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Research on Environmental Regulation, Technological Innovation and Green Transformation of Manufacturing Industry in the Yangtze River Economic Belt

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Abstract: The green transformation of the manufacturing industry is crucial for high-quality development of the Yangtze River Economic Belt, and environmental regulation and technological innovation may play key roles. Considering the undesirable output of the manufacturing industry, this paper adopted the undesirable-SE-SBM Model to measure the green transformation efficiency, which can reflect the core transformation performance. On this basis, this paper respectively adopted system generalized method of moments (SYS-GMM) and differential generalized method of moments (DIF-GMM) to explore the driving factors of green transformation, which fully considered the lag variable of transformation efficiency. The estimated results of green transformation showed that the efficiency of the Yangtze River Economic Belt has maintained an overall growth trend, while that of the eastern regions was higher than that of the central and western regions. The regional difference of transformation efficiencies showed a trend of convergence first and then expansion, however, a few regions such as Chongqing have achieved leapfrog development. The estimated results of driving factors showed the first-stage lag affected the green transformation positively, while the second-stage lag had a significantly negative effect. The ratchet effect and cumulative effect led to the continued efforts on green transformation, however, the timeliness of policy might cause a rebound in practice. As mentioned in green paradox, the environmental regulation had a negative effect, which might bring compliance costs. The technology innovation level indeed promoted the green transformation of manufacturing, but the scientific research investment did not exert the expected positive effect, while the utilization of many research funds lacked market orientation. Economic development level had a negative effect on green transformation, and it would play a positive effect only if it reached a certain stage. The industrialization and urbanization affected the efficiency positively, and the external dependence degree had a significant negative effect. It was not clear whether foreign direct investment (FDI) brought a pollution haven or pollution halo effect. In view of these conclusions, local governments should strictly enforce environmental regulations, build the regional green innovation system, improve marketization of research funds, optimize the export structure, and promote new urbanization and new industrialization.

Keywords: green transformation of manufacturing industry; environmental regulation; SYS-GMM and DIF-GMM models; technological innovation; Yangtze River Economic Belt

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1. Introduction

As the largest inland river economic belt in the world, the Yangtze River Economic Belt carried 43% of China's population and 46.4% of GDP in 2019. Ecological development and green priority have become the basic criteria for the high-quality development of the

Yangtze River Economic Belt. In 2019, China's GDP energy consumption per 10,000 yuan was 0.49 tons of standard coal, much higher than developed countries such as the United States. According to the BP statistical yearbook of world energy, China's total primary energy consumption was 1.5 times that of the United States in 2019, while China's gross domestic product was only 67.2% that of the US in the same period. According to the report by Rhodium Group consulting firm, China's greenhouse gas emissions reached 14.093 billion tons of carbon dioxide equivalent in 2019. The Yangtze River Economic Belt is the economic corridor with the highest density in China, with five worldwide manufacturing clusters, such as electronic information, high-end equipment, automobiles, household appliances, textiles, and clothing. The spatial agglomeration of the manufacturing industry in the Yangtze River Economic Belt also brings about the problems of excessive consumption of water resources and water pollution [1]. The proportion of sections with good water quality was only 74.9% in the 1940 national surface water assessment, while these regions of Yangtze River Economic Belt discharged 42.75% of China's total sewage. Since the economic reform and opening more than 40 years ago, developed countries have transferred resource-intensive and pollution-intensive industries to developing countries. The Yangtze River Economic Belt has also partly been served as a pollution haven for developed industrial countries, with the rapid development of the manufacturing industry. The per capita GDP of Yangtze River Economic Belt exceeded 11 thousand dollars in 2019, which meant it was reaching the income level of a moderately developed country. Green transformation and upgrading of the manufacturing industry have become the primary task for the high-quality development of Yangtze River Economic Belt. It is necessary to explore this green transformation of the manufacturing industry considering the perspective of environmental regulation and technological innovation.

In the 1990s, scholars proposed the Environmental Kuznets Curve, pointing out the inverted U-shaped relationship between environmental quality and economic development level, and many studies have confirmed that the environmental regulation will be gradually promoted [2,3]. Environmental regulation usually includes command, market, and voluntary policy tools, which would be designed to solve the problem of environmental externalities and to protect the ecological environment [4]. Experts also proposed the cross-country pollution transfer, which was named the hypothesis of pollution haven by Copeland and Taylor (1994), and the research began to focus on the transfer of polluting industries within the country [5,6]. Ding (2019) adopted the threshold model to examine the nonlinear relationship between environmental regulation and water utilization efficiency and revealed the possible water pollution transfer in the Yangtze River Economic Belt [7]. Many experts have explored some typical environmental problems in the river economic belt. Ingold K. (2021) explored the matching degree of physical affectedness and regulatory embeddedness in drinking water supply along Rhine River [8], and Barbosa CCD. (2016) explored the tragedy of the commons in resource exploitation and ecosystem service depletion in the Amazon estuary [9]. Some experts also tried to verify the effectiveness of environmental regulations, while the green paradox implied the promotion of environmental regulation may not achieve the original intention of policymaking [10,11]. However, many experts said it depended on different countries' situations. Gronwald M. (2017) analyzed two popular second-best clean energy policies, and experiences from various European countries showed that the further expansion of climate-friendly technology applications faced substantial technological as well as political constraints [12]. On the other hand, the competition forms of environmental regulation can be divided into two types which were named as "race to the bottom" and "race to the top" [13]. The role of environmental regulation is unclear in some specific areas. Tsurumi T. (2015) insisted that stringent environmental regulations were generally thought to harm export flows, while the overall effect of appropriate regulation benefited trade flows [14]. Therefore, it is necessary to explore the role of environmental regulations on the ecological efficiency of the Yangtze River Economic Belt.

According to the traditional view of neoclassicism, although environmental regulation helps to control and solve the problem of environmental pollution, it is bound to increase enterprise production costs and squeeze profit space, thus hindering technological innovation and green transformation in the manufacturing industry [15]. However, some experts have proposed and supported the Porter hypothesis that after the 1990s, strict environmental regulations should force enterprises to save energy and reduce emissions, which would stimulate the compensation effect of innovation to offset the cost of enterprise compliance [16,17]. Scholars have done a lot of empirical tests on the relationship between environmental regulation and technological innovation. Klemetsen M.E. (2018) adopted a rich Norwegian dataset to analyze the effects of direct regulations on environmental patenting [18], and Hu D.X. (2021) studied the impacts of the global value chain position on green technology innovation in the context of environmental regulation [19]. Some experts also discussed the effectiveness of environmental policy tools for renewable energy technologies. Hille E. (2020) adopted policy and patent data in 194 countries to examine how different renewable energy support policies affect innovation in solar and wind power technologies [20]. In order to make up for the defect that empirical analyses rarely distinguished between different areas of the environment, Horbach J. (2012) adopted a new unique dataset from the German Community Innovation Survey to test whether different types of eco-innovation were driven by different factors [21]. In addition, as mentioned in the pollution halo theory, transfer enterprises can spread more green and cleaner production technologies to the receiving areas, and whether the technology is relatively green or not also depends on local production levels and the economic development stage [22]. This paper will comprehensively consider the water resources and energy consumption in the manufacturing process, changing the previous practice of only adopting single environmental factors. Considering all kinds of undesirable outputs, this paper measured the green efficiency of the manufacturing industry and grasped the spatial differentiation law of manufacturing industry transformation in the Yangtze River Economic Belt. In order to clarify the driving factors of ecological efficiency, this paper adopted a dynamic regression model to test the driving effect of environmental regulation and technological innovation on the transformation of the manufacturing industry, considering the lag effect and cumulative effect of ecological efficiency. Finally, it provided suggestions for high-quality green development of the manufacturing industry in the Yangtze River Economic Belt.

2. Model Construction

2.1. Undesirable-SE-SBM Model

The data envelopment analysis (DEA) was built by Charnes, Cooper and Rhodes in 1978, the first DEA model was named CCR model, and then basic models such as BCC and FDH were developed [23]. It is a non-parametric technical analysis of the relative comparison between the evaluated objects, which would avoid the miscalculation risk caused by these models of pre-set basic form [24]. Tone (2001) proposed the SBM (slack-based measure) model, and then the super efficiency model was proposed by Andersen (1993) to solve the problem that multiple DMUs cannot be further distinguished [25,26]. Due to the manufacturing industry wasting water and gas and creating other bad outputs, the undesirable output model should be more appropriate to measure real efficiency. Reducing resource consumption and pollution should be as important as industrial growth. The undesirable-SE-SBM model can perfectly solve these problems above and was adopted by many scholars in measuring the eco-environmental efficiency [7,27]. Iftikhar Y. (2016) adopted this non-parametric analysis to measure energy and CO_2 emission efficiency of major economies, and Yan D. (2019) adopted this method to account for the total-factor energy efficiency of 104 resource-based cities [28,29]. In Formula (1), the production system has n decision-making units, m kinds of inputs defined as x, s_1 kinds of expected outputs defined as y^g, s_2 kinds of expected outputs defined as y^b. The matrix is defined, such as $X = [x_1, x_2, \cdots x_n]$, $Y^g = \left[y_1^g, y_2^g, \cdots y_n^g\right]$, $Y^b = \left[y_1^b, y_2^b, \cdots y_n^b\right]$. s is the relaxation variable of input and output, and the objective function ρ is about s^{-}, s^{b} and s^{g}. The DMU is valid if and only if its value is 1.

$$\begin{gathered} \min\rho = \frac{1+1/m\sum s_i^{-}/x_{ik}}{1-(\sum s_r^{+}/y_{rk}+\sum s_t^{b-}/b_{rk})/(q_1+q_2)} \\ S.t.\sum x_{ij}\lambda_j - s_i^{-} \leq x_{ik}\sum y_{rj}\lambda_j + s_r^{+} \geq y_{rk}\sum b_{ij}\lambda_j - s_t^{b-} \leq b_{ik} \\ 1-(\sum s_r^{+}/y_{rk}+\sum s_t^{b-}/b_{rk}) > 0\,,\ \lambda \geq 0\,,\ s^{-} \geq 0\,,\ s^{+} \geq 0 \\ i = 1,2,\cdots,m\,;\ r = 1,2,\cdots,q\,;\ j = 1,2,\cdots,n\,;\ j \neq k \end{gathered} \tag{1}$$

2.2. Dynamic Panel Regression Model

Many scholars have explored the driving factors of green transformation of manufacturing, using the Tobit model, threshold model, and other regression models to propel the empirical process [30,31]. This paper focused on exploring the green transformation of the manufacturing industry from the perspective of environmental regulation and technological innovation and adopted the green transformation efficiency as the explained variable from 2005 to 2017. However, many experts have insisted that the efficiency would be affected by the previous efficiency of green transformation, while the current behavior may depend on the past behavior under economic and social inertia [32]. Therefore, it is necessary to adopt the dynamic panel model to estimate the lag term of the green transformation efficiency. In empirical studies of the dynamic panel model, many scholars adopted the differential generalized method of moments (DIF-GMM) model by Arellano (1991), while others adopted the system generalized method of moments (SYS-GMM) model by Blundell (1998) [33]. The DIF-GMM method uses all the possible lag variables as tool variables to effectively solve the problems of inconsistency of estimators and measurement errors, while the disturbance term does not have autocorrelation [34]. The SYS-GMM model can improve the limited sample size of the DIF-GMM model and promote the estimation efficiency of the dynamic panel model, which requires uncorrelated between-difference terms and individual effects [35]. Bashir M.A. (2020) adopted the system GMM and difference GMM to explore the important contributors of energy efficiency in OECD countries, and Berk I. (2020) employed the System Generalized Method of Moments to investigate whether the contribution of renewable energy sources to primary energy consumption was characterized by a convergence across core EU countries [36,37]. The Formula (2) is a general dynamic panel model, while Formulas (3) and (4) respectively represent the first-order DIF-GMM model and the SYS-GMM model. The DIF-GMM and SYS-GMM models are used to estimate the driving factors. On the basis of various tests and model estimation results, a specific dynamic panel model is selected. Considering the empirical literature of previous studies, the horizontal GMM model was no longer considered for this study.

$$y_{it} = \alpha + \rho y_{i,t-1} + x_{it}'\beta + z_i'\delta + u_i + \varepsilon_{it} \tag{2}$$

$$\Delta y_{it} = \rho\Delta y_{i,t-1} + \Delta x_{it}'\beta + \Delta\varepsilon_{it} \tag{3}$$

$$y_{it} = \alpha + \rho_1 y_{i,t-1} + \rho_2 y_{i,t-2} + \cdots + \rho_p y_{i,t-p} + x_{it}' + z_i'\delta + u_i + \varepsilon_{it} \tag{4}$$

3. Measurement of Green Transformation of Manufacturing Industry

3.1. Index Selection and Efficiency Measurement

In order to figure out the relationship between environmental regulation, technical innovation, and green manufacturing transformation, this study first tried to measure green transformation of the manufacturing industry. Many scholars have used a single indicator or complex indicators to represent the transition process, and some manufacturing green evaluation systems covering three levels of indicators have been constructed, while some core indicators such as emission intensity of sulfur dioxide were directly regarded as the green transformation level [38]. This study decided to adopt the undesirable-SE-SBM to measure the green manufacturing transformation, which can consider the undesirable output, the effective decision unit differentiation, and the slack variables. Considering the inherent requirement of green development in manufacturing production, capital, labor, water, and energy were selected as input variables; industrial added value was selected as desirable output variable; and industrial wastewater, sulfur dioxide, and solid waste were selected as undesirable output variables [39]. This paper did not select dozens of indicators as other empirical studies have, but rather selected some core variables to measure the transformation efficiency which would highlight the green production capacity. Due to the limitations of data collection, this study selected the sulfur dioxide as an alternative indicator of industrial emissions, which local governments tried to cut down. This paper selects the fixed assets of the secondary industry as a labor input index and the number of employees in the secondary industry as another labor input index. The data of input and output are from the China Statistical Yearbook, China Environmental Statistics Yearbook, China Industrial Statistics Yearbook, etc. The weight ratio of the desirable output and undesirable output was 1:1, and the weight proportion of three kinds of undesirable outputs was one third, respectively. The process of efficiency measurement was realized by Maxdea Pro software. The specific measurement results are shown in Table 1.

Table 1. Estimating results of green transformation efficiency of manufacturing industry in Yangtze River Economic Belt from 2005 to 2017.

Area	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Shanghai	0.38	0.42	0.45	0.46	0.43	0.51	0.57	0.59	0.59	0.64	0.67	0.75	1.64
Jiangsu	0.23	0.26	0.28	0.31	0.33	0.38	0.43	0.45	0.46	0.47	0.49	0.53	1.00
Zhejiang	0.32	0.35	0.41	0.49	0.51	0.58	1.00	0.67	0.72	0.73	0.75	1.00	1.11
Anhui	0.14	0.14	0.15	0.17	0.18	0.24	0.30	0.32	0.35	0.38	0.36	0.40	0.45
Jiangxi	0.15	0.17	0.18	0.20	0.22	0.28	0.33	0.35	0.38	0.39	0.38	0.40	0.45
Hubei	0.16	0.17	0.18	0.21	0.23	0.27	0.32	0.35	0.41	0.45	0.47	0.54	0.75
Hunan	0.15	0.17	0.19	0.22	0.22	0.27	0.33	0.35	0.38	0.45	0.46	0.51	1.03
Chongqing	0.15	0.16	0.18	0.20	0.27	0.32	0.39	0.43	0.43	0.45	0.52	0.72	1.12
Sichuan	0.16	0.18	0.20	0.24	0.25	0.31	0.40	0.48	0.52	0.58	0.50	0.55	0.60
Guizhou	0.13	0.14	0.15	0.18	0.16	0.19	0.21	0.23	0.31	0.34	0.37	0.43	0.57
Yunnan	0.19	0.21	0.23	0.26	0.25	0.28	0.31	0.33	0.37	0.40	0.41	0.43	0.45
AVG	0.20	0.21	0.23	0.27	0.28	0.33	0.42	0.41	0.45	0.48	0.49	0.57	0.83
CV	0.40	0.41	0.41	0.39	0.36	0.34	0.49	0.30	0.25	0.24	0.24	0.31	0.43

3.2. Analysis of Green Transformation Efficiency of Manufacturing Industry

From the overall development trend of green transformation, the efficiency of Yangtze River Economic Belt showed an overall upward trend, which also implied great environmental governance achievements after 2005. The hidden ecological environmental problems behind China's manufacturing power have been getting more and more attention from governments and scholars, therefore the Strictest Water Resources Management System and Blue-Sky Protection Campaign were introduced one after another [40]. With the rapid economic development, central and local governments should be more willing and able to reduce resource consumption and pollution emissions to achieve an economic development and ecological environment win-win [41]. However, the average efficiency of green transformation increased from 0.20 to 0.83 during the study period. The total energy consumption only increased by 57.5% and the total industrial emissions decreased by 48.5%, while the industrial added value nearly quadrupled. Especially in the year of 2017, the efficiency of green transformation significantly improved in each study area, which may be related to the double control actions of the total consumption and intensity of energy, water resources, and construction land. Relative to other areas in China, high-quality development of Yangtze River Economic Belt required ecological and environmental priority, and a green manufacturing system has been gradually established [42,43]. In addition, the improvement of green transformation efficiency was inseparable from the progress of energy conservation and emission reduction technology, the enhancement of ecological and environmental protection awareness, and the transformation of economic growth mode from extensive to intensive.

From the spatial differentiation of manufacturing transformation, the eastern regions were significantly higher than the central and western regions, but Chongqing and Hunan achieved leapfrog development in green transformation. Jiangsu, Zhejiang, and Shanghai were China's most economically developed eastern coastal regions. The efficiency levels of these regions were significantly higher than other regions in 2005, and efficiency values of these regions were greater than one in 2017. As mentioned, in the Environmental Kuznets Curve Theory, environmental quality will be improved only when the economic development reaches a certain stage, however, these regions of Yangtze River Economic Belt were at different development stages in the period [44]. The labor intensive and capital processing industries are moving to the upper and middle streams, so eastern coastal areas are more inclined towards technological innovation industries which will consume less resources and produce less pollution [45]. Although major differences exist in green development among different regions, individual regions such as Chongqing city have already included the environmental protection industry in its top ten strategic emerging industries. The downstream region is the core driving force for the green transformation of manufacturing in Yangtze River Economic Belt, while Changsha-Zhuzhou-Xiangtan city group and Wuhan metropolitan area are leading the central region in the green manufacturing transformation. Anhui and Jiangxi province have become subsidence areas of green transformation, and the efficiency values were even lower than Sichuan and Guizhou in the western region. On the one hand, the economic development of these provinces was relatively backward, so the government and enterprise could not put forward enough money for pollution governance and industrial upgrading [46]. On the other hand, these provinces have become a pollution haven for nearby developed provinces, and the local governments loosened environmental enforcement standards for the economic growth need.

From the regional convergence of manufacturing green transformation, the difference of efficiency values had a U-shaped trend, narrowing first and then expanding, and the turning point came in the year 2015. Although there were significant differences in green development in the manufacturing industry, the spillover effect of green transformation has been proved by many experts, which can be spread by the talent flow, technology sharing, and industrial relocation [47]. The coordinated development of Yangtze River Economic Belt will undoubtedly accelerate the convergence of green innovation, but this spatial overflow also decreases with the increasing distance. However, with green transformation and stricter environmental regulations, some high energy-water consumption and high pollution-discharge enterprises will be transferred to relatively underdeveloped areas, which has been performed many times in developed industrial countries [48]. Especially in the year 2017, the green transformation efficiency of Shanghai was three times more than that of Anhui, Jiangxi, and Yunnan, however, the most central and western provinces relaxed the implementation standards of environmental regulations, which was also unavoidable in the manufacturing development process. The pollution effect of interregional industrial transfer is closely related to government policy, and the "race to the bottom" will partly help the economic growth and official promotion [49]. Some scholars put forward different views; compared with the original industries in the backward areas, the transfer pollution industries may also bring relatively cleaner production technology, to some degree.

4. Analysis on Driving Factors of Green Transformation of Manufacturing Industry

4.1. Index Selection and Driving Estimation

As discussed in the above sections, the green transformation efficiency of manufacturing was selected as the explained variable, while the environmental regulation and technological innovation were regarded as the core explanatory variables. Economic development level, industrial structure, foreign direct investment (FDI), urbanization level, and external dependence degree were selected as control variables, which will be described below. Unlike other empirical studies, this paper measured technological innovation in terms of capital input and patent output, which more comprehensively reflect the willingness and ability of technological innovation. Chrisman J.J. (2015) also explored the innovation management based on ability (discretion to act) and willingness (disposition to act) as two drivers, and Campopiano G (2021) also discussed the circumstances under which social innovation unfolded based on a willingness–ability paradigm [50,51]. This paper selected the number of patents granted per 10,000 people to represent the technological innovation level, which generally reflects the improvement of energy conservation, emission reduction, and production efficiency. On the other hand, the proportion of internal R&D expenditure in regional GDP was selected as the technological innovation investment, which represents the efforts made for technological innovation [52]. There have been many measurement methods for environmental regulation in related research, such as the single index method and composite index method. This paper selected the proportion of industrial pollution control investment in industrial added value as the regional environmental regulation level, which measures the environmental regulation effort from the perspective of economic expenditure [53]. The different types of environmental regulation are discussed in many studies, but these data are not easily collected and quantified and are relatively unreliable according to some scholars.

The paper will introduce the selection of each control variable as follows. Firstly, the paper selected the natural logarithm of per capita GDP to represent the regional economic development level. As mentioned in the above analysis, the ecological environment would be improved with certain economic development, which has been elaborated in the Environmental Kuznets Curve Theory [54]. Secondly, the paper selected the proportion of urban population as the urbanization level, and many studies have confirmed the positive relationship between urbanization and manufacturing agglomeration [55]. In terms of local development strategies, green industrialization and green urbanization have become two wheels driving for regional sustainable development. Thirdly, the proportion of added value of the secondary industry was adopted to represent the industrialization level, which meant the position of the manufacturing industry and industrial structure, while green transformation of manufacturing industry itself should be an advanced stage of industrialization [56]. Fourthly, the paper selected the proportion of total registered investment of foreign-funded enterprises in GDP to represent the foreign direct investment level, which needed to be verified for green production technology spillover or pollution industry transfer [57]. This paper also selected the proportion of the total import and export value to the regional GDP as the external dependence level to represent the openness. The foreign trade of export orientation has guided manufacturing for decades, which would bring out another form of potential pollution transfer.

The relevant data of explanatory variables and control variables are mainly from the China Statistical Yearbook, China Energy Statistical Yearbook, and China Science and Technology Statistical Yearbook from 2006 to 2018. The explained variables are from Table 1, which are the measurement results of green transformation efficiency of the manufacturing industry by SE-SBM. In order to explore the driving factors, this paper decided to respectively adopt the DIF-GMM and the SYS-GMM to verify the relationship between environmental regulation, technological innovation, and green transformation efficiency of the manufacturing industry. As seen in Table 2, the estimation results of SYS-GMM were more significant than those of DIF-GMM, and the estimation of SYS-GMM passed the correlation test of the un-autocorrelation of the disturbance term, therefore this paper decided to adopt the regression results of SYS-GMM. In general, both the first-stage and second-stage lags of green transformation efficiency passed the significance test, which also confirmed the correctness of the dynamic panel regression model adopted [58]. In terms of core explanatory variables, the environmental regulations had a significant negative effect on the green transformation of manufacturing, which was unexpectedly contrary to the hypothesis, but the technological innovation had a significant positive effect. In terms of control variables, the economic development level, urbanization level, and external dependence passed the significance test, while the level of industrialization and FDI did not pass the significance test.

Table 2. The estimation results of green transformation of the manufacturing industry in Yangtze River Economic Belt.

Variable	Estimated Coefficient	Z Value	p Value	Estimated Coefficient	Z Value	p Value
	DIF-GMM			SYS-GMM		
The first-stage lag	−12.6607	−2.07	0.038	24.6673	2.16	0.031
The second-stage lag	−16.2509	−2.17	0.030	−11.9834	−1.70	0.088
Environmental regulation	−654.5167	−2.20	0.028	−541.6738	−2.16	0.031
Technological innovation	0.0340	2.13	0.033	0.0886	2.01	0.044
R&D investment	1453.45	2.17	0.030	−2615.665	−2.18	0.029
Economic development	0.2783	0.24	0.808	−12.6374	−1.94	0.052
Urbanization	17.0346	1.52	0.128	178.8834	2.05	0.041
Industrialization	−6.4836	−1.10	0.270	30.9842	1.64	0.101
FDI	2.4152	2.70	0.007	0.0909	0.14	0.891
External dependence	12.7796	2.23	0.026	−21.9789	−1.86	0.063
Cons	−28.0300	−2.24	0.025	67.0775	1.98	0.047

4.2. Estimation Discussion of Transformation Efficiency

First, as mentioned in the above paragraph, the first-stage lag of manufacturing green transformation efficiency was significantly positive, while the second-stage lag was significantly negative, the extent of which was weaker than the first-stage lag. On the one hand, the green transformation has a certain demonstration and ratchet effect: the green manufacturing system established would continue to work for one period, so promoting the green transformation of manufacturing should be a long-term job [59]. On the other hand, the lag effect diminishes as time goes on, and to some extent, there is even a rebound effect, which is closely related to local policies. In other words, when the central government formulated the relevant green policies, local governments initially enforced these policies strictly, but the execution would be weakened after a period of time [60]. As seen in Table 1, the green transformation efficiency of the manufacturing industry has been wholly improving, however, the green transformation efficiency of some regions decreased slightly over a few years. Wu H.T. (2020) proposed that environmental supervision and environmental monitoring decentralization had negative impacts on regional green development, which was also named the “race to the bottom” effect [61]. Of course, whether green transformation of the manufacturing industry would be effectively and sustainably carried out would depend on the policies’ environment. In general, local governments should maintain consistency in policymaking for the positive effects of green transformation.

Second, environmental regulation was significantly negative on the green transformation of the manufacturing industry, which might not be in line with what most readers expect. Many scholars have confirmed the green paradox: good intentions do not always bring good results, so environmental regulation sometimes does not necessarily drive a green shift in manufacturing [62]. As is known to all, environmental regulation can undoubtedly force transformation and upgrading of the manufacturing industry, which also can prevent the landing and expansion of polluting industries [63]. However, the compliance costs of environmental regulation inversely increase pollution control costs of manufacturing enterprises, which is not conducive for the improvement of enterprise R&D and production efficiency [64]. On the other hand, the stricter environmental regulations push polluting industries to the suburbs or some small cities, which does not promote the green upgrading of manufacturing across the whole region [65]. Many empirical studies have confirmed the “Pollution Haven Hypothesis” across world and in China. Bulus G.C. (2021) indicated that the PHH was established in South Korea to a medium extent, and Liu Y.J. (2019) proposed that industrial transfer would have a significant accelerating effect on haze pollution in the transferred-in areas, therefore the environmental regulation did not achieve the desired effects [66,67]. Compared with command control environmental tools, many studies proposed that the market incentive tools and public participation tools should be more effective, which has been applied in environmental governance practice. The market trading of emission rights was introduced in water governance in the Xin'an River Basin, and Shandong and Henan provinces have been betting against each other on the quality of Yellow River [68,69]. In general, the governments should consider the effects of industrial transfer by these regulations and should strictly enforce environmental regulations and reasonably select environmental policy tools.

Third, technological innovation of the patent ownership level had a significantly positive effect on the green transformation of the manufacturing industry, while R&D investment level did not show a theoretically positive effect. Technological innovation can raise economic output levels, promote energy conservation and emission reduction, and improve manufacturing industrial structure, which is helpful for the green transformation [70]. Furthermore, revolutionary technological innovations would change the whole way of production and create new manufacturing industries, especially with the green innovation technology applied to each link of traditional industries [71]. Ali S.A. (2021) confirmed that productive expenditures on R&D for clean technological innovation could simultaneously enhance economic growth and improve environmental conditions in G7 countries, and Wang K.H. (2021) adopted the evidence of China's changing growth story to confirm that technological innovation had been making the world greener [72,73]. However, as can be seen in Table 2, the large amount of investment for R&D funding has not brought about corresponding and continuous promotion of technological innovation capabilities. Almost invariably, the government appropriations such as scientific research funds in colleges were wasteful and redundant in China, and the market conversion rate of these scientific results was relatively lower [74]. Gao P. (2015) adopted the China's case of administrative intervention to explore the important indispensable role of government in the catching-up of technology innovation [75]. Many experts have suggested that the regional green technology innovation system should be established, which would require more research funds to be put into energy conservation and emission reduction, while the current technological innovation is oriented by increasing GDP [76]. In general, innovation networks of green development should be established, transformation of technological innovations should be promoted, and technological innovation funds should be reasonably utilized.

Fourth, the economic development level had a negative effect on the green transformation of the manufacturing industry, which may be inconsistent with the public perception but proved the existence of the Environmental Kuznets Curve. Many empirical studies have confirmed that only when economic development has reached a certain stage will the developed regions be able to invest more resources and energy in environmental governance [77]. Therefore, in the whole research period from 2005 to 2017, most samples were lower than the development stage threshold, however, only the per capita GDP of Jiangsu, Zhejiang, and Shanghai region exceeded 1000 dollars. Alam M.M. (2016) proposed that an increase in income over time would not always reduce CO_2 emissions in developing countries, and Ben Jebli M. (2016) also confirmed the inverted U-shaped Environmental Kuznets Curve hypothesis for the sample of OECD countries [78,79]. Economic growth and official promotion in developing regions always include a more-or-less tendency to loosen environmental regulations. In general, the developing regions should avoid taking the road of pollution first and treatment later, instead choosing to take the road of new industrialization and appropriate industrial relocation from the eastern coastal areas.

Fifth, the urbanization had a significantly positive effect on the green transformation of the manufacturing industry, and the industrialization reluctantly passed the positive significance test, while the process of industrialization and urbanization was basically consistent. The urbanization should be a process of gathering non-agricultural industries and should be the aggregation process of innovative talents and advanced resources. The new-type urbanization has paid more attention to low carbonization and intensification, and the requirements for environmental quality and ecological protection have been higher and stricter [80,81]. However, the green transformation of the manufacturing industry has already been the future development direction of industrialization, while higher eco-efficiency enterprises have been replaced with lower eco-efficiency enterprises [82]. Of course, the blind urbanization has occurred in some regions while the industrialization in some areas was still in its infancy, undertaking a large number of eliminated industries. Some scholars put forward different views. Sadorsky P (2014) explored how urbanization decreased energy consumption while industrialization increased energy consumption in emerging economies [83]. In general, new urbanization and new industrialization should be promoted in coordination, and the concept of green development should be embedded in urbanization and industrialization.

Sixth, the external dependence degree had a significantly negative effect on green transformation of the manufacturing industry, while FDI agglomeration did not have significant positive or negative effects. During the decades of reform and opening, China acted as the manufacturing workshop of world and exported many dirty products to developed countries [84]. Many studies have explored the export of pollution. Barrows G. (2021) proposed that foreign demand growth increased growth in CO_2 emissions at the firm level via output growth, while wealthy countries have relied increasingly on imports from developing countries [85]. In addition, the environmental problems caused by the cross-border transfer of FDI have already aroused widespread concern, but the debate about pollution haven or pollution halo has not stopped [86]. For developing countries, Mert M. (2020) adopted hidden co-integration techniques to test the asymmetric pollution haven and asymmetric pollution halo hypotheses, and showed that increases in FDI led to a decrease in the rate of emission growth [87]. There were significant differences in manufacturing structure and regional development of Yangtze River Economic Belt, so FDI played an unclear role on green transformation of the manufacturing industry. In general, the policymakers should promote the export structure optimizing, make full use of both international and domestic markets, and improve access standards for the foreign direct investment.

Considering the important role of environmental regulation and technological innovation, this paper separately adopted DIF-GMM and SYS-GMM models to examine how these factors affected the green transformation efficiency, in which the lagged variable of transformation efficiency was taken into account. This paper firstly adopted the undesirable-SE-SBM Model to measure its green transformation efficiency, in which the outputs of industrial wastewater, SO_2, and solid waste were fully considered and all the valid decision units were further distinguished. As seen in the estimation results of green transformation in the manufacturing industry, the whole efficiency presented a continuous upward trend, however, the eastern regions were significantly higher than the central and western regions. A few regions also achieved leapfrog development, while the regional differences showed a trend of narrowing first and then expanding. After the in-depth comparison and inspection, we think the SYS-GMM model was more appropriate than the DIF-GMM model for estimating which factors affected the green transformation efficiency.

As can be seen in the driving factors estimation, the following findings could be drawn from this paper. The first-stage lag variable was significantly positive, while the second-stage lag was significantly negative. The efficiency of green transformation can indeed be transmitted vertically, which is caused by an accumulative effect, ratchet effect, and demonstration effect, but the effect would be diminished or reversed for policy timeliness. The environmental regulation had a negative effect on green transformation, however, these regulations caused compliance costs and crowded out the innovation resources, which is explained by the "Green Paradox" theory. The technological innovation of patent ownership had a significant positive effect which greatly improved the production efficiency and reduced resource consumption. However, R&D investment level had a negative effect, which might be caused by the huge waste and low application of research funds. On the other hand, in many manufacturing sectors, technology research and development activities might not be green innovation-oriented. The economic development level also implied the difference of environmental governance at different stages of development, which was mentioned in the Environment Kuznets Curve. The external dependence degree had a significant negative effect caused by the export-oriented economy of high cost and high pollution. The effect of FDI has not been clear regarding a pollution haven or pollution halo, while there were already many regional differences in how FDI was treated by local governments. The industrialization and urbanization affected green transformation positively, and the development direction of these process is consistent with greenization.

This paper proposed that policymakers should adopt the following recommendations to promote green transformation of the manufacturing industry. First, green transformation policies should be maintained continuously, and a national green manufacturing system should be established. Second, environmental regulations should be strictly enforced by local governments, and various environmental governance policy tools should be adopted in a reasonable combination innovation. Third, technological innovation should be promoted to enhance the endogenous impetus of green manufacturing development, and local governments should promote the green innovation system and industrial application. Fourth, FDI should be directed to high-tech industries to avoid becoming a pollution haven for developed countries; export structure and quality should be improved; and the new pattern of a dual cycle should be promoted emphatically. Fifth, new industrialization and new urbanization should be unswervingly promoted, while traditional manufacturing industries causing excessive resources consumption and pollution emissions should be discouraged. Sixth, the promotion pattern of local officials with GDP growth should be changed, which will help avoid the cross-regional transfer of polluting industries in the Yangtze River Economic Belt.

However, we recognize that this paper has some shortcomings, which will be the focus of future research direction. For some indicators there were no public data at the provincial level, therefore only a few proxy indicators were used. For example, only SO_2 was considered in the undesirable output of the manufacturing industry, while the industrial waste gas contained many pollutants. The paper also only adopted the single indicator to represent environmental regulation intensity, however, environmental regulation can be divided into command control tools, market incentive tools, and public participation tools. We explored how different types of environmental regulations affected industries' green transformation, however, we will properly quantify these environmental policy tools first in a future study. The green technological innovation should also be distinguished from technological innovation, which is oriented to improving production efficiency, and will be another topic worth exploring.

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