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RESEARCH ARTICLE

Effects of environmental regulation on the upgrading of Chinese manufacturing industry

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Abstract

In recent years, China has constantly strengthened environmental regulation (ER) to force the manufacturing industry to upgrade. This study theoretically analyzes interaction mechanism of ER on the upgrading of manufacturing industry through foreign direct investment (FDI) and technological innovation (TI) and carries out empirical verification by using provincial panel data from 2000 to 2016 in China. The results demonstrate that the current ER intensity in China is unable to directly promote the upgrading of manufacturing industry, while through the interaction effects of FDI and TI do boost the upgrading of the industry. The above mechanisms are also robust even if we take the regional heterogeneity into consideration. Basic education and urbanization are favorable for the upgrading of the manufacturing industry. However, the increase in dependence on foreign trade is not conducive to upgrading manufacturing industry. Chinese government should further strengthen ER and give full play of the interaction mechanism of ER to guide the flow of foreign investment and force enterprises to carry out TI. In the meanwhile, Chinese government also needs to ensure balanced regional development, thus better promoting the upgrading of manufacturing industry.

Keywords Manufacturing upgrading · Environmental regulation · Foreign direct investment · Technological innovation · Interaction

Introduction

Since the reform and opening up, the scale of Chinese manufacturing industry has been growing continuously and rapidly. At present, a relatively complete industrial system has been built, capable of producing more than 500 types of products. Of them, production of more than 220 types of products ranks first in the world. Therefore, China has become the world's largest manufacturing economy and the world's second-largest country of R&D input and application for Patent Cooperation Treaty (PCT) patent. China's manufacturing industry has become the main driving force of the development of China's economy ((Zeng and Li 2018). However, Chinese manufacturing industry has been oriented by low-end exports for a long time, so technical content and the proportion of high-tech products are low and capacity of independent innovation is weak. Moreover, the substantial foreign investment, which is attracted by reducing the threshold of environmental regulation (ER) in the period of rapid economic development, is more likely to flow into industries with high energy consumption and pollution, so that environmental quality continues to deteriorate for a while (Zeng and Li 2016; Wang and Li 2019). According to environmental performance index (EPI) published by Yale University in the USA, China ranked the 120th among 180 economies in 2018, so it is urgent to improve environmental standard.

Chinese government has been aware of these problems. In recent years, the government has gradually strengthened ER

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and limited the development of low-end industries with high energy consumption and pollution (Wang et al. 2017a), so as to promote the upgrading of manufacturing industry. The Ministry of Industry and Information Technology of the People's Republic of China formulated the *Plan for the Green Development of the Industry (2016~2020)* on June 30, 2016. The plan aims to carry out the strategic deployment of the *Outline of the "13th Five-Year Plan" for National Economic and Social Development* and *Made in China 2025* and fully implement the strategy of becoming a manufacturing power. Furthermore, the purpose of the plan is to pursue an efficient, clean, low-carbon, and recycling path of green development, promote harmony and integration between industrial civilization and ecological civilization, and realize harmony between human and nature.

The improvement of ER level makes enterprises face new challenges and forces them to carry out technological innovation (TI), which gradually becomes a new law for the survival and development of enterprises. In addition, ER can limit the inflow of foreign direct investment (FDI) in pollution industry and serves as an admission criterion for FDI. Therefore, whether the upgrading of Chinese manufacturing industry is objectively affected by interactions of ER with FDI and TI is the core problem concerned in the study.

For this purpose, we theoretically analyzes interaction mechanism of ER on the upgrading of manufacturing industry through FDI and TI, then carries out a series of empirical verification by using provincial panel data from 2000 to 2016 in China. Furthermore, we divide China into the eastern, central, and western regions, then investigate the influences of spatial heterogeneity on the above interaction mechanism. The conclusions are made as follows: firstly, the current ER intensity of China is unfavorable for the upgrading of manufacturing industry, while the technology spillover effects caused by FDI and the strong power provided by TI indeed remarkably promote the upgrading of manufacturing industry. Secondly, ER can promote the upgrading of manufacturing industry by screening and guiding foreign investment to flow into tech-intensive manufacturing industry and forcing enterprises to carry out TI. In other words, the interaction effects of ER through FDI and TI can promote the upgrading of manufacturing industry. Thirdly, the above mechanisms are also robust even if we take the regional heterogeneity into consideration. Furthermore, strengthening basic education and advancing urbanization are favorable for promoting the upgrading of manufacturing industry. However, enhancing trade dependence is unfavorable for the upgrading of manufacturing industry. Besides, this study also proposes policy suggestions from the two aspects, in order to provide some reference for further promoting the upgrading of manufacturing industry and leaping of China from a large country to a powerful country of manufacturing industry.

This research has three contributions to the existing literature. First, we propose a theoretical analysis framework for ER to promote manufacturing upgrading through FDI and TI, providing a new research perspective. Based on this, two theoretical hypotheses are proposed and proved by empirical analysis. Second, using the manufacturing high-level indicators built on the theory of industrial organization to measure the upgrading of manufacturing industry, this indicator takes into account the weight of input and output of each sub-sector, and thus has a good consistency. Our research supports the applicability of this indicator. Thirdly, the stability of the above mechanism is examined from the perspective of regional heterogeneity, which provides a reference for the formulation of differentiated policies.

The rest of the paper is organized as follows: the "Literature review" section shows literature review. The "Empirical design" section presents empirical design, including theoretical analysis and hypotheses, variables and data, and the setting of econometric model. Empirical results and discussions are demonstrated in the "Analysis on empirical results" section. Moreover, conclusions and policy suggestions are presented in the "Conclusions, policy suggestions, and future work" section.

Literature review

The existing studies on FDI mainly focus on two hypotheses. One is pollution heaven hypothesis, mainly researching environmental pollution. It considers that developed countries tend to transfer pollution-intensive industries to developing countries with loose regulation, so that environment in the host country deteriorates (Copel and Taylor 1995). Many scholars have conducted theoretical and empirical research on the hypothesis (Keller and Levinson 2002; Chung 2014; Abdouli and Hammami 2016), which provides powerful evidences for the hypothesis. The second one, technology spillover hypothesis, believes that enterprises in developed countries master more efficient technologies for dealing with pollutions and can effectively help developing countries improve environment quality through technology spillover (Birdsall and Wheeler 1993; Eskeland and Harrison 2003; Ning and Wang 2018).

Owing to technology spillover effects of FDI play an important role in improving the technical level of the host country, lots of scholars further studied the mechanisms of FDI influencing the manufacturing industry. Gábor (2002) studied the performance of FDI in manufacturing industries in Romanian through company balance sheets, and found FDI does have some positive effects, especially in export growth and economic growth. Zhang (2017) took changes of productivity and efficiency caused by spillover effects as objects for research. The results demonstrate that spillover effects resulting from inflow of foreign investment have positive influences on the performances of China's provincial research activities. By making use of the arguably exogenous relaxation of FDI regulations upon China's accession to the WTO, Lu et al. (2017) found that FDI has a negative and significant effect on the productivity of domestic firms in the same industry. For further identification, employing the dynamic panel model, Orlic et al. (2018) discussed the relationship between spillover effects of FDI and productivity of enterprises in manufacturing industry in five transition countries in Europe. They found that spillover effects of FDI can significantly improve total productivity of the manufacturing industry. Through Merritt's theoretical model of enterprise heterogeneity, Anwar and Sun (2018) found that FDI is conducive to raising technical level of Chinese manufacturing industry and significantly improving output quality of the industry.

TI, as an essential factor for the development of high-tech manufacturing industry, can strongly motivate the upgrading of manufacturing industry. Roos (2016) believed that manufacturing industry increasingly innovates to ensure the growth of productivity and realize nonprice competition, especially in management environment with high costs. Lots of scholars have noticed the effects of TI on the upgrading of Chinese manufacturing industry and obtained a highly consistent conclusion, that is, TI can effectively promote the upgrading and development of manufacturing industry. Yang et al. (2018) subdivided the manufacturing industry into labor-, capital-, and technology-intensive ones and verified the promotion of TI to Chinese manufacturing industry. By utilizing the DEA-range-adjusted measure (RAM) model, Wang et al. (2017b) investigated the unified efficiency of green innovation performances of 29 industries in Chinese manufacturing industry and verified the importance of innovation to green growth. Kang et al. (2018) pointed out that China should increase investment intensity and input in R&D, so as to ensure the improvement of unified efficiency of light industries. In the meanwhile, China should highlight the promotion of innovation in strategic emerging industries.

At present, there are two opinions about researches on economic effects of ER. One is compliance cost hypothesis. The hypothesis considers that ER forces enterprises to increase the input for dealing with pollutions, which increases production cost of enterprises and limits production and investment of enterprises, thus inhibiting competitiveness of enterprises (Gollop and Roberts 1983; Gray 2001). The other one is Porter hypothesis. It believes that the proper ER can encourage enterprises to carry out research and development (R&D) innovation and technology upgrading, thus improving production efficiency and competitiveness (Porter and Linde 1995). After that, Jaffe and Palmer (1997) further divided the Porter hypothesis into weak and strong ones. By researching influences of different regulatory tools and relatively strict ER on Green productivity, Xie et al. (2017) verified that the strong Porter hypothesis is feasible in China.

The main reason for the disputes on the understanding of the economic effects of ER is shown as follows. The compliance cost hypothesis is based on the short-term and static perspective, which assumes that these factors, like resource allocation, technical level, and consumer demand, are unchanged, so ER can raise the costs for environmental governance. Therefore, this definitely increases the production burdens and weakens competitiveness of enterprises. However, the Porter hypothesis is from the perspective of the long-term dynamic analysis. It believes that proper ER can encourage enterprises to carry out R&D innovation and enterprises in turn are motivated to improve technical level and optimize resource allocation, which covers compliance costs, thus enhancing competitiveness of enterprises.

In view of different economic performances caused by long-term and short-term ER, some researches consider that ER has a nonlinear relationship with industrial transformation and upgrading. Armando et al. (2013) intensively analyzed the relationship between ER and productivity and proved that the relationship is actually nonlinear. Moreover, trade-off of these variables in the manufacturing industry gradually reduces. By utilizing the data envelopment analysis (DEA) model, Gong and Chen (2017) evaluated input and output performances of the manufacturing industry by taking environmental pollution in the region of Yangtze River Delta in China as an example. Based on this, they found that the optimal solution of the normal distribution model is superior to that of the linear distribution model. By using systematic general moment method (GMM), Liu and Ran (2015) analyzed the effects of ER on progress of production technologies in different industries and found that ER has a significantly positive or negative U-shaped relationship with some industries.

Based on a large number of studies on the direct impact of FDI and TI on manufacturing industry, what happens if ER is added to the impacts of FDI and TI on manufacturing industry? Some scholars have begun to explore the interaction and obtain some important conclusions. One reason for the differences of the two hypotheses of FDI is that ER intensities are different. Beginning with a theoretical framework of firm production and abatement decisions, Dean et al. (2009) derived and estimated a location choice model using data on a sample of EJV projects, Chinese effective levies on water pollution, and Chinese industrial pollution intensity. Results showed the location choice for equity joint ventures in highly polluting industries funded through Hong Kong, Macao, and Taiwan were attracted by weak environmental standards. Instead, based on the Two Control Zones policy implemented by the Chinese government in 1998, Cai et al. (2016) used the difference-in-difference-in-differences estimation to explore three-dimension variations, then they found that tougher environmental regulation leads to less foreign direct investment. Moreover, based on sub-sector panel data of Chinese manufacturing industry, Yang et al.

(2016) also verified the presence of threshold effects between ER and FDI, which showed the screening effects of ER on FDI. The admitted FDI can bring new technologies for the host country, thus generating technology spillover effects.

Lin and Yang (2011) empirically studied the relationship between ER and TI in three different regions of China by using Co-integration and Granger Test, and their results show that environmental regulation has a positive effect on technology innovation in these regions in the long term. By taking manufacturing industry in Taiwan, China, as an example, Yang et al. (2012) discussed the relationships of ER, R&D, and productive forces. They found that stronger ER can result in more input in R&D and is likely to strengthen, rather than reduce, industrial competitiveness. Zhao and Sun (2015) also found that ER has significant positive effects on corporation's innovation. Similarly, through developing an integrated model and using the structural equation model (SEM), Guo et al. (2017) studied the relationships of ER, TI with regional green growth performances. One of their results is that ER significantly positively influences TI. Furthermore, Song et al. (2018) researched the relationships of ER, employee's quality, R&D efficiency, and green technology with profits of 1197 enterprises in 16 manufacturing industries in China. Through the research, they found that ER plays a role of regulation and can improve employee's quality and green technology, thus further increasing profits. However, Yuan and Xiang (2018) constructed the extended Crépon-Duguet-Mairesse (CDM) model to examine the effects of ER on industrial innovation and green development, and their findings showed that ER has crowded out R&D investment, which makes the mechanism worth further exploration.

In conclusion, most of previous researches focus on the direct influences of ER, FDI, and TI on the upgrading of Chinese manufacturing industry. Although some studies also explore the interaction of ER with FDI or TI, they have not focused on the impact of interactions on manufacturing upgrades. In fact, ER not only directly affects the upgrading of manufacturing industry, but also has influences on the upgrading of manufacturing industry through FDI and TI. Of course, whether this hypothesis is true needs to be tested through normative empirical analysis, which is exactly the work of our study.

Empirical design

Theoretical hypotheses

In the development of Chinese manufacturing industry, FDI plays an extremely important role. The increase of foreign investment not only causes technology spillover effects (Eskeland and Harrison 2003), but also promotes innovation activities of the host country through spillover channels, such as reserve engineering, flow of skilled labor, demonstration effect, and the relationship between supplier and customer (Cheung and Lin 2004). In the aspect of capital input, there are also spillover effects, so that manufacturing industry with domestic capital constantly increases investment, scales up production, and increases input in R&D, thus upgrading manufacturing industry. The benefits of FDI inflow to the upgrading of Chinese manufacturing industry are evident (Zhang 2017; Anwar and Sun 2018). However, as the admittance threshold for FDI, ER plays a role in screening FDI (Yang et al. 2016), allowing high-quality foreign direct investment to flow into China and rejecting low-quality investment targeted at low-tech and high-pollution industries out. Some high-pollution and low-tech enterprises are forced to close down when they are unable to obtain low-quality foreign capital in the face of stricter environmental regulations. In the meantime, enterprises that can introduce high-quality foreign capital to achieve technological breakthroughs will stand out. In a sense, this may create a good environment for the development of high-tech manufacturing. Therefore, does ER have a positive impact on the upgrading of Chinese manufacturing industry by guiding inflow of FDI? In view of this, hypothesis 1 is proposed.

> Hypothesis 1: ER can promote the upgrading of Chinese manufacturing industry through FDI. In other words, interaction effects of ER and FDI can promote the upgrading of Chinese manufacturing industry.

Based on the compliance cost hypothesis, ER indeed increases the cost of enterprises for pollution control, thus raising production cost. To some extent, this reduces the expenditure of enterprises on R&D and innovation of technologies and limits competitiveness of enterprises (Gollop and Robert 1983; Gray 2001), which is unfavorable for the upgrading of manufacturing industry. However, this reflects the effects of short-term and loose ER. The weak ER cannot motivate the enterprises to carry out TI and technological upgrading. On the contrary, many enterprises do not have enough motivation to increase R&D intensity, because they can avoid the update of pollution control equipment and upgrade of pollution control technology and production technology at a small cost. Under such situations, ER fails to motivate enterprises to carry out technological upgrading; it does not change anything but increases the cost of pollution control, which indeed limits the competitiveness of enterprises. When ER intensity is high, in view of the serve tax penalties, it has been unfeasible to evade equipment update and technological upgrading merely in the form of imposing fines (Feng et al. 2017). After clearly knowing that stronger ER will appear in the future and weighing the pros and cons, more enterprises will determine to carry out TI, vigorously introduce new equipment, and intensify technological R&D, so as to cope with ER policy (Porter and Linde 1995; Yang et al. 2012). At this time, the remaining enterprises are bound to have strong capacity for TI and master advanced technologies. Therefore, ER with reasonable intensity can better optimize resource allocation, force enterprises to increase input in R&D for upgrading technology (Hamamoto 2006; Guo et al. 2017) and promote the upgrading of manufacturing industry. It is very essential to study the influences of interaction effects of ER and TI on the upgrading of manufacturing industry (Fig. 1). Based on this, hypothesis 2 is put forward.

> Hypothesis 2: ER can force enterprises in manufacturing industry to increase the intensity of R&D and carry out TI, thus promoting the upgrading of manufacturing industry. That is, interaction effects of ER and TI can promote the upgrading of manufacturing industry.

Establishment of variables

(1) Explained variable: In general, the upgrading of manufacturing industry is the process of manufacturing industry changing from labor intensive to technology intensive. According to the industrial structure theory, with reference to the construction method of Han et al. (2017) and Liu and Luo (2018), this paper constructs a manufacturing high-level indicator to measure the manufacturing upgrading. Manufacturing high-level indicator, which can reflect the continuous innovation of the production technology of the industry or the improvement of the technological content of the product, is usually measured by the product of the output ratio of each industry and the labor productivity. Therefore, the manufacturing high-level indicator can be defined as:

$$\mathrm{MU} = \sum_{i}^{n} (Q_i/Q)(\mathrm{LP}_i/\mathrm{LP}_0)$$

where, i indicates each industry, LP_i means labor productivity in industry i, which is defined as $\mathrm{LP}_i = Q_i/L_i$, Q_i represents the total output value of industry i, and L_i stands for the average number of employees in industry i. Besides, we will use 2000 as the base period. That is, $\mathrm{LP}_0 = Q_0/L_0$. In this method of measurement, both high and low technology-intensive manufacturing industries can be taken into consideration, thus obtaining a reasonable indicator for measuring manufacturing upgrades.

(2) Explaining variable

① ER. At present, various indexes have their own problems in explanatory ability, so there is no uniform ER index. From the perspective of ER cost and in view of availability and consistency of data, the ratio of investment in industrial pollution control in each province to the total output of industries above designated scale is selected to establish the cost-based ER index. In other words, it is represented by the investment in industrial pollution control in the total output of each industry above designated scale.
② FDI. The amount of FDI actually used in each province is selected as a proxy variable of FDI after converting it based on the of USD/RMB exchange rate published by the World Bank in that year.
③ TI. The variable of TI is established based on output of scientific and technological innovation, and the number of patent applications in regional high-tech industries is regarded as the proxy variable of TI.

(3) Control variable. Control variables selected in this research are shown as follows: Urbanization (URB) rate is expressed by the ratio of urban population to permanent resident population in the region. Human capital (HC) shows the proportion of personnel who receive education higher than junior college in each province.

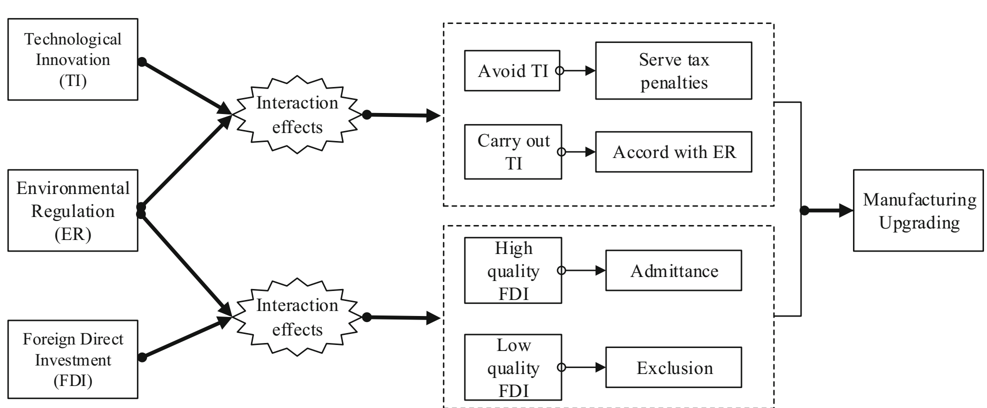

Fig. 1 The mechanism of ER through FDI and TI to MU

Trade dependence (TD) is expressed by the ratio of regional total import and export to regional GDP after the conversion based on exchange rate published by the World Bank at that time, so as to investigate the influences of foreign trade on the upgrading of manufacturing industry.

Data specification

The panel data of the above variables from 2000 to 2016 in 30 provinces and cities of China (excluding Tibet Autonomous Region) are collected as the dataset for the following empirical analysis. The total industrial output value and number of employees in the manufacturing sub-sectors of each province, which are the components of manufacturing upgrade indicators, come from the statistical yearbooks of each province and. Some province did not count the number of employees in the industry in the statistical yearbooks, so we supplement these data through the National Research Network. Data of investment in industrial pollution control and URB rate come from Wind dataset, while total regional import and export are from iFinD dataset of Straight Flush. Total output of industries above designated scale comes from *China Industry Statistics Yearbook* of each year and statistics yearbooks of each province. Furthermore, the number of patent applications, the actually used FDI and regional GDP in that year are from the website of National Bureau of Statistics of China. Data of education degrees of employees are obtained from the *China Labor Statistics Yearbook* and *China Population & Employment Statistics Yearbook* of each year. The above and some missing data are supplemented through the website of National Bureau of Statistics of China and statistics yearbooks of each province. Partially missing values are complemented by interpolation method.

In order to eliminate effects of price change on empirical results, by using GDP deflator taking the year of 2000 as base period, FDI are pre-processed. In the meanwhile, to reduce non-stationary of data and solve the problem of heteroscedasticity, this study conducts logarithmic processing on all variables. Descriptive statistics of each variable are shown in Table 1.

Setting of econometric model

This research firstly builds the benchmark model by using ER, FDI, and TI as explaining variables.

$$\mathrm{lnmu}_{i,t} = \alpha_i + \beta_1 \mathrm{lner}_{i,t} + \beta_2 \mathrm{lnfdi}_{i,t} + \beta_3 \mathrm{lnti}_{i,t} + \delta X_{i,t} + \varepsilon_{i,t} \quad (1)$$

where, i indicates each province, city, or region and t represents each period. $\mathrm{mu}_{i,t}$, $\mathrm{er}_{i,t}$, $\mathrm{fdi}_{i,t}$, and $\mathrm{ti}_{i,t}$ show the degree of upgrading of manufacturing industry, the intensity of ER, FDI, and the level of TI of the ith province in the tth year, respectively. X stands for vector group of control variables, including URB rate, HC, and TD. α_i and $\varepsilon_{i,t}$ denote the individual effect and the random error term, respectively.

In order to test hypotheses 1 and 2, the interactive terms of ER and FDI as well as ER and TI are introduced into the benchmark model, thus obtaining the following two econometric models.

$$\mathrm{lnmu}_{i,t} = \alpha_i + \beta_1 \mathrm{lner}_{i,t} + \beta_2 \mathrm{lnfdi}_{i,t} + \beta_3 \mathrm{lnti}_{i,t} + \beta_4 \mathrm{lner}_{i,t} \times \mathrm{lnfdi}_{i,t} + \delta X_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$\mathrm{lnmu}_{i,t} = \alpha_i + \beta_1 \mathrm{lner}_{i,t} + \beta_2 \mathrm{lnfdi}_{i,t} + \beta_3 \mathrm{lnti}_{i,t} + \beta_4 \mathrm{lner}_{i,t} \times \mathrm{lnti}_{i,t} + \delta X_{i,t} + \varepsilon_{i,t} \quad (3)$$

In the above two models, $\mathrm{lner}_{i,t} \times \ln \mathrm{fdi}_{i,t}$ indicates the interactive term of ER and FDI, while $\mathrm{lner}_{i,t} \times \ln \mathrm{ti}_{i,t}$ represents the interactive term of ER and TI. Other variables are same with the above. When the coefficients β_4 of the two interactive terms are significantly larger than zero, hypotheses 1 and 2 are verified. In other words, ER, as the admittance threshold for FDI, can guide foreign investment to flow into technology-intensive industry and force enterprises to carry out TI, thus promoting the upgrading of manufacturing industry.

Model selection

After establishing the needed econometric models, in order to determine whether the empirical research on the econometric models should be conducted with mixed OLS model, random effect model (RE) or fixed effect model (FE), we should take a series of model selection tests. F test, LM test, and Hausman test are carried out on the above three models. The test results are shown in Table 2. It can be seen that after all the tests we have taken, we can make a conclusion that fixed model (FE) is proper for the following estimation.

Analysis on empirical results

According to the above test, M1, M2, and M3 should be estimated by using the FE regression model. M1 is the initial model without introducing interactive terms and adopted as the reference to show the effects of interactive terms. Interactive terms of ER with FDI and TI are introduced respectively into M2 and M3 for testing hypotheses 1 and 2. In the structure of panel data, although it is usually assumed that disturbing terms of different individuals are independent, self-correlation is generally found in disturbing terms of the same individual in different times. At this time, standard deviation

Table 1 Descriptive statistics of major variables

Variable	Definition	Obs	Mean	Std. Dev.	Max	Min
lnmu	Manufacturing upgrading	510	1.4100	0.8265	0	2.9391
lner	Environmental regulation	510	2.5159	0.8644	− 0.2821	4.6851
lnfdi	Foreign direct investment	510	7.0295	1.7116	2.1972	9.9283
lnti	Technology innovation	510	4.6531	1.6663	0.2151	8.5417
lner × lnfdi	The interaction of ER and FDI	510	16.7601	5.2156	− 2.3742	31.5008
lner × lnti	The interaction of ER and TI	510	10.8198	3.6431	− 1.8785	19.9533
lnurb	Urbanization rate	510	− 0.7715	0.3150	− 0.1098	− 1.6607
lnhc	Human capital	510	2.1716	0.1331	1.8017	2.5663
lntd	Trade dependence	510	− 1.6949	0.9661	0.5122	− 4.3428

should be estimated by using cluster-robust standard error and the results are demonstrated in Table 3.

Direct effects of ER, FDI, and TI on the upgrading of manufacturing industry

As shown in Table 3, the estimation results of the three key explaining variables are consistent by using M1, M2, and M3 and the R^2 values are all larger than 0.87, indicating high fitting degree of models. The coefficients of ER are negative: the coefficients are all significant at least at the 10% level in all three models, and even significant at 1% level in M3. The magnitude of the coefficients are also roughly the same in the estimation where the interaction term is introduced, M2 and M3; they are − 0.4101 and − 0.3861, respectively. This demonstrates that ER inhibits the upgrading of manufacturing industry. From the national level, the current intensity of ER of China is still weak (Zhang and Yao 2018), which is unfavorable for the upgrading of manufacturing industry. The policy implication is to further enhance intensity of ER, so as to promote ER to exert positive promoting effects on the upgrading of manufacturing industry.

The coefficients of FDI are all positive. Coefficients are 0.1875 and 0.1546 in M1 and M3 and show significance at the levels of 1% and 5%, respectively. Besides, the coefficient is also positive in M2. This indicates that FDI indeed plays an important promoting role in the upgrading of manufacturing industry to some extent and well verifies the technology spillover hypothesis of FDI. Therefore, China should build a good investment environment to attract more FDI especially in tech-intensive industry, thus producing positive spillover effects of foreign investment and promoting the upgrading of manufacturing industry of the host country.

The capacity of TI is the base and motivation for the upgrading of manufacturing industry. In M1 and M2, its coefficient is 0.2640 and 0.3023 respectively and significant at 1% level. The coefficients in M3 are positive and significant at 5%. This shows that TI significantly promotes the upgrading of Chinese manufacturing industry. Therefore, China should positively promote the implementation of the policy of science and technology innovation and fully implement the strategy of becoming a great power of science and technology. Furthermore, China should formulate preferential innovation policy favoring manufacturing industry, so as to give full play to the driving role of TI in the upgrading of manufacturing industry.

Table 2 Model selection

Model	Test type	H_0	Test statistics	*P* value	Conclusion
M1	*F* test	PLS	6895.11	0.0000	Refuse H_0
	LM test	PLS	360.03	0.0000	Refuse H_0
	Hausman test	RE	256.73	0.0000	Refuse H_0
M2	*F* test	PLS	3440.98	0.0000	Refuse H_0
	LM test	PLS	368.90	0.0000	Refuse H_0
	Hausman test	RE	260.97	0.0000	Refuse H_0
M3	*F* test	PLS	3904.21	0.0000	Refuse H_0
	LM test	PLS	388.52	0.0000	Refuse H_0
	Hausman test	RE	263.48	0.0000	Refuse H_0

Influences of interaction effects on the upgrading of manufacturing industry

Table 3 presents that M2 introduces the interactive term of ER and FDI based on M1 and R^2 value is 0.8814, which shows high fitting degree of the model. The coefficient of interactive term of ER and FDI is positive, being 0.0440, which meets the expectation and it shows significance at the level of 10%. This demonstrates that the interaction effects of ER and FDI can promote the upgrading of Chinese manufacturing industry, which well verifies hypothesis 1. As an important admittance threshold, ER plays a limiting role in the inflow of FDI, guiding it to flow into tech-intensive manufacturing industry to some extent. Although the current weak ER of China is probably not conducive to the transformation and upgrading of manufacturing industry in some aspects, its role in guiding flows of foreign investment cannot be ignored. Further enhancing the intensity of ER can not only play the positive promoting effects of ER in the upgrading of manufacturing industry, but also more

Table 3 Effects of ER, FDI, and TI on the upgrading of manufacturing industry

Explaining variable	(1) M1	(2) M2	(3) M3
lner	− 0.0832* (0.088)	− 0.4103** (0.035)	− 0.3861*** (0.007)
lnfdi	0.1875*** (0.009)	0.0427 (0.595)	0.1546** (0.022)
lnti	0.2640*** (0.001)	0.3023*** (0.000)	0.1737** (0.028)
lner × lnfdi		0.0440* (0.057)	
lner × lnti			0.0621*** (0.008)
lnhc	2.0717*** (0.001)	1.8613*** (0.005)	1.7444*** (0.008)
lnurb	0.9839*** (0.006)	0.9516*** (0.006)	0.8844*** (0.006)
lntd	− 0.0654 (0.567)	− 0.0514 (0.666)	− 0.0355 (0.760)
Constant term	− 4.7778*** (0.001)	− 3.3964** (0.034)	− 3.3517** (0.032)
Individual effect	Y	Y	Y
R^2	0.8783	0.8814	0.8861
N	510	510	510

*, **, and *** indicate being significant at the levels of 10%, 5%, and 1%, respectively. *p* values are displayed in parentheses

effectively guide the flow of foreign investment. Therefore, this gives a full play to interaction between ER and FDI in the upgrading of manufacturing industry.

M3 introduces the interactive term of ER and TI based on M1 and R^2 value is 0.8861, so the fitting degree is high. Coefficient of ER is negative and significant at the level of 1%; that of FDI and TI are both positive and significant at 5%, which is consistent with the estimation results of the first two models. The coefficient of interactive term of ER and TI is positive, being 0.0621, which meets the expectation and is significant at the level of 1%. This indicates that the interaction effects of ER and TI indeed promote the upgrading of Chinese manufacturing industry, which well verifies hypothesis 2. Therefore, a reasonable ER intensity can result in more input in R&D (Yang et al. 2012), force enterprises to enhance R&D intensity and realize technology upgrading, thus promoting the upgrading of manufacturing industry. In view that the ER intensity of China is weak on the whole at present, China should properly improve ER intensity, so as to intensively force enterprises to carry out technology upgrading, thus better and more quickly promoting the upgrading of manufacturing industry.

Influences of control variables on the upgrading of manufacturing industry

As shown in Table 3, the coefficients of control variables in M1–M3 are meeting the expectation. Of them, coefficients of HC and URB rates are both positive and significant at the level of 1% in all models, indicating the two variables significantly promote the upgrading of manufacturing industry. Therefore, they are important factors for facilitating the upgrading of manufacturing industry. The variable of HC is represented by the proportion of employees with education degree of junior college or above. The improvement of HC can bring richer human resources for tech-intensive manufacturing industry, which facilitates to introducing a large number of highly skilled personnel and is conducive to the development of tech-intensive manufacturing industry. This can effectively promote the upgrading of manufacturing industry. The policy implication is to further introduce high educational talents and innovative talents of science and technology. UBR rates are expressed by the ratio of urban population to permanent resident population in the region. The promotion of urbanization can generate effects of talent and economic aggregation, improving education degree and living level of labors, then effectively promoting the upgrading of manufacturing industry. Thus, vigorously increasing the rate of urbanization is a measure that must be implemented to promote the upgrading of manufacturing industry.

The coefficients of TD are negative and not significant even at the level of 10% in three models. This only yields the preliminary conclusion that TD cannot promote but inhibit the upgrading of manufacturing industry. The reason is shown as follows: trade dependence of China is too high, which is reflected by the comparative advantages in the export of labor-intensive products. Products, like textile and garment, footwear, and toy, have always been the commodities for bulk export in China, but actually the supply of these industries has exceeded demand. In fact, the constant expansion of these low-value-added industries cannot improve domestic industrial structure and promote the upgrading of technologies in Chinese manufacturing industry. In addition, Chinese manufacturing industry relies heavily on imports from other countries for some key components and technologies. Obviously, the higher the TD is and the stronger the dependence on foreign imports is, the more unfavorable for improving independent R&D capability of Chinese enterprises and upgrading Chinese manufacturing industry.

The IV estimation

In the empirical specification, ER, FDI, and TI are all endogenous, thus the estimated coefficients for these variables maybe biased. In order to solve this problem, we adopt a common approach of using the lag phase of key explanatory variables as a tool variable and re-estimating M2 and M3. We use both 2SLS and GMM methods for IV estimation. The consequences are presented in Table 4. The four estimates all pass the F test of the excluded instruments, and the Sargan/Hansen tests indicate that there is no over-identification problem. In general, the results are robust compared with former estimation without considering the problem of endogeneity. As we can see, the coefficients of ER are all meet expectations and significant at 1% level in all estimation methods, which is very robust compared with previous results. The estimated results of two interaction terms we are most concerned about are very consistent with before. They are both positive, significant at 1% level, and there is no major change in the magnitude. Furthermore, signification of the interaction term between ER and FDI has been improved, from previous 10% level to 1% level. The consequences of the IV estimates confirm our previous analysis is correct.

The empirical evidence of ER effects on FDI and TI

In this paper, we propose two hypotheses. One is that ER can promote the upgrading of Chinese manufacturing industry through FDI. The other is that ER can promote the upgrading of Chinese manufacturing industry through TI. We have empirically proved the two hypotheses through the above analysis. However, are FDI and TI really affected when stricter environmental regulations implemented? In a word, whether the effects that ER can influence FDI and TI and further influence manufacturing upgrades through them exist. For this purpose, we take FDI and TI as dependent variable respectively and ER as independent variable, then conduct these two estimations. The results are presented in Table 5.

As shown in Table 5, the first column presents the regression result when FDI is used as a dependent variable. We can find ER has a significant negative impact on FDI, which is consistent with our theoretical analysis. ER, as the admittance threshold for FDI, has screening effect on FDI and will limit the inflow of it (Cai et al. 2016; Yang et al. 2016). When we move to the estimation where TI as the explanatory variable in column 2, we find that ER also has a significant negative influence on TI, indicting a stricter environmental regulation may suppress technological innovation. It seems that the regression results cannot meet our expectations. However, considering ER may have a nonlinear relationship with TI, which is just like the previous research between environmental regulation, productivity, and progress of production technologies (Armando et al. 2013; Liu and Ran 2015), we introduce the square of the environmental regulation and make a further regression. The consequence is shown in column 3 of Table 5; the primary and secondary items of ER are both significant at 1% level. Coefficient of the primary item is negative but the secondary is positive, which means there is a U-shaped relationship between ER and TI. In the initial stage of enhancing the intensity of environmental regulation, not all companies are able to embark on the road of technological innovation, and more likely to respond to stricter environmental regulation by taking on more pollution fines. However, after a period of time, companies will find that pure increase in pollution control expenditures will not bring substantial performance. At this time, they will turn to technological innovation to control the pollution in the production process, so as to respond stricter environmental regulation. This shift is in line with our theoretical analysis.

Discussion on regional heterogeneity

Different regions in China demonstrate great differences in economic development level, resource endowment, and industrial structure, so the attentions paid on the environment vary, which leads to great spatial heterogeneity in policy for attracting foreign investment and ER policy in different regions. In other words, the effects of ER, FDI, and TI as well as interactive terms of ER with FDI and TI on the upgrading of manufacturing industry maybe different in different regions. Therefore, by further dividing three economic regions, i.e., eastern, central, and western regions[1], this study discusses the possible influences of spatial heterogeneity on the above mechanisms. Table 6 summarizes the estimation results of FE model in the three regions.

Based on fitting degrees of the six models in Table 6, all of the R^2 values are larger than 0.89, showing satisfactory fitting results. For the sake of simplicity, control variables are not individually listed in the table, while only key variables are shown. The influences of ER intensity in three regions on the upgrading of manufacturing industry are all negative and most of the estimates are significant, which is consistent with estimation results of the whole national samples. In the eastern region, after 40-year development since the reform and opening-up, economically developed regions along the eastern coastal areas have a good

[1] In this research, we merge the three provinces in the Northeast into the eastern region, then the region divisions are shown as follows: the eastern region mainly includes 13 provinces and cities, i.e., Beijing, Tianjin, Hebei, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Shandong, Fujian, Guangdong, and Hainan. The central region mainly comprises 6 provinces, i.e., Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan. Furthermore, the western region mainly consists of 11 provinces and cities, i.e., Inner Mongolia Autonomous Region, Guangxi Zhuang Autonomous Region, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia Hui Autonomous Region, and Xinjiang Uygur Autonomous Region. Owing to lots of data of Tibet Autonomous Region are absent, this study only selects panel data of these 30 provinces and cities.

Table 4 IV estimation of the interaction

	(1)	(2)	(3)	(4)
Explaining variable	M2-2SLS	M3-2SLS	M2-2SLS	M3-2SLS
lner	− 1.1316*** (0.005)	− 0.8423*** (0.000)	− 1.1316*** (0.000)	− 0.8423*** (0.000)
lnfdi	− 0.2149 (0.186)	0.0908* (0.092)	− 0.2149* (0.064)	0.0908** (0.034)
lnti	0.3349*** (0.000)	0.0675 (0.341)	0.3349*** (0.000)	0.0675 (0.266)
lner × lnfdi	0.1168*** (0.009)		0.1168*** (0.000)	
lner × lnti		0.1184*** (0.000)		0.1184*** (0.000)
lnhc	0.9103* (0.069)	0.9272** (0.038)	0.9103** (0.026)	0.9272** (0.017)
lnurb	0.9307*** (0.000)	0.8421*** (0.000)	0.9307*** (0.000)	0.8421*** (0.000)
lntd	− 0.0752 (0.269)	− 0.0385 (0.552)	− 0.0752 (0.174)	− 0.0385 (0.484)
Individual effect	Y	Y	Y	Y
F test of excluded instruments	Y	Y	Y	Y
Sargan/Hansen test	Y	Y	Y	Y
R^2	0.8346	0.8416	0.8346	0.8416
N	480	480	510	480

*, **, and *** indicate being significant at the levels of 10%, 5%, and 1%, respectively. *p* values are displayed in parentheses

business environment and are attractive to foreign investment. In M2E and M3E, coefficients of FDI variable are 0.0922 and 0.4116 separately and the coefficient in M5 is significant at the level of 1%. This demonstrates that FDI substantially promotes the upgrading of manufacturing industry, which verifies that the technology spillover hypothesis is feasible in the eastern region to some extent. Furthermore, the coefficient of interactive term of ER and FDI is positive and significant at the level of 10%. This shows that ER can improve the marginal effects of FDI on the upgrading of manufacturing industry, thus promoting the upgrading of the industry (Yang et al. 2016). Although the interaction term of ER and TI is not significant, its coefficient is positive and, to some extent, consistent with previous conclusions.

Similar to the eastern region, the coefficients of the two interactive terms of the central and western region are also positive and significant at the level of 5%. This indicates that the above interaction mechanism is also verified in these two regions. However, the direct influence of FDI and TI is heterogeneous in these two regions. We notice that the coefficient of FDI is negative in M2C and M3C, and significant even at the 1% level in M2C. The reason that ER has a negative impact in central region may be due to the low technical

Table 5 The effects of ER on FDI and TI

	(1)		(2)	(3)
Explaining variable	lnfdi		lnti	lnti
lner	− 0.1459* (0.073)	lner	− 0.0857** (0.050)	− 0.4986*** (0.002)
		lner2		0.0896*** (0.005)
lnti	0.4401*** (0.000)	lnfdi	0.2876*** (0.003)	0.2953*** (0.002)
lnhc	− 0.5351 (0.624)	lnhc	4.9518*** (0.000)	4.9886*** (0.000)
lnurb	0.8680* (0.078)	lnurb	1.9883*** (0.000)	2.0157*** (0.000)
lntd	0.3538 (0.142)	lntd	− 0.3258** (0.011)	− 0.3442*** (0.005)
Individual effect	Y		Y	Y
R^2	0.6289		0.8589	0.8638
N	510		510	510

*, **, and *** indicate being significant at the levels of 10%, 5%, and 1%, respectively. *p* values are displayed in parentheses

Table 6 Effect of spatial heterogeneity on interaction effects of ER with FDI and TI

Explaining variable	Eastern region		Central region		Western region	
	M2E	M3E	M2C	M3C	M2W	M3W
lner	− 1.1508** (0.049)	− 0.4371 (0.168)	− 1.2343** (0.013)	− 0.6589* (0.053)	− 0.3940* (0.081)	− 0.2617 (0.134)
lnfdi	0.0922 (0.611)	0.4116*** (0.007)	− 0.5806*** (0.007)	− 0.1255 (0.175)	− 0.1675 (0.231)	0.0690 (0.470)
lnti	0.2914*** (0.003)	0.1522 (0.153)	0.1474 (0.427)	− 0.1351 (0.309)	0.2183** (0.048)	0.0166 (0.856)
lner × lnfdi	0.1294* (0.055)		0.1443** (0.010)		0.0792** (0.016)	
lner × lnti		0.0608 (0.242)		0.1110** (0.025)		0.0811** (0.021)
Other variables	Control	Control	Control	Control	Control	Control
Individual effect	Control	Control	Control	Control	Control	Control
R^2	0.9025	0.8938	0.9289	0.9273	0.9181	0.9200
N	221	221	102	102	187	187

*, **, and *** indicate being significant at the levels of 10%, 5%, and 1%, respectively. *p* values are displayed in parentheses

capacity of local enterprises and the low level of industrial technology in the central region (Fu et al. 2014). Domestic and foreign-funded enterprises cannot compete effectively. Local enterprises cannot learn to absorb and acquire the technologies from foreign-funded enterprises (Abdouli and Hammami 2016). In a word, the technology spillover effect of foreign capital is difficult to occur, thus failing to effectively promote manufacturing upgrades.

In general, although some key explanatory variables have different roles in different regions when regional heterogeneity is considered, the above interaction mechanisms are also established, which provides further empirical evidence for the effects of environmental regulation through FDI and TI to promote manufacturing upgrades.

Conclusions, policy suggestions, and future work

This research discusses the effects of ER on the upgrading of manufacturing industry through the perspective of FDI and TI and investigates influences of spatial heterogeneity on the above interaction mechanism by dividing China into the eastern, central, and western regions. The conclusions are made as follows: firstly, the current ER intensity of China is unfavorable for the upgrading of manufacturing industry, while the technology spillover effects caused by FDI and the strong power provided by TI indeed remarkably promote the upgrading of manufacturing industry. Secondly, ER can promote the upgrading of manufacturing industry by screening and guiding foreign investment to flow into tech-intensive manufacturing industry and forcing enterprises to carry out TI. In other words, the interaction effects of ER through FDI and TI can promote the upgrading of manufacturing industry. Thirdly, the above mechanisms are also robust even if we take the regional heterogeneity into consideration. Furthermore, strengthening basic education and advancing urbanization are favorable for promoting the upgrading of manufacturing industry. However, enhancing TD is unfavorable for the upgrading of manufacturing industry. In order to further promote the upgrading of manufacturing industry and leaping of China from a large country to a powerful country of manufacturing industry, this study proposes policy suggestions from the following two aspects.

Firstly, Chinese government is supposed to implement stricter ER policy, improve admittance threshold for FDI, guide enterprises to increase R&D input, and carry out TI. According to the overall situation of China, the ER intensity of China is weak and cannot promote the upgrading of manufacturing industry. In the research, it is proposed and verified the interaction mechanism that ER can guide FDI to flow into high-tech manufacturing industry and force enterprises to increase R&D input and carry out TI. On the one hand, the implementation of stricter ER policy can improve admittance threshold for FDI and fully play the screening role of ER for foreign investment, so as to improve the quality of FDI inflows and guide foreign investment into tech-intensive manufacturing industry as far as possible. Moreover, the aim is to better exert spillover effects of FDI and promote the transformation and upgrading of manufacturing industry. In the meanwhile, China should further improve domestic market environment, promote the participation of foreign investment in fair competition and establish incentive mechanisms. On the other hand, TI plays a very important role in the upgrading of manufacturing industry and stricter ER can greatly force enterprises to increase R&D input and carry out TI. This can exert the interaction between ER and TI to a greater extent and speed up the progress of technology upgrading, thus promoting the development of high-tech manufacturing industry and upgrading Chinese manufacturing industry.

Secondly, although the mechanisms of ER to promote manufacturing upgrades through FDI and TI have been confirmed to exist even in different regions of China, Chinese government should implement differentiated regional policies. Because economic development and current situation of resource and environment are quite different in various regions, policies suiting for each region should be implemented. Although the intensity of ER policy needs to be improved in all three regions, the government should avoid blindly improving ER intensity or implementing one-size-fits-all policies in order to rapidly achieve the goal of promoting the upgrading of manufacturing industry through ER. The government should implement guidelines and policies that are compatible with various regions according to actual demands, regional characteristics, and development stage of different regions. For example, both domestic and foreign investments are abundant in the eastern region, while those in the central and western regions are relatively short. Therefore, it is very necessary to implement different regional policy, investment policies, and environmental policies, enhancing admittance threshold in the eastern region while decreasing that in the central and western regions, so as to cover the financing gap in inland regions. This helps promote the economic growth in the central and western regions, quickly realizes coordinated development of regions and common prosperity, and further boosts the overall upgrading of manufacturing industry. However, in view of that FDI has a negative impact on manufacturing upgrades in central region for now, government should pay more attention to the quality of FDI inflows. ER policy needs to be properly adjusted to screen FDI, so as to fully play the interaction of ER and FDI. As for the western region, it is reasonable to continuously implement the great western development strategy. It is precisely because there are a large number of tax incentives policies that attract foreign investment; the development of the western region in recent years has been so rapid. Once a more reasonable environmental regulation level was formulated, ER can effectively promote the upgrading of manufacturing industry through the interaction mechanisms.

Unlike existing studies, which are mostly based on direct influence of ER, FDI, and TI on manufacturing industry, this research evaluates the interaction effects of ER and FDI/TI on manufacturing upgrades. It thus provides a new research perspective. However, our research also has its limitations. If environmental regulations drive polluted enterprises or some polluted industries to shut down, these enterprises will disappear from the sample; this could be one form of industry upgrading. Nevertheless, in our research, we use a macro dataset not a micro one, thus we are unable to identify these enterprises that disappeared due to stricter environmental regulation from the sample. Clearly, we need to use a micro level dataset of enterprise to discuss this form of manufacturing upgrades in detail in subsequent studies.

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References

Abdouli M, Hammami S (2016) Economic growth, FDI inflows and their impact on the environment: an empirical study for the MENA countries. Qual Quant 51(1):1–26

Anwar S, Sun S (2018) Foreign direct investment and export quality upgrading in China's manufacturing sector. Int Rev Econ Financ 54:289–298

Armando SV, Ricardo MS, Alonso AI (2013) An empirical analysis of the nonlinear relationship between environmental regulation and manufacture productivity. J Appl Econ 16(2):357–372

Birdsall N, Wheeler D (1993) trade policy and industrial pollution in Latin America: where are the pollution havens? J Environ Dev 2(1):137–149

Cai XQ, Lu Y, Wu MQ, Yu L (2016) Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. J Dev Econ 123:73–85

Cheung KY, Lin P (2004) Spillover effects of FDI on innovation in China: evidence from the provincial data. China Econ Rev 15(1): 25–44

Chung S (2014) Environmental regulation and foreign direct investment: evidence from South Korea. J Dev Econ 108(C):222–236

Copel BR, Taylor MS (1995) Trade and transboundary pollution. Am Econ Rev 85(4):716–737

Dean JM, Lovely ME, Wang H (2009) Are foreign investors attracted to weak environmental regulations? Evaluating the evidence from China. J Dev Econ 90(1):0–13

Eskeland GS, Harrison AE (2003) Moving to greener pastures? Multinationals and the pollution haven hypothesis. J Dev Econ 70(1):1–23

Feng W, Ji G, Pardalos PM (2017) Effects of government regulations on manufacturer's behaviors under carbon emission reduction. Environ Sci Pollut Res 26(18):17918–17926 1-9

Fu YH, Ye XS, Wang ZX (2014) The selection of technology process path of manufacturing structure optimization——an empirical analysis based on dynamic panel data model. China Ind Econ 9(9):79–90

Gábor H (2002) Restructuring through FDI in Romanian manufacturing. Econ Syst 26(4):387–394

Gollop FM, Roberts MJ (1983) Environmental regulations and productivity growth: the case of fossil-fueled electric power generation. J Polit Econ 91(4):654–674

Gong Z, Chen X (2017) Analysis of interval data envelopment efficiency model considering different distribution characteristics—based on environmental performance evaluation of the manufacturing industry. Sustainability 9(12):2080

Gray WB (2001) The cost of regulation: OSHA, EPA and the productivity slowdown. Am Econ Rev 77(77):998–1006

Guo LL, Qu Y, Tseng ML (2017) The interaction effects of environmental regulation and technological innovation on regional green growth performance. J Clean Prod 162:894–902

Hamamoto M (2006) Environmental regulation and the productivity of Japanese manufacturing industries. Resour Energy Econ 28(4):299–312

Han YH, Huang LX, Wang XB (2017) Do industrial policies promote industrial structure upgrading? Theory and evidence from China's development-oriented local government. Economic Research Journal 52(08):33–48

Jaffe AB, Palmer K (1997) Environmental regulation and innovation: a panel data study. Rev Econ Stat 79(4):610–619

Kang YQ, Xie BC, Wang J, Wang YN (2018) Environmental assessment and investment strategy for China's manufacturing industry: a non-radial DEA based analysis. J Clean Prod 175:501–511

Keller W, Levinson A (2002) Pollution abatement costs and foreign direct investment inflows to U.S. States. Rev Econ Stat 84(4):691–703

Liu JJ, Luo SC (2018) Housing price rise, factor flow and upgrading of manufacturing industry. Modern Econ Sci 40(06):98–106

Liu J, Ran M (2015) An analysis of environmental regulation influence on production technological progress of industry. Sci Res Manag 36(02):107–114

Lin MH, Yang YZ (2011) Environmental regulation and technology innovation: evidence from China. Energy Procedia 5:572–576

Lu Y, Tao ZG, Zhu LM (2017) Identifying FDI spillovers. J Int Econ 107:75–90

Ning L, Wang F (2018) Does FDI bring environmental knowledge spillovers to developing countries? The Role of the local industrial structure. Environ Resour Econ 71(2):381–405

Orlic E, Hashi I, Hisarciklilar M (2018) Cross sectoral FDI spillovers and their impact on manufacturing productivity. Int Bus Rev 27(4):777–796

Porter ME, Linde CVD (1995) Toward a new conception of the environment-competitiveness relationship. J Econ Perspect 9(4):97–118

Roos G (2016) Design-based innovation for manufacturing firm success in high-cost operating environments. She Ji: The Journal of Design, Economics, and Innovation 2(1):5–28

Song ML, Wang SH, Sun J (2018) Environmental regulations, staff quality, green technology, R&D efficiency, and profit in manufacturing. Technol Technol Forecast Soc Chang 133:1–14

Wang W, Yu B, Yan X, Yao X, Liu Y (2017b) Estimation of innovation's green performance: a range-adjusted measure approach to assess the unified efficiency of China's manufacturing industry. J Clean Prod 149:919–924

Wang ZX, Hao P, Yao PY (2017a) Non-Linear relationship between economic growth and CO_2 emissions in China: an empirical study based on panel smooth transition regression models. Int J Environ Res Public Health 14(12):1568

Wang ZX, Li Q (2019) Modelling the nonlinear relationship between CO_2 emissions and economic growth using a PSO algorithm-based grey Verhulst model. J Clean Prod 207:214–224

Xie RH, Yuan YJ, Huang JJ (2017) Different types of environmental regulations and heterogeneous influence on "Green" productivity: evidence from China. Ecol Econ 132:104–112

Yang CH, Tseng YH, Chen CP (2012) Environmental regulations, induced R&D, and productivity: evidence from Taiwan's manufacturing industries. Resour Energy Econ 34(4):514–532

Yang, J., He, Z. Y., Cong, J. H. (2016) Environmental regulation, FDI of manufacturing industry and threshold effect. On Econ Problems (11), 24-28.

Yang LG, Gong SH, Wang B et al (2018) Human capital, technology progress and manufacturing upgrading. China Soft Sci 1:138–148

Yuan BL, Xiang Q (2018) Environmental regulation, industrial innovation and green development of Chinese manufacturing: based on an extended CDM model. J Clean Prod 176:895–908

Zeng B, Li C (2016) Forecasting the natural gas demand in China using a self-adapting intelligent grey model. Energy 112:810–825

Zeng B, Li C (2018) Improved multi-variable grey forecasting model with a dynamic background-value coefficient and its application. Comput Ind Eng 118: 278-290

Zhang L (2017) The knowledge spillover effects of FDI on the productivity and efficiency of research activities in China. China Econ Rev 42:1–14

Zhang T, Yao H (2018) The improvement on the implementation level of environmental policies is demanded in China. Environ Sci Pollut Res 25:1–4

Zhao X, Sun BW (2015) The influence of Chinese environmental regulation on corporation innovation and competitiveness. J Clean Prod 112(4):1528–1536