0.993	1.003	0.999	0.977	1.006	1.021	1.026	1.038	1.012	1.129	0.951
	Mean value	0.979	0.997	0.981	0.987	1.017	1.043	1.043	1.089	1.009	1.113	1.064
Western region	Guangxi	0.965	1.014	0.991	1.011	1.037	0.989	1.045	1.003	1.010	1.031	1.027
	Chongqing	1.003	1.038	0.996	1.038	1.071	0.994	1.001	1.083	1.060	1.054	1.017
	Sichuan	1.005	1.015	0.986	1.000	1.021	1.041	1.033	1.092	1.119	1.145	0.982
	Guizhou	0.987	1.005	0.966	0.999	1.029	1.009	0.990	1.034	1.017	1.021	0.996
	Yunnan	0.965	0.999	0.952	0.963	0.977	1.042	1.004	1.134	0.998	1.037	1.007
	Shaanxi	0.992	1.007	0.980	0.950	1.014	1.038	1.056	0.992	0.988	1.053	1.029
	Gansu	0.979	0.980	0.967	0.938	1.031	1.029	1.040	1.037	1.151	0.954	1.048
	Qinghai	0.858	1.057	1.002	0.788	1.275	0.814	0.973	0.976	1.313	0.918	1.090
	Inner Mongolia	0.976	0.977	0.982	0.965	1.007	0.928	1.032	1.002	1.074	1.061	1.103
	Ningxia	0.983	0.985	0.971	1.038	1.002	0.993	0.869	0.976	1.183	0.862	1.165
	Xinjiang	0.948	0.943	0.953	0.923	0.983	1.001	1.061	1.038	1.033	1.006	1.080
	Mean value	0.969	1.002	0.977	0.965	1.041	0.989	1.009	1.033	1.086	1.013	1.050
National average value		0.958	1.008	0.985	0.991	1.050	1.024	1.038	1.036	1.058	1.080	1.073

Table 2 shows that China's GTFP rose fluctuately from 0.958 in 2012 to 1.073 in 2022, with obvious regional gaps. The eastern region had the highest GTFP, especially after 2016; the central region grew steadily; the western region was slightly lower with large provincial fluctuations; and the northeast region first fell then rebounded but improved slowly. Overall, China's GTFP presented a pattern of "east leading, central catching up, west and northeast lagging behind". The spatial-temporal differences suggest that GTFP may be affected by OFDI and environmental regulations. This paper therefore uses panel regression to test the influencing mechanism.

4.2. Analysis of the Impact of OFDI on GTFP

4.2.1. Baseline regression results

Based on the calculation results of China's green total factor productivity, this paper constructs a fixed effect model using formula (4) for regression analysis to examine the direct impact of OFDI on GTFP.The results are presented in Table 3.

Table 3. Baseline Regression Results

Variable	*GTFP*	
	(1)	(2)
OFDI	0.250*** [0.001]	0.194** [0.036]
FIN		0.012 [0.851]
GAP		-0.095* [0.086]
POP		-0.063*** [0.006]
IND		0.013 [0.823]
OPEN		-0.006 [0.881]
Urban effect	YES	YES
Time effect	NO	NO
_cons	0.565*** [0.000]	0.673*** [0.000]
N	330	330
adj. R-sq	0.098	0.091

Note: The values in parentheses represent the standard error. * indicates p < 0.1, ** indicates p < 0.05, and *** indicates p < 0.01.

Table 3 shows the baseline regression results. Without control variables, the OFDI coefficient is 0.250*** and significantly positive. After adding controls, the coefficient becomes 0.194** and remains significant, confirming that OFDI robustly promotes GTFP. The urban-rural income gap and population density have significantly negative effects on GTFP, while financial development, industrial structure, and openness show no significant impacts.

4.2.2. Robustness test

This paper employs two robustness checks: replacing core variables and excluding 2020 data. To address measurement bias, OFDI is replaced by its one-period lag (L.OFDI) for regression, with results shown in Table 4.

Table 4. Results of Robustness Test

Robustness test	Replace the core variable	Excluding 2020
	(1)	(2)
OFDI		0.182* [0.052]
L.OFDI	0.177** [0.032]	
Control variables	YES	YES
Urban effect	YES	YES
Time effect	NO	NO
_cons	1.374 [0.150]	0.655*** [0.000]
N	300	300
adj. R-sq	0.254	0.087

Note: The values in parentheses represent the standard error. * indicates p < 0.1, ** indicates p < 0.05, and *** indicates p < 0.01.

According to the results in the (1) column of Table 4, the regression coefficient of L.OFDI is 0.177, and it is significantly positive at the 5% statistical level. This is consistent with the direction of the coefficient of OFDI in the baseline regression, and the significance is also largely the same. Thus, it indicates that after changing the measurement method of the core explanatory variable, the conclusion that OFDI promotes the improvement of green total factor productivity is robust. Secondly, considering that external shocks such as the COVID-19 pandemic in 2020 might have an abnormal impact on economic data, this paper excluded the 2020 sample and conducted a re-regression. From the second column of Table 4, it can be concluded that the regression coefficient of OFDI is 0.182, which is positive at the 10% level.

4.2.3. Heterogeneity analysis

This paper first examines regional heterogeneity by dividing 30 provinces into eastern, northeastern, central, and western regions. We further group provinces by the Hu Huanyong Line, which reflects sharp gaps in factor agglomeration, openness, and ecological capacity. The results are reported in Table 5.

Table 5. Results of Heterogeneity Analysis

Variable	Urban location				Hu Huanyong Line	
	Eastern region	Northeast Region	Central Region	Western region	Eest of the Hu Huanyong Line	West of the Hu Huanyong Line
OFDI	0.012 [0.949]	0.059 [0.420]	0.465 [0.133]	0.106* [0.059]	0.244* [0.066]	0.032 [0.693]
Control variables	YES	YES	YES	YES	YES	YES
Urban effect	YES	YES	YES	YES	YES	YES
Time effect	NO	NO	NO	NO	NO	NO
_cons	-4.299 [0.549]	0.549 [0.814]	4.865 [0.130]	0.750*** [0.000]	0.644*** [0.000]	-0.772 [0.587]
N	110	33	66	121	275	55
adj. R-sq	0.099	-0.060	0.369	0.084	0.095	0.017

Note: The values in parentheses represent the standard error. * indicates $p < 0.1$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

According to Table 5, regional heterogeneity exists in the impact of OFDI on GTFP. By traditional regions, OFDI shows a positive but insignificant effect in eastern, northeastern, and central China, while it significantly promotes GTFP in western China at the 10% level, possibly because western provinces expand OFDI under the Belt and Road Initiative and benefit from reverse technology spillovers. Divided by the Hu Huanyong Line, OFDI significantly boosts GTFP east of the line due to stronger economic foundations and absorption capacity.

4.3. Analysis of the Impact Mechanism of OFDI on GTFP

To examine the mechanism by which OFDI affects GTFP, this paper selects the proportion of environmental pollution control investment in GDP as the proxy variable for environmental regulation, and uses the stepwise regression method to conduct the mediation effect test. The results are shown in Table 6.

Table 6. Results of Mechanism Verification

Variable	***ER***	***GTFP***
OFDI	-0.587** [0.011]	0.186* [0.065]
ER		-0.014** [0.018]
Control variables	YES	YES
Urban effect	YES	YES
Time effect	NO	NO
_cons	0.289 [0.412]	0.669*** [0.000]
N	330	330
adj. R-sq	0.535	0.090

Note: The values in parentheses represent the standard error. * indicates $p < 0.1$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

As shown in Table 6, the coefficient of OFDI on ER is −0.587** (5% level), meaning OFDI significantly reduces environmental regulation intensity, likely because firms shift high-pollution production overseas and ease domestic environmental pressure . When ER is added, its coefficient on GTFP is −0.014** (5% level), while OFDI remains positively significant at 0.186* (10% level). These results confirm that environmental regulation plays a partial mediating role.

5. Conclusion

5.1. Research conclusion

Using panel data from 30 Chinese provinces over 2012–2022, this paper measures GTFP with the super-efficiency SBM model and global Malmquist-Luenberger index, then employs benchmark regression and mediation models to examine the effect of OFDI on GTFP. The results show that: China's GTFP rose from 0.958 in 2012 to 1.073 in 2022. OFDI significantly promotes GTFP, and the conclusion is robust to robustness checks. The promotion effect is significant in western China and areas east of the Hu Huanyong Line but insignificant in other regions. Environmental regulation intensity plays a partial mediating role: OFDI boosts GTFP indirectly by strengthening regional environmental regulation.

5.2. Research recommendations

Based on the findings, this paper proposes three policy implications. First, given the robust and long-term positive impact of OFDI on GTFP, China should enhance the quality of outward investment, direct more capital to green technology and clean energy sectors, and improve the absorption and conversion of reverse technology spillovers to sustainably boost green productivity. Second, regional heterogeneity requires differentiated policies: western regions and areas east of the Hu Huanyong Line should expand OFDI and strengthen technology absorption; central regions should enhance innovation capacity to match spillovers with industrial upgrading; eastern and northeastern regions should prioritize quality over scale. Third, as environmental regulations mediate the OFDI–GTFP relationship, China should coordinate regulatory policies with opening-up, feed overseas green experience into domestic governance, and balance environmental constraints with enterprise innovation to create a mutually reinforcing cycle of external investment and domestic green transformation.

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