Dual Environmental Regulation, Technological Innovation and Green Total Factor Productivity of Manufacturing Industry: Based on the Development Background of Information Technology

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Abstract: In the context of the development of information technology, the impact of technological innovation on the green transformation of manufacturing industry will be affected by the intensity of environmental regulation. Therefore, based on the perspective of dual environmental regulation, the path of technological innovation affecting green transformation of manufacturing industry is discussed. The empirical results show that technological innovation has a significant promoting effect on the improvement of manufacturing total factor productivity, and with the improvement of the formal environmental regulation level, the promoting effect of technological innovation on improving manufacturing green total factor productivity is gradually weakened; while in the informal environment When the level of regulation is between the second threshold and the third threshold, technological innovation has the greatest effect on promoting green total factor productivity of manufacturing; when the level of dual environmental regulation exceeds the threshold, the impact of technological innovation on the improvement of green total factor productivity in manufacturing will also reduce.

1 INTRODUCTION

In today's society, the development of manufacturing industry is inseparable from the support of information technology. The continuous innovation and development of information technology also promote the high-quality development of manufacturing industry. Theoretical and practical experience shows that technological innovation is not only the source of power to transform the mode of economic development, but also the main driving force for the green transformation of the manufacturing industry (Jaffe and Karen, 1997). However, in fact, technological innovation is affected by many factors in the process of promoting the development of the manufacturing industry, among which the most significant is the environmental regulation factor. A major feature of the transformation of the manufacturing industry is the improvement of total factor productivity, and technological innovation is mainly achieved through technological progress and the improvement of market competitiveness (Abramovitz, 1993). Under the background of specialized division of labor, the technological progress brought about by technological innovation is the driving force for the transformation of the manufacturing industry. The realization of technological progress by increasing R&D investment and independent research and development can ensure that the output remains unchanged, while reducing the production costs of enterprises (Gallego et al. 2015). Since the 1990s, with the introduction of the environmental Kuznets curve, the research on environmental regulation has gradually increased (Moutinho et al. 2020). Environmental regulation consists not only of formal environmental regulation from the government, but also informal environmental regulation formed by the public (Tian and Feng, 2020) Due to the different operating mechanisms of the two types of environmental regulations, the impact mechanisms on technological innovation and the green transformation of manufacturing are also different. According to the theory of "Porter Hypothesis" (Porter and Linde, 1995) the impact of formal environmental regulation mainly changes through the

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game between the "compliance cost" effect and the "innovation compensation" effect (Peuckert, 2014). Under the appropriate formal environmental regulation, in order to legally avoid the cost of pollutant discharge, and to obtain government environmental protection subsidy funds, enterprises will increase technological innovation to improve the production process (Porter and Linde, 1995). However, when the intensity of formal environmental regulation is unreasonable, enterprises often adopt negative measures such as “tail-end governance” to deal with formal environmental regulation, which will lead to a reduction in enterprise output, productivity and innovation motivation (Gray and Ronald, 2003). Under the reasonable intensity of informal environmental regulation, the government, the public and enterprises form an organic whole, and the green product consumption market is further expanded. In order to maintain competitiveness in the green market, enterprises must increase technological innovation. Therefore, in the context of the rapid development of information technology, the relationship between technological innovation and environmental regulation is more complex, which leads to the path of technological innovation in promoting green change in manufacturing industry will change with the level of environmental regulation.

2 MODEL CONSTRUCTION AND INDICATOR SELECTION

Based on the above analysis, to empirically test whether there is a threshold effect of environmental regulation when technological innovation promotes the green transformation of the manufacturing industry, the following panel threshold regression model is established for research:

$$Green_{it} = \alpha_0 + \alpha_1 lnT_{it} \times I(ER \le \gamma_1) + \alpha_2 lnT_{it} \times I(\gamma_1 < ER \le \gamma_2) + \alpha_3 lnT_{it} \times I(ER > \gamma_2) + \sum \alpha_m Controls + V_i + \mu_t + \varepsilon_{it}$$

$$Green_{it} = \beta_0 + \beta_1 lnT_{it} \times I(INER \le \gamma_1) + \beta_2 lnT_{it} \times I(\gamma_1 < INER \le \gamma_2) + \beta_3 lnT_{it} \times I(INER > \gamma_2) + \sum \beta_m Controls + V_i + \mu_t + \varepsilon_{it}$$

$$Green_{it} = \chi_0 + \chi_1 lnT_{it} \times I(CossER \le \gamma_1) + \chi_2 lnT_{it} \times I(\gamma_1 < CossER \le \gamma_2) + \chi_3 lnT_{it} \times I(CossER > \gamma_2) + \sum \chi_m Controls + V_i + \mu_t + \varepsilon_{it}$$

Among them, $Green_{it}$ is the green total factor productivity of manufacturing, *t* represents the year, *i* represents the province, β0 represents the intercept term, Controls represents all control variables, *Vi* represents the individual effect, and *εit* represents the random disturbance term. *γi* represents the *i* threshold values (i=1, 2, 3), *I(·)* is the indicator function, and μi represents the time fixed effect. The threshold variables of the above models are formal environmental regulation (*ER*) and informal environmental regulation (*INE*R) and dual environmental regulation (*CossER*) expressed as (*ER×INER*).

Explained variable: manufacturing green total factor productivity (*Green*). Its calculation method relies on the EBM-GML model. The measurement of total factor productivity will inevitably involve the input and output in the production process, and one of the characteristics of green total factor productivity is that the output indicators take into account the unexpected output.

Capital input is represented by the total social fixed asset investment in the manufacturing industry in each province; labor input is measured by the average number of workers employed in the manufacturing industry in each province; since there is no statistical data on direct manufacturing energy input in each province, this paper draws on Zhang and Qiao (2021) The method of estimating the final energy consumption of the manufacturing industry in each province is used to characterize the energy input index.

The expected output is measured by the operating income of the manufacturing industry, and the undesired output mainly refers to the output of pollutants in the production process, which is generally represented by the "three wastes" emissions. Characterization of carbon dioxide emissions.

Since the direct result measured by the EBM-GML model is the growth rate of green total factor, the green total factor productivity of each year is calculated based on the multiplication method of Lei et al. (2020).

Core explanatory variable: technological innovation (*T*). In the existing research on measuring technological innovation indicators, it is mainly measured from the perspective of input and output. This paper uses the internal expenditure of manufacturing R&D funds in each province to measure, in order to avoid the biased results caused by data heteroscedasticity, logarithmic processing.

Core explanatory variable: dual environmental regulation (*CossER*). Based on the research purpose of this paper, the characterization variables of environmental regulation are selected from both formal and informal aspects. Formal Environmental Regulation (*ER*). Calculated as follows:

$$ER_{it} = \frac{ER_{it}^*}{R_{it}}$$

Among them, ER_{it}^* is the ratio of industrial pollution control investment to gross industrial output value, and R_{it} is the ratio of gross industrial output value to regional GDP. The larger the ER_{it} value, the greater the intensity of formal environmental regulation in the region.

Informal Environmental Regulation (*INER*). Referring to the research of Wheeler and Pargal (1996), the indicators of income level, education level, and population density were selected, and the entropy weight method was used to combine the three indicators into one indicator to represent informal environmental regulation variables.

Controls: Referring to existing research, the regional economic development level (*PGDP*), government intervention (*GOV*), human capital (*HUM*) and transportation infrastructure level (*ROAD*) were used as control variables in this study. The specific meaning of each control variable indicator: the per capita GNP of each province is used to reflect the regional economic development level, and the logarithm is used to process it; the ratio of government fiscal expenditure to regional GDP is used to measure government intervention; the average education years of each province is used to express Human capital; the ratio of the mileage of railways and highways in each province to the provincial area is used to represent the level of transportation infrastructure.

Most of the sample data mentioned above can be obtained from the 2012-2021 China Industrial Statistical Yearbook, the China Science and Technology Statistical Yearbook, the China Statistical Yearbook, the 2012-2020 China Environmental Statistical Yearbook, and China 30 Statistical yearbook query for each province (because of the limited availability of relevant data in Tibet and Hong Kong and Macao), and use interpolation method to supplement individual missing values in the data. The data of the price variables involved are uniformly based on 2011 Flatten. Table 1 shows the descriptive statistics of the main variables.

Table 1: Descriptive statistics.

Variable	N	Average	SD	Min	Max
Green	300	1.316	0.263	0.831	2.358
ER	300	1.226	1.437	0.041	8.163
INER	300	0.17 5	0.171	0.038	0.943
lnT	300	14.087	1.460	10.619	16.96
GOV	300	0.250	0.103	0.110	0.643
lnPGDP	300	10.841	0.436	9.705	12.013
HUM	300	0.360	0.254	0.135	1.716
ROAD	300	11.711	0.840	9.441	12.898

Table 2 reports the test results of repeated sampling using the Bootstrap method for 1000 times. It can be seen that when ER is used as the threshold variable, the F values of the single threshold and the double threshold have passed the 1% significance test, indicating that with the increase of ER intensity , there is a double threshold effect with threshold values of 0.8900 and 2.2261 between technological innovation and manufacturing green transformation; When INER is used as the threshold variable, the F values of single threshold and double threshold have passed the 5% significance test, indicating that with the increase of INER, there is a double threshold value of 0.0693 and 0.5255 between technological innovation and manufacturing green transformation. threshold effect; When CossER is used as the threshold variable, only the F value of a single threshold passes the 1% significance test, indicating that as the intensity of CossER increases, there is a single threshold effect with a threshold value of 0.0986 between technological innovation and manufacturing green transformation.

Table 2: Threshold effect test.

Variable	Thresh-old number	Threshold	*F value*	*P* value	Confidence interval
ER	single	0.8900	30.71***	0.004	[0.8345, 0.9268]
	double	2.2261	22.64**	0.013	[2.1774, 2.2486]
	triple	0.2712	11.58	0.683	
lnER	single	0.0693	33.54**	0.025	[0.0686, 0.0699]
	double	0.5255	32.79**	0.012	[0.5225, 0.5308]
	triple	0.5410	15.93	0.355	
Coss -ER	single	0.0986	54.12***	0.000	[0.0975 ,0.0988]
	double	0.2668	9.60	0.189	
	triple	0.0337	7.06	0.651	

Note: 1) The P value and confidence interval are the results obtained by the Bootstrap method repeated sampling 1000 times; 2) ***, *** and * indicate that the regression coefficients are significant at the 1%, 5% and 10% levels, respectively.

3 OUTCOME OF PRACTICE

From the threshold regression results, it can be seen that there are significant differences in technological innovation on the green transformation of manufacturing under different environmental regulation intensities.

When ER is in the low-intensity range, the regression coefficient of technological innovation to the green transformation of the manufacturing industry is 0.174; when ER is in the medium-intensity range, the regression coefficient of technological innovation to the green transformation of the manufacturing industry is 0.164; when ER is in the high-intensity range, the regression coefficient of technological innovation on the green transformation of manufacturing is 0.154. That is to say, as the intensity of formal environmental regulation continues to exceed the threshold, technological innovation maintains a positive role in promoting the green transformation of manufacturing, but this role is also weakening. The reason may be that the transformation and upgrading of my country's manufacturing industry is still in the "pain period", and the "following cost" effect produced by formal environmental regulation still constrains the development of manufacturing enterprises, and the regulatory costs generated may lead to "negative behavior" of enterprises. , that is, reducing pollutant emissions by reducing production, thereby reducing the profit margin of enterprises and weakening the innovation power of enterprises, so the role of technological innovation in promoting the transformation and upgrading of the manufacturing industry is further weakened.

When INER is in the low-intensity range, the regression coefficient of technological innovation to the green transformation of manufacturing is 0.217; when INER is between 0.0693 and 0.5255, the regression coefficient of technological innovation to the green transformation of the manufacturing industry is 0.236; When INER is greater than 0.5255, the regression coefficient of technological innovation on the green transformation of manufacturing is 0.200. This shows that with the increasing intensity of informal environmental regulation, the positive effect of technological innovation on the green transformation of manufacturing industry shows a trend of first increasing and then decreasing. The reason may be that under informal environmental regulation, the green consumer market has a good development prospect. In order to meet the needs of the green consumer market, enterprises will increase green technology innovation and green product development, but when informal environmental regulation crosses the second threshold At the same time, in order to deal with excessive public opinion pressure, enterprises will occupy too much of their own resources, which will reduce the investment in technological innovation, and the role of technological innovation in promoting the green transformation of manufacturing industry will decrease.

When CossER is in the low-intensity range, the regression coefficient of technological innovation to the green transformation of the manufacturing industry is 0.218; when CossER intensity is greater than 0.0986, the regression coefficient of technological innovation to the green transformation of the manufacturing industry is 0.206. This shows that the intensity of dual environmental regulation needs to be maintained within an appropriate intensity, so that the role of technological innovation in promoting the green transformation of manufacturing can be at a high level. Manufacturing enterprises are facing more and more stringent government system constraints and public opinion pressure. The focus of enterprises' resource allocation will gradually shift, and the core competitiveness of enterprises will be reduced, thus weakening the role of technological innovation in promoting the green transformation of manufacturing.

Table 3: Threshold model regression results.

Variable	*ER*	*INER*	*CossER*
GOV	1.686*** (4.32)	1.940*** (5.13)	1.502*** (3.82)
lnPGDP	0.575*** (5.97)	0.352*** (3.54)	0.521*** (5.39)
HUM	2.476*** (3.36)	3.356*** (4.76)	2.389*** (3.23)
ROAD	-0.012 (-0.07)	0.288 (1.78)	0.098 (0.60)
lnT(*ER*≤0.8900)	0.174*** (3.55)		
lnT(0.8900＜*ER*≤2.2261)	0.164*** (3.35)		
lnT(*ER*＞2.2261)	0.154*** (3.11)		
lnT(*INER*≤0.0693)		0.217*** (4.46)	
lnT(0.0693＜*INER*≤0.5255)		0.236*** (4.86)	
lnT(*INER*＞0.5255)		0.200*** (4.18)	
lnT(*CossER*≤0.0986)			0.218*** (4.47)
lnT(*CossER*＞0.0986)			0.206*** (4.22)
Constant	-8.482*** (-5.48)	-10.842*** (-7.31)	-9.697*** (-11.25)
N	300	300	300
F	74.76***	79.43***	86.93***

In order to verify the robustness of the above empirical results, this paper adopts the proxy variable of replacing technological innovation, which is different from the original index. Therefore, based on the perspective of innovation output, the number of manufacturing patents is selected as the proxy variable of technological innovation. Repeat the above steps to obtain the estimation results in Table 4 and Table 5. It can be seen from the estimation results in the observation table that they are basically consistent with the previous ones, so the research conclusions drawn are considered to be robust.

Table 4: Threshold effect test (robustness check).

Variab-le	Threshold	Thres-hold	*F*	*P*	Confide-nce interval
ER	single	0.5315	36.44***	0.000	[0.7888 ,0.9268]
	double	2.2261	23.86**	0.004	[2.1774 ,2.2486]
lnER	single	0.0693	34.35**	0.011	[0.0686 ,0.0699]
	double	0.5396	32.79*	0.094	[0.5307 ,0.5410]
Coss -ER	single	0.0986	51.80***	0.000	[0.0975 ,0.0988]
	double	0.2668	11.55*	0.080	[0.2386 ,0.2681]

Table 5: Threshold model regression results (robustness check).

Variable	*ER*	*INER*	*CossER*
lnT(*ER*≤ 0.5315)	0.103*** (2.78)		
lnT(0.5315＜ *ER*≤2.2261)	0.092*** (2.48)		
lnT(*ER*＞2.2261)	0.069* (1.87)		
lnT(*INER*≤ 0.0693)		0.046 (1.22)	
lnT(0.0693＜ *INER*≤0.5396)		0.080*** (2.13)	
lnT(*INER*＞0.5396)		0.031 (0.81)	
lnT(*CossER*≤0.0986)			0.125*** (3.34)
lnT(0.0986＜ *CossER*≤ 0.2668)			0.106*** (2.85)
lnT(*CossER* ＞0.2668)			0.095** (2.55)
Controls	Control	Control	Control
Constant term	-7.107***(-3.60)	-9.381*** (-4.78)	-6.433*** (-3.25)
N	300	300	300
F	73.61***	72.41***	74.28***

4 CONCLUSION AND SUGGESTION

This study analyzes the impact of technological innovation on green total factor productivity in manufacturing from the perspective of environmental regulation. According to the analysis of the above results: The role of technological innovation in promoting green transformation of manufacturing industry will weaken as the intensity of formal environmental regulation increases; As the intensity of informal environmental regulation increases, the impact of technological innovation on the green transformation of the manufacturing industry has a significant double threshold feature. When the informal environmental regulation is in the optimal range (0.0693 < INER ≤ 0.5255), technological innovation has a significant impact on the manufacturing industry. The promotion effect of green transition is higher than the other two intervals.

Based on the above analysis conclusions and in combination with the development background of information technology in China, suggestions are made for the green transformation of manufacturing industry:

Give full play to the advantages of information technology, formulate formal environmental regulatory policies reasonably, and strengthen the government's regulatory capacity while ensuring the mandatory force of formal environmental regulation.

Through Internet information technology, improve the public's awareness of environmental protection, increase the public's participation in the environmental supervision and governance system, ensure that the government, the public and enterprises cooperate with each other, and transform reasonable public demand for environmental protection into a driving force for enterprise technology innovation and green transformation of the manufacturing industry.

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