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RESEARCH ARTICLE

Do foreign direct investment and environmental regulation improve green technology innovation? An empirical analysis based on panel data from the Chinese manufacturing industry

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Abstract

The environmental regulation and foreign direct investment (FDI) inflow have an important impact on the progress of green technology. This study analyzes the impacts of environmental regulation and FDI on green technology innovation (GTI) based on the panel data of 13 Chinese manufacturing sectors. The results of static panel regression show that the environmental regulation has a positive impact on GTI, while the FDI has a negative impact. The results of the panel threshold model reveal that the effect of environmental regulation on GTI presents a nonlinear shape. The negative effect of FDI on GTI is strengthened when the environmental regulation exceeds its threshold. Increasing FDI inflow can inhibit the effect of environmental regulation. Meanwhile, a strict environmental regulation can enhance the inhibiting effect of FDI on GTI. The FDI inflow into high-tech manufacturing sectors has a less negative impact on GTI than the FDI inflow into low-tech sectors in the case of the enhancement of environmental regulation. This study provides some implications for the formulation of environmental regulation and the FDI inflow into China to improve the GTI.

Keywords FDI · Environmental regulation · Green technology innovation · Panel threshold model

Introduction

China actively introduces foreign direct investment (FDI) to promote economic development associated with economic globalization. As a country with a large population, China mainly takes advantage of the vast demand market and labor force to attract foreigners to invest into China (Xu et al. 2018). The influence of FDI inflow on one country can be divided into direct and indirect effects. The direct effect includes the technology spillover and "pollution paradise" effect, while the indirect effect includes the economic development promotion and industrial output value increase (Zhang et al. 2016). The FDI flowing into China reached 1381.3 billion US dollars, and its stock reached 17694.86 billion US dollars in 2019 (China National Bureau of Statistics); the cumulative foreign-funded enterprises exceeded 1 million in 2019. Meanwhile, the

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proportion of foreign investment into high-tech industries increased as well. The huge FDI inflows into China's manufacturing industry because China has already been a world leader in this industry. However, the environmental pollution emerged associated with the FDI inflow. In 2020, China declared that the carbon emission peak would reach by 2030 and carbon neutrality would be realized by 2060, which has been a national strategy. China has implemented various environmental regulation policies in recent years. The market-oriented policy instruments mainly include feed-in tariff (FIT), emission trading scheme (ETS), and some taxes (CO_2 tax, NO_X tax). The nonmarket-oriented policy instruments include the government research and development (R&D) expenditure on renewable energy, emission limit value (ELV), and so on. The "Porter hypothesis" proposes that the environmental regulation can stimulate the high energy-consuming and high-polluting enterprises to innovate technology and improve production efficiency, thereby reducing pollutant emissions. The "pollution paradise" hypothesis suggests that the pollution-intensive firms tend to be established in countries with lower environmental standards, which exacerbates the environmental degradation in host countries. The "pollution halo" effect shows that the FDI improves the environmental quality of the host country through technology spillovers (Duan et al. 2020). China has established an environmental policy system to alleviate the environmental damage in the process of manufacturing industry development. This makes manufacturing enterprises cleaner and more eco-friendly. As we know, the green production technology is the key factor for cleaner production. In 2019, The China Ministry of Science and Technology declared that the market-oriented green technology innovation (GTI) system should be built. China has implemented the green regulation for several industries to encourage the GTI, which is conducive to the competitive advantage and sustainable development of enterprises (Zhang et al. 2020c). Although some measures can reduce pollutant emissions and achieve the purpose of environmental protection in the short term, the fundamental means to achieve green economic development lies in the GTI in the long run. The GTI in the industrial sectors is an important driving force to realize the construction of ecological civilization and the transformation of economic development, because the pollution-intensive sectors are concentrated in the industry. In this regard, how do the FDI inflow and environmental regulation influence the GTI? How does the FDI with different technology levels affect the GTI? To clarify these questions, this study explores the influences of FDI and environmental regulation on GTI using the panel data of the Chinese manufacturing industry.

Literature review and hypotheses

It is known that the environmental regulation affects the GTI. A positive effect of environmental regulation on GTI, or a "U-shape" relationship between environmental regulation and GTI, has been put forward. The environmental regulation has a negative effect on GTI in the short term because enterprises increase the cost for environmental protection (Du et al. 2021). This results in the lack of motivation on GTI. According to the "Porter hypothesis," the environmental regulation can stimulate enterprises to promote productivity and green technology in long term, which has a positive effect on GTI (Santis et al. 2021; Li et al. 2021; Song et al. 2018). The literature on the influence of environmental regulation on GTI are mainly from the regional level. For example, Li and Wu (2017) studied the relationship between environmental regulation and GTI in the Chinese Yangtze River economic belt using a spatial dynamic panel model and found that the local environmental regulation has a positive spatial spillover effect on GTI. Yang et al. 2020a) used the singular boundary method (SBM) to study the mediating role of environmental regulation in carbon intensity and GTI for 30 Chinese provinces. The results show that the effect of environmental regulation on GTI is nonlinear. As for the nonlinear relationship, Li et al. 2013) used a panel threshold model to explore the nonlinear relationship between environmental regulation and industrial development pattern. The results show the green total factor productivity increases when the environmental regulation crosses its threshold. Wang et al. (2019) received the same result using the OECD countries as a case. Ouyang et al. (2020) found that there is a "U-shape" relationship between environmental regulation and GTI, based on Chinese provincial panel data, which is consistent with the conclusion of Qiu et al. (2021) and Guo et al. (2018). Zhai and An 2020) used the structural equation model to study the green transformation of the Chinese manufacturing industry and found that the environmental regulation promotes the green transformation of the manufacturing industry. It is widely acceptable that the improvement of environmental regulation can increase the cost of environmental protection (Boyd and McClelland 1999; Zhang et al. 2020a). The total factor productivity declines if the environmental regulation exceeds a certain degree (Wang and Liu 2014). Based on the comprehensive review of previous research, we give the following hypothesis.

Hypothesis 1: the environmental regulation has a "U-shape" relationship with GTI

The impact of FDI on GTI mainly embodies the "industry structure" effect and "technology spillover" effect. The "industry structure" effect means that the FDI inflow can change the industry structure in the host country; the "technology spillover" effect means that the FDI inflow can promote the technology progress in the host country. Wang and Luo (2020) conducted a panel threshold regression with the quantity and quality of FDI as the double thresholds, and used the panel data of 30 Chinese provinces from 2006 to 2016, to investigate the effect of GTI on environmental pollution. The results show that the high quantity and quality of FDI lead to the positive effect of GTI on pollution control. Zhao (2019) found that the FDI has a "technology spillover" effect, but it has a negative effect on the proportion of green patents, which does not promote the development of GTI towards a cleaner direction. The "pollution paradise" hypothesis suggests that the FDI tends to flow into areas with low environmental standard, so the environment is further aggravated in the areas associated with the expansion of FDI inflow (Xu et al. 2020). This is also called as the "race to the bottom" effect, which means that the enterprises will reduce the standard of cleaner production for cost saving and seldom focus on GTI (Feng et al. 2021). Qiu et al. (2021) analyzed the influencing factors of GTI in 30 Chinese provinces and found that FDI has a negative impact on GTI. Jiang et al. (2020) applied the fixed effect model and DID (difference-in-difference) method to study city innovation. The results showed that the technology spillover effect of FDI is weakened by the "talent gathering" effect. China's GTI cannot rely on the advanced technology transfer but depends on the domestic innovation (Zhang and Zhao 2012; Su and Zhang 2020). The current relative studies on the effect of FDI are mainly from a regional perspective (Lin and Kwan 2016; Du and Li 2019), so it is necessary to explore this topic from a sectoral level. Thus, hypothesis 2 is proposed considering the reality of China's FDI inflow.

Hypothesis 2: the FDI has a negative effect on GTI

The GTI is influenced by both environmental regulation and FDI. The existing literature mainly use the threshold regression to study the relationship between FDI, environmental regulation, and GTI. The "crowding out" effect of FDI suggests that the high cost in pollution control will reduce the R&D investment under a strict environmental regulation (Grossman and Krueger 1991). From this perspective, the negative impact of FDI on GTI is strengthened. Luo et al. (2021) used the system GMM (generalized method of moments) and found that the command-and-control environmental regulation has a negative impact on the relationship between FDI and GTI. The "pollution paradise" hypothesis shows that developing countries do not focus much attention on the environmental protection in order to introduce more FDI, which weakens the positive effect of environmental regulation on the GTI (Hou et al. 2017; Dean et al. 2009). Chung (2014) studied the FDI pattern of South Korea and suggested that the pollution-intensive industry tends to be invested into countries with loose environmental regulation. Yang and Tian 2017) pointed out that strengthening environmental supervision has an inhibitory effect on FDI in view of different regions in China. Shen et al. (2019) found that the migration of pollution-intensive industry results in "pollution paradise" phenomenon in the Pearl River Delta. Zhang et al. (2020b) suggested that a strict environmental regulation enhances the entry threshold of FDI and restricts the "high-energy-consumption" and "high-pollution" FDI inflow. Zhang and Zhao 2012) found that the environmental regulation weakens the positive effect of FDI on GTI, based on the GMM model and Chinese provincial data. Hu et al. (2019) used the panel static model and threshold model to study the effect of environmental regulation on GTI in regard to labor- and capital-oriented FDI. The results show that strengthening environmental regulation can reduce the negative impact of labor-oriented FDI on GTI. Thus, we propose the following hypothesis.

Hypothesis 3: there is a moderating effect in the relationship between environmental regulation, FDI, and GTI

The FDI inflow may result in technological progress, which is called as "technology spillover" effect of FDI. The high-tech sectors have relatively low cost in GTI for the "technology-spillover" effect compared with that of low-tech sectors. From this perspective, the FDI inflow is helpful for GTI in high-tech sectors. The firms with strong absorptive capacity have a positive spillover effect of FDI (Moralles and Moreno 2020). Glauco et al. (2021) used R&D investment as a threshold variable and found that the negative effect of FDI on energy intensity decreases as the level of technology increases. Other scholars also confirmed the results that technology has an inhibitory effect on the relationship between FDI and GTI (Ghebrihiwet 2018; Demena and Afesorgbor 2019; Xie and Sun 2020). Thus, the following hypothesis is proposed considering China's sectoral heterogeneity.

Hypothesis 4: the FDI in high-tech sectors has a less negative impact on GTI than that in low-tech sectors

The existing literature provide an important reference for this study. However, the existing literature lack further analysis of the relationship between FDI, environmental regulation, and GTI in the manufacturing industry. Compared with the existing studies, the novelties of this paper are as follows. First, the existing literature usually study the relationship between FDI and GTI or environmental regulation and GTI. The "pollution paradise" hypothesis suggests that the entry of FDI can be affected by environmental policy. Both FDI and environmental regulation have impacts on GTI. In this regard, this study tries to investigate the impact of FDI and environmental regulation on GTI. This paper adds cross-terms in the basic model to study the moderating effect of environmental regulation. Moreover, we use the threshold model to study the mediating effects of environmental regulation and FDI on GTI separately. Through the analysis of moderating and threshold effects, this paper studies the interaction effect between FDI and environmental regulation on GTI more comprehensively. This study uses a variety of models for empirical analysis and performs robustness test and system GMM, which expands the research perspective compared with the existing literature. This paper sets different threshold intervals for environmental regulation and FDI, and the findings from the empirical analysis are helpful for policy suggestions on environmental regulation implementation. Second, the existing literature mainly study from the national, regional, or industrial level, whereas few studies touch on the sectoral heterogeneity in the manufacturing industry. Different technologies in the manufacturing industry result in differences in carbon efficiency (Li and Cheng 2020). In this regard, this paper studies the impact of FDI and environmental regulation on GTI in view of manufacturing industry segmentation. Meanwhile, we investigate the sectoral heterogeneity of the relationship between FDI on GTI under different environmental regulation intensity. This provides a new insight. Third, most studies take green total-factor productivity as a dependent variable to measure GTI. This paper uses the number of domestic green patents to describe GTI because the number of patents can better quantify the degree of GTI and provide a basis for manufacturing industry segmentation.

Methodology

The framework of methodology is shown in Fig. 1. We first put forward the hypothesis development by literature review and theoretical analysis, then introduce the econometric model, and finally conduct empirical analyses and test the hypothesis using the relative data for the Chinese manufacturing industry.

Econometric model

We construct the basic model and threshold model and use panel data from the Chinese manufacturing industry, for empirical analysis. Through the basic model, we investigate the relationship between FDI, environmental regulation, and other control variables on GTI. Through the threshold model, we study the nonlinear relationship of FDI and environmental regulation on GTI and comprehensively explore the mediating effect on GTI between FDI and environmental regulation.

The specific model construction is as follows. The baseline regression is performed shown as model (1). The Hausman test is conducted for the selection of random or fixed effects.

$$lnGT_{i,j} = \alpha_0 + \alpha_1 lnER_{i,j} + \alpha_2 lnFDI_{i,j} + \alpha_3 lnER_{i,j} \times lnFDI_{i,j} + \alpha_4 lnX_{i,j} + \mu_{i,j} \quad (1)$$

where "*GT*" denotes the GTI and "*ER*" and "*FDI*" denote the environmental regulation and FDI inflow, respectively. "*lnER*lnFDI*" is a cross-term, reflecting the moderating effect

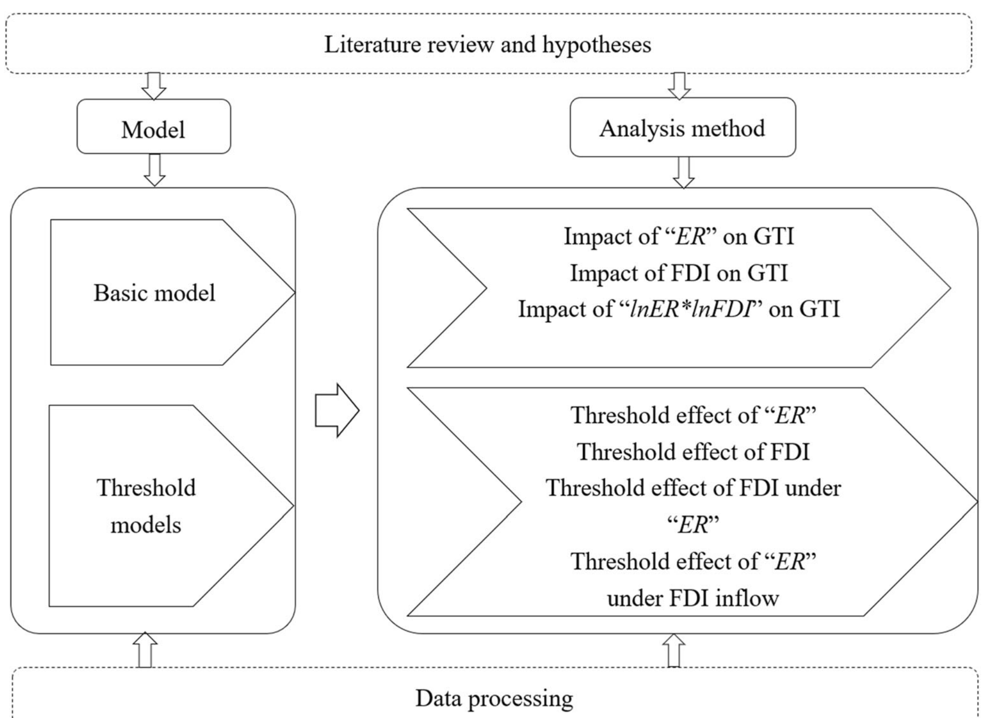

Fig. 1 The framework of methodology for this study

of "*FDI*" on the relationship between environmental regulation and GTI. "*X*" represents the control variables which include the industry scale (*scale*), industry structure (*structure*), human capital (*HC*), technical level (*tec*), and capital deepening degree (*cap*). α_0 is the intercept term. α_1, α_2, α_3, and α_4 are regression coefficients; *u* is the error term; *i* and *j* represent the time and sectors in Chinese manufacturing industry, respectively.

We construct the panel threshold model to study the threshold effect of different explanatory variables on a dependent variable. The threshold effect means the influence on dependent variables can change if the explanatory variable reaches a certain value (threshold value). The panel threshold model is nonlinear, which can accurately reveal the dynamic relationship between the dependent and explanatory variables.

The specific threshold model construction is as follows. First, the effect of environmental regulation on GTI is discussed. "*ER*" is used as a threshold variable (γ is the value for the threshold) to explore the influence of different environmental regulation level on GTI, shown as model (2), where, I () is the indicator function and θ is the regression coefficient. The "winsorized mean" is used to handle the "*ER*" data considering the reliability of regression result (Wu and Zuo 2009).

$$\ln GT_{ij} = \theta_0 + \theta_1 lnER_{ij} \times I\left(lnER_{ij} \leq \gamma_1\right) + \theta_2 lnER_{ij} \times I\left(\gamma_1 < lnER_{ij} \leq \gamma_2\right) + \ldots + \theta_3 lnER_{ij} \times I\left(lnER_{ij} > \gamma_q\right) + \theta_4 lnFDI_{ij} + \theta_5 lnX_{ij} + \mu_{ij} \quad (2)$$

Second, "*FDI*" is taken as a threshold variable (ε is the value for the threshold) to study the nonlinear relationship between FDI and GTI, shown as model (3), where ρ is the regression coefficient.

$$\ln GT_{ij} = \rho_0 + \rho_1 lnFDI_{ij} \times I\left(lnFDI_{ij} \leq \varepsilon_1\right) + \rho_2 lnFDI_{ij} \times I\left(\varepsilon_1 < lnFDI_{ij} \leq \varepsilon_2\right) + \ldots + \rho_3 lnFDI_{ij} \times I\left(lnFDI_{ij} > \varepsilon_q\right) + \rho_4 lnER_{ij} + \rho_5 lnX_{ij} + \mu_{ij} \quad (3)$$

Third, "*ER*" is taken as a threshold variable (δ is the value for the threshold) and "*FDI*" as an explanatory variable to study whether different environmental regulation levels have a mediating effect on the relationship between FDI and GTI, shown as model (4), where φ is the regression coefficient.

$$\ln GT_{ij} = \varphi_0 + \varphi_1 lnFDI_{ij} \times I\left(lnER_{ij} \leq \delta_1\right) + \varphi_2 lnFDI_{ij} \times I\left(\delta_1 < nER_{ij} \leq \delta_2\right) + \ldots + \varphi_3 lnFDI_{ij} \times I\left(lnER_{ij} > \delta_q\right) + \varphi_4 lnX_{ij} + \mu_{ij} \quad (4)$$

Fourth, "*FDI*" is taken as a threshold variable (λ is the value for the threshold) and "*ER*" as an explanatory variable to investigate the effect of environmental regulation on GTI in the case of the change in FDI inflow, shown as model (5), where ω is the regression coefficient.

$$\ln GT_{ij} = \omega_0 + \omega_1 lnER_{ij} \times I\left(lnFDI_{ij} \leq \lambda_1\right) + \omega_2 lnER_{ij} \times I\left(\lambda_1 < lnFDI_{ij} \leq \lambda_2\right) + \ldots + \omega_3 lnER_{ij} \times I\left(lnFDI_{ij} < \lambda_q\right) + \omega_4 lnX_{ij} + \mu_{ij} \quad (5)$$

Data

The manufacturing output accounts for over 80% of the total industrial output in China, which is closely related to the economic development (Chen et al. 2020). In recent years, China's manufacturing industry has grown rapidly, and it has also led to serious environmental pollution (Yang et al. 2020b). Hence, it is necessary for the government to encourage GTI in the manufacturing industry (Cao et al. 2020). The manufacturing industry is divided into 13 sectors based on the green patent data for different manufacturing sectors: papermaking and paper products, petroleum, coal and other fuels, chemical industry, rubber and plastic products, nonmetallic mineral product manufacturing, metal product industry, general equipment manufacturing, special equipment manufacturing, transport equipment manufacturing, electrical machinery and equipment manufacturing, computer communications, and other electronic equipment manufacturing, instrumentation manufacturing and other manufacturing. The number of GTI patents per R&D personnel is used to measure the "*GT*" variable in different sectors. The list of green granted patents released by the *World Intellectual Property Organization* (WIPO) contains seven GTI patents (IPC green inventory). The number of patent grants comes from the *State Intellectual Property Office* (SIPO) of China. This paper uses the indicator (wastewater and gas operating costs divided by total industrial output value) to represent the "*ER*" variable. The data for wastewater and gas operating costs are from *China Environmental Statistics Yearbook*. The total industrial output value is collected from *China Industrial Economic Statistics Yearbook*. The sectoral FDI data are calculated based on proportional FDI in different sectors (Yu and Peng 2020). The sectoral and total FDI data are from *China Statistical Yearbook* and *China Industrial Economic Statistics Yearbook*, respectively. The "*scale*" variable is expressed by the gross industrial sale value which comes from *China Industrial Economic Statistics Yearbook*. The data for "*structure*" variable are from *China Energy Statistical Yearbook* and *China Industrial Economic Statistics Yearbook*, using the indicator (industry energy consumption divided by industry labor force). The "*HC*" variable is measured by the ratio of R&D personnel number to the total workforce. The "*tec*" variable is represented by energy

Table 1 Results of Fisher-ADF test

Variables	Statistic	*p* value
ln GT	47.396	0.0063
ln FDI	58.305	0.0003
ln ER	97.405	0.0000
ln scale	61.158	0.0001
ln structure	333.110	0.0000
ln HR	178.146	0.0000
ln cap	106.925	0.0000

efficiency (energy consumption divided by sales value) in various sectors. These basic data are obtained from *China Science and Technology Statistical Yearbook*. The "*cap*" variable is expressed by the net value of fixed assets in various sectors which comes from *China Industrial Economic Statistics Yearbook*. The sample period is from 2003 to 2018 for the availability of data.

Empirical results and discussion

Data test

The test of stationarity and correlation was conducted before regression.

Stationarity test

The Fisher-ADF (augmented Dickey-Fuller) method was used for unit root tests (Zeren and Kzlkaya 2020). The result shows that each variable is stationary at 1% level (Table 1).

Correlation test

Pearson correlation analysis was performed on different variables. As shown in Table 2, the "*FDI*" has a negative impact on GTI; the "*ER*" has a positive relationship with GTI. The correlation coefficients between other variables are small, which indicates that the multicollinearity is not serious, and the empirical results are reliable.

Table 3 Regression results of panel data

Variable	Regression coefficient	Standard error
ln ER	0.687**	0.2544
ln FDI	−0.557***	0.1386
*ln ER*ln FDI*	−0.052**	0.0164
ln scale	0.748***	0.1664
ln structure	−0.234	0.1896
ln HC	0.038**	0.1461
ln cap	0.726***	0.1680
ln tec	0.849***	0.1603

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Estimation results of the basic model

The Hausman test was carried out for model (1), and the fixed effect model was selected. The result is shown in Table 3.

The coefficient of "*ER*" is 0.687, and it is statistically significant at 5% level. This indicates that the environmental regulation can promote the GTI, which supports the result of Zhang et al. (2018). The coefficient of "*FDI*" is −0.557 and significant statistically at the 1% level. The FDI inflow can inhibit the GTI. This reflects the existence of "pollution paradise" phenomenon and conforms to the result of Hu et al. (2019). The possible explanations for this result are as follows. First, the spillover effect for FDI may lead to the innovation of production technology, but it does not concentrate in the field of GTI caused by the factor distortion. For example, the export enterprises rely on cheap production factors and lack the motivation to absorb international advanced experience (Lin and Chen 2018). Second, the FDI may be introduced into the

Table 2 Results of Pearson correlation analyses

	lnGT	*lnFDI*	*lnER*	*lnscale*	*lnstructure*	*lnHR*	*lncap*	*lntec*
lnGT	1							
lnFDI	−0.154**	1						
lnER	0.449***	−0.164**	1					
lnstructure	−0.438***	−0.331***	0.773*	1				
lnscale	0.601***	0.479***	−0.103	−0.045	1			
lnHR	0.325***	0.197***	−0.254***	−0.120	0.155**	1		
lncap	0.498***	0.464***		0.034	0.336***	−0.029	1	
lntec	−0.664	−0.272***	0.691*	0.227*	−0.456**	−0.231***	−0.345***	1

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

pollution-intensive industry, and the products are mainly labor- and energy-intensive. China is a large manufacturing country, and the labor force is a comparative advantage for a long time. The inflow of FDI further strengthens the structure dominated by labor- and energy-intensive products and leads to increases in the production of polluting products. In this case, the enterprises are not motivated to carry out measures to improve the GTI. The "pollution halo" effect and "pollution haven" effect exist at the same time in China, and the "pollution haven" effect of FDI is stronger than the "pollution halo" effect (Peng 2020; Singhania and Saini 2021). The term "*lnER*lnFDI*" has a negative effect on GTI. This indicates that FDI reduces GTI through environmental regulation. The FDI has a negative moderating effect on the relationship between "*ER*" and GTI, so hypothesis 3 is verified. Higher FDI has reduced the effect of environmental regulation on GTI (Yu and Li 2020; Luo and Lu 2020). Thus, the comprehensive effect of FDI and environmental regulation is negative. The effects of FDI and environmental regulation on GTI have not achieved the desired goal (Feng et al. 2019).

For other variables, the "*scale*" has a positive effect on GTI. The "*structure*" has a negative effect on GTI, but the result is not statistically significant. These sectors tend resource- and pollution-intensive and may have "race to the bottom" behavior (Olney 2013). The "*HC*" has a positive effect on GTI, because the R&D personnel promote the investment in GTI research. The "*cap*" has a positive effect on the GTI, indicating that the sector with higher fixed assets is helpful for GTI. The "*tec*" has a promoting effect on the GTI. This indicates that there is a positive relationship between the technical level and GTI.

Estimation results of the threshold panel model

Threshold effect of environmental regulation

Table 4 shows that the environmental regulation has double thresholds. The values for "*ER*" are 1.30 and 59.68, respectively. There is a "U-shape" relationship between environmental regulation and GTI, which is consistent with hypothesis 1. Table 5 shows that the coefficient of "*lnER*" changes from −0.336 to 0.049 if "*ER*" surpasses the first threshold value and finally becomes 1.716 if "*ER*" surpasses the second threshold. The environmental regulation has a relatively strong negative effect on GTI if it is lower than the threshold value. The possible reason for the result is that the environmental regulation leads to increases in pollution control cost for enterprises. The enterprises pay more attention to the cost reduction than the GTI in relatively loose environmental regulation. The impact of environmental regulation on GTI becomes positive if "*ER*" surpasses its first threshold value, and the impact is strongly enhanced if "*ER*" surpasses the second threshold. This is because enterprises begin to seek clean and efficient technology in case of the mandatory and strict protection policy (Jing and Zhang 2014). The enterprises may go into areas with loose environmental policies to reduce the cost if they cannot satisfy the strict environmental regulation. This result conforms to the studies by Kesidou and Wu (2020), Wu and Zuo 2009), and Song et al. (2020).

Some studies suggest that the environmental regulation has an "inverted-U" relationship with GTI (Wang et al. 2019; Wang and Shen 2016). The "compliance cost" effect produced by environmental policies is greater than the "innovation offset" effect under the strict environmental regulation. The reasons for the different results are as follows. First, the GTI is measured by the number of green patents in this study, while some studies measure the regional GTI through green productivity. Second, this paper analyzes the impact of environmental regulation on GTI from the perspective of the

Table 5 Regression results of environmental regulation in its effect on GTI

Variable	Threshold coefficient	Standard error
ln ER ≤ 0.2632	−0.336*	0.0873
0.2632<*lnER*≤4.089	0.049	0.0828
ln ER > 4.089	1.716***	0.5814
ln FDI	−0.619***	0.1295
ln scale	0.701***	0.1610
ln structure	−0.163	0.1824
ln HC	−0.013	0.1166
ln cap	0.814***	0.1656
ln tec	0.937***	0.1571

Note: * p < 0.10, ** p < 0.05, *** p < 0.01

Table 4 Threshold value for "ER" in its effect on GTI

Threshold quantity	F value	*p* value	Threshold value
Single threshold	12.92	0.0033	1.30
Double threshold	12.86	0.0200	59.68

Note: To obtain the actual threshold data, the logarithmic value is converted to the original value. The "threshold value" here is the original value

Table 6 Threshold value for "FDI" in its effect on GTI

Threshold quantity	F value	*p* value	Threshold value
Single threshold	26.65	0.0100	700045.07
Double threshold	13.96	0.1233	

Note: To obtain the actual threshold data, the logarithmic value is converted to the original value. The "threshold value" here is the original value

Table 7 Regression results of FDI in its effect on GTI

Variable	Threshold coefficient	Standard error
ln FDI ≤ 13.4589	−1.376***	0.1990
ln FDI>13.4589	−1.312***	0.1907
ln ER	−0.237*	0.0696
ln scale	0.921***	0.1641
ln structure	−0.2400	0.1773
ln HC	−0.1066	0.1111
ln cap	0.523**	0.1688
ln tec	0.903***	0.1465

Note: * p < 0.10, ** p < 0.05, *** p < 0.01

Table 9 Regression results of FDI in its effect on GTI under environmental regulation

Variable	Threshold coefficient	Standard error
ln FDI (ln ER ≤ 4.089*)*	−0.590***	0.1303
ln FDI (ln ER>4.089*)*	−0.624***	0.1293
ln scale	−0.031 *	0.0779
ln structure	0.693***	0.1605
ln HC	−0.161	0.1820
ln cap	−0.011	0.1165
ln tec	0.818***	0.1293

Note: * p < 0.10, ** p < 0.05, *** p < 0.01

manufacturing industry, while some studies consider the effect of environmental regulation from a regional perspective.

Threshold effect of FDI

There is a single threshold value for "*FDI*" (Table 6). The *p* value is 0.01. The regression coefficient of "*lnFDI*" changed from −1.376 to −1.312. There is not much change in the coefficient. The FDI has a significant inhibitory effect on GTI before and after the threshold which is consistent with hypothesis 2. This indicates that the negative effect is not obviously influenced by the FDI quantity (Table 7).

Threshold effect of FDI under environmental regulation

The "*ER*" variable has a single threshold value in this case (Table 8). The coefficient of "*lnFDI*" changes from −0.59 to −0.624, when "*ER*" exceeds the threshold value of 59.68 (to obtain the actual threshold data, the logarithmic value is converted to the original value). The negative impact of FDI on the GTI is strengthened as enhancement of environmental regulations; "*ER*," as an intermediary variable, enhances the restraining effect of FDI on the GTI if more FDI is introduced (Table 9). The possible explanations are as follows. First, the environmental regulation has a significant crowding-out effect on FDI's technology spillover, which means that stricter environmental regulation may result in higher production cost and crowd-out investment in technological innovation. This may be caused by economic underdevelopment or insufficient attention to GTI (Liu et al. 2020). Some studies show that, for industries with a high development level, the negative impact of FDI is small and even conducive to realizing the goal of green growth; for industries with a low development level, the negative impact of FDI cannot be alleviated and will even be enhanced in a short period (Hille et al. 2019). Second, the environmental regulation is not well enforced for pursuing the economic growth. Third, the products are mainly labor-intensive, which results in the "product structure" effect. This is detrimental to the GTI (Zhou et al. 2019; Ren et al. 2014).

Threshold effect of environmental regulation under FDI inflow

As shown in Table 10, the *p* value is 0.0267, and there is a single threshold value for "*FDI*."

Table 11 shows that the coefficient of "*lnER*" changes from 0.333 to 0.020. This indicates that "*ER*" can promote GTI when "*FDI*" variable is lower than its threshold value. Increasing FDI inflow results in the reduction in the positive impact of environmental regulation on GTI if FDI inflow exceeds the threshold value. This indicates that the comprehensive effect of "*FDI*" and "*ER*" is negative on GTI. The possible explanations are as follows. First, most foreign enterprises inflow into labor- and pollution-intensive industries, which

Table 8 Threshold values for "ER" in its effect on FDI under environmental regulation

Threshold quantity	F value	*p* value	Threshold value
Single threshold	29.63	0.0400	59.68
Double threshold	6.67	0.5700	

Note: To obtain the actual threshold data, the logarithmic value is converted to the original value. The "threshold value" here is the original value

Table 10 Threshold value for "*FDI*" in its effect on environmental regulation under FDI inflow

Threshold quantity	F value	*p* value	Threshold value
Single threshold	17.67	0.0267	223775.81
Double threshold	9.64	0.3600	

Note: To obtain the actual threshold data, the logarithmic value is converted to the original value. The "threshold value" here is the original value

Table 11 Regression results of environmental regulation under FDI inflow

Variable	Threshold coefficient	Standard error
ln ER (ln FDI ≤ 12.3184)	0.333***	0.0885
ln ER (ln FDI> 12.3184)	0.020*	0.0877
ln scale	0.611***	0.1568
ln structure	−0.026	0.1748
ln HC	0.255**	0.1171
ln cap	0.728***	0.1672
ln tec	0.442**	0.1616

Note: * p < 0.10, ** p < 0.05, *** p < 0.01

may strengthen the negative impact of "*ER*" on GTI (Xie 2017). Second, the foreign enterprises have "race to the bottom" behavior. They hunt for profit maximization without focusing on the GTI. Zhao (2019) pointed out that the government attracted more foreign-funded enterprises to promote economic development through preferential policies for a long time. This results in the ignorance of environmental protection and the "non-enforcement phenomenon" of environmental regulation before 2016. Considering the negative interaction of FDI and "*ER*" on GTI, it is necessary to reduce the entry of pollution-intensive foreign enterprises and strengthen the environmental regulation.

Analysis of sectoral heterogeneity

The samples are classified into two kinds of subsamples according to high-tech and low-tech sectors based on the technical level index. We tested the threshold effect of "*ER*" on GTI in high-tech and low-tech sectors. A single threshold test was carried out for the limited number of sectoral classifications. The *p* values are 0.38 and 0.0367 in high-tech and low-tech sectors, respectively, which are not statistically significant in high-tech sectors. Similarly, we found that the threshold effect of FDI on GTI is not statistically significant in high-tech sectors. As for the threshold effect of "*ER*" on GTI under different FDI inflow levels, the *p* value is 0.17 in high-tech sectors and 0.233 in low-tech sectors, which are not statistically significant. We tested the threshold effect of "FDI" on GTI at different "*ER*" levels. As shown in Table 12, the *p*-values are 0.03 for high-tech sectors and 0.0067 for low-tech sectors, respectively. This indicates that the relationship between FDI and GTI is affected by "*ER*." Therefore, this section focuses on the analysis of the threshold effect of FDI on GTI at different "*ER*" levels.

Table 13 Threshold regression results for high-/low-tech sectors

Variable	High-tech sectors	Low-tech sectors
ln FDI (ln ER ≤ λ)	−0.154*	−1.262***
ln FDI (ln ER> λ)	−0.250	−1.288***
ln ER	0.834***	0.091*
ln scale	0.902***	0.606***
ln structure	0.238	−0.1973
ln HC	0.347	0.042
ln cap	0.200	0.853***
ln tec	1.335	0.837***

Note: * p < 0.10, ** p < 0.05, *** p < 0.01

As shown in Table 12, there is a single threshold value taking "*ER*" as a threshold variable and "*FDI*" as an explanatory variable in high-tech and low-tech sectors, respectively. The threshold for low-tech sectors is lower than the threshold for high-tech sectors. This indicates that environmental regulation has a strong moderating effect on low-tech sectors. Table 13 indicates that the FDI in low-tech sectors has an obvious inhibitory effect on GTI. The coefficient of "*lnFDI*" changes from −1.262 to −1.288, while the coefficient of "*lnFDI*" in high-tech sectors is from −0.154 to −0.250. The negative impact of FDI under environmental regulation on GTI in low-tech sectors is greater than that in high-tech sectors, which conforms to hypothesis 4. The possible reasons are as follows. First, the technology progress can offset the negative effect of FDI on GTI, which is consistent with Wang and Luo (2020). The low-tech sectors lack sufficient GTI capacity while high-tech sectors have the optimal GTI potential (Cai et al. 2020). The enterprises with a high technological level have less cost and more technological advantage to carry out R&D (Cai et al. 2021). Thus, the technology spillover effect of FDI is more obvious. Second, the environmental regulation is still loose, and the introduced FDI is still concentrated in low-tech sectors (Dong et al. 2020). The low-tech sectors will produce more pollution-intensive products, which is detrimental to the GTI. This indicates that attention should be paid to the quality rather than the quantity of FDI in the enforcement of environmental regulation.

Table 12 Threshold value for "ER" in its effect on FDI under environmental regulation in different technical-level sectors

Threshold quantity	High-tech sectors	*p* value	Low-tech sectors	*p* value
Single threshold	14.04	0.03	1.30	0.0067

Note: To obtain the actual threshold data, the logarithmic value is converted to the original value. The "threshold value" here is the original value

Table 14 Regression results of panel data

Variable	Regression coefficient	Standard error
ln ER	1.015*	0.6751
ln FDI	−0.531***	0.1477
*ln ER*ln FDI*	−0.060*	0.0498
ln scale	0.990***	0.1551
ln structure	−0.468*	0.1729
ln HC	0.193*	0.1127
ln cap	0.656	0.1583
ln tec	0.622***	0.1539

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Robustness test

Alternative variable for GTI

In order to verify the accuracy of baseline regression, it is necessary to perform a robustness analysis of the results. This study uses the number of green patent applications as a substitution of GTI (Qi et al. 2018). We choose the fixed effect model. Compared with the results in Table 1, the explanatory variables are consistent in sign except for differences in the magnitude and significance of the values (Table 14). This indicates that the previous estimation results are robust and reliable.

Endogenous analysis

This paper uses a two-step system GMM for regression. The effect of endogeneity can be mitigated by introducing the instrumental variables. The first-order lag term of GTI is incorporated in the model. As shown in Table 15, the *p* value of AR (2) is greater than 0.1, showing the absence of second-order serial correlation (Pei et al. 2021). The *p* value of Sargan test is greater than 0.1, indicating that the setting of the instrumental variable is reasonable (Gok and Sodhi 2021). Therefore, the system GMM is valid (Tran 2020). Moreover, Table 13 shows that the coefficient of "$lnGT_{i-1}$" is 1.002 with statistical significance at 1% level, indicating that the previous GTI has a positive effect on the current GTI. This is because the progress of R&D is progressive and cumulative and the technological breakthroughs have a positive effect on the current GTI.

Table 15 Regression results of dynamic panel data

Variable	Regression coefficient	Standard error
$ln\ GT_{i-1}$	1.002***	0.1246
ln ER	1.873***	0.1487
ln FDI	−0.512**	0.2317
*ln ER*ln FDI*	−0.133***	0.0241
ln scale	1.235**	0.4091
ln structure	−1.632***	0.4567
ln HC	0.373**	0.1582
ln cap	−0.156	0.3259
ln tec	1.823***	0.4075
AR(1)(p-value)	0.002	
AR(2)(p-value)	0.116	
Sargan Test(*p-value*)	0.112	

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. "$i-1$" denotes the lag of the corresponding variable

Conclusions and policy implications

This study uses a dynamic panel model and threshold model to explore the effect of FDI and environmental regulation on GTI in the Chinese manufacturing industry. The conclusions received are as follows. (1) The environmental regulation has a positive effect and the FDI has a negative effect, on GTI. The interaction between FDI and environmental regulation has a negative effect on GTI. (2) The environmental regulation has a "U-shape" relationship with GTI; the FDI has a similar strong inhibitory effect on GTI if it exceeds the threshold value. The inhibitory effect of FDI on GTI is enhanced in the enhancement of environmental regulation; the positive impact of environmental regulation on GTI is weakened if the FDI exceeds its threshold value. (3) For industries with different technology levels, the FDI under environmental regulation can reduce GTI in high-tech and low-tech sectors, and the negative impact is strengthened when FDI exceeds its threshold value. The negative impact of environmental regulation on GTI in low-tech sectors is greater than that in high-tech sectors.

The following policy suggestions are put forward based on the conclusions. (1) The environmental regulation has an important promoting role in GTI. Thus, the local government should formulate a reasonable environmental regulation policy to improve the environmental policy system and environmental standards. It is important to stimulate enterprises to improve the clean production and pollution treatment technology. It is necessary to eliminate the non-implementation phenomenon of environmental regulation, strengthen the efficiency of policy implementation, and supervise enterprises to implement a cleaner production to meet environmental standards. The environmental performance should be taken into the evaluation of the performance of local officials. The interconnection and share of environmental data should be realized in different regions. The environmental regulation should shift from command and control to innovation incentives. In environmental protection, the government should pay attention to the market-oriented instruments and give enterprises more flexibility to reduce emissions. (2) In the introduction of

FDI, the government should set a threshold for FDI inflow and conduct different attraction strategies while strengthening the environmental regulation, actively introduce capital- and technology-intensive enterprises and decrease pollution-intensive enterprises, in order to reduce the negative impact of the "pollution haven" phenomenon and product structure effect. It is important to pay attention to the linkage effect of environmental regulation and FDI on GTI. The government should adjust the intensity of environmental regulation according to the actual changes in FDI and green innovation to avoid the negative regulatory effect. (3) It is crucial to upgrade the sectoral technology levels. Enterprises need to accelerate their R&D to enhance the technology spillover effect of FDI and form a "pollution halo" effect. High polluted sectors need to change their production modes, achieve a cleaner production, and adjust the energy consumption structure. The government should formulate different environmental policies based on industry heterogeneity, encourage GTI through subsidies, formulate different environmental regulation strategies for sectors with different technology levels, and promote the environmental regulation level in low-tech sectors. Besides, the policy maker should strengthen the assessment of green patents' quality.

This paper provides some new findings compared with the current studies. There are of course some limitations. This study does not consider the effect of FDI quality on GTI for different industries, so this is an issue for future study.

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