The Impact of China's Environmental Regulation on Total Factor Productivity of Pharmaceutical Manufacturing Industry: An Analysis Based on the Spatial Spillover Effect

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The Impact of China's Environmental Regulation on Total Factor Productivity of Pharmaceutical Manufacturing Industry: An Analysis Based on the Spatial Spillover Effect

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Abstract

As an important embodiment of a country's economic strength and national health, pharmaceutical manufacturing industry has made rapid development in China in recent years. But at the same time, the pharmaceutical manufacturing industry is facing many environmental problems, such as large pollution emissions, complex pollution components, controlling difficulties and so on. This paper measures the total factor productivity of pharmaceutical manufacturing industry (HTFP) by using data envelopment analysis (DEA), and studies the effect of environmental regulation (ERI) on the total factor productivity of pharmaceutical manufacturing industry (HTFP) by establishing panel data regression model and spatial econometric model based on 30 provinces in China from 2004 to 2019. The conclusions are as follows: (1) Environmental regulation and total factor productivity of pharmaceutical manufacturing industry have significant spatial autocorrelation, showing "high-high" or "low-low" spatial aggregation characteristics; (2) Environmental regulation has a significant promoting effect on improving HTFP in local and surrounding areas, and there are differences in the impact of eastern, central and western regions; (3) Green technology, production technology and industrial structure play an important role in the impact of ERI on HTFP, which provides theoretical guidance and policy recommendations for improving the level of total factor productivity of pharmaceutical manufacturing industry in the environmental aspect.

Keywords: Environmental regulation; Total factor productivity of pharmaceutical manufacturing industry; Spatial spillover effect; Data envelopment analysis

1 Introduction and Literature Review

Pharmaceutical manufacturing industry is one of the high-tech industries, which only reflects the national economic strength, but also closely related to the health level of the people [1, 2]. In early 2020, the COVID-19 swept across the world, which once again proved the importance of the development of pharmaceutical manufacturing industry [3]. In recent years, China's pharmaceutical manufacturing industry has made rapid development, with the total profit of China's pharmaceutical manufacturing industry reaching 369.3 billion yuan in 2020, an increase of 341.8 billion yuan compared with 2004. It has achieved nearly 13 times growth (*Statistical Yearbook of China's High-tech Industry*, 2005-2021). However, it cannot be ignored that the pharmaceutical manufacturing industry is facing serious pollution problems while giving full play to the advantages of knowledge-intensive and advanced technology. The pollution problems such as large pollution emissions, complex pollution components, are difficult to degrade and harmful to organisms, which are serious for environment [4]. Therefore, environmental regulation is very important to effectively alleviate the pollution problem of pharmaceutical manufacturing industry, which is promoting the sustainable development of pharmaceutical manufacturing industry.

In the field of pharmaceutical manufacturing industry, most scholars focus on the research of high-tech industry as a whole, but less on the research of pharmaceutical manufacturing industry in the field of high-tech industry [5, 6]. Moreover, for the efficiency of pharmaceutical manufacturing industry, most scholars focus on innovation efficiency [2], investment efficiency [7, 8] and enterprise management efficiency [9, 10], but there is less research on the environment of pharmaceutical manufacturing industry. Pda et al.(2019) believed that the pharmaceutical manufacturing industry is an important driving force for modernization, and innovative production technology helps to prevent the shortage of drugs in recent years [11]. Shi(2019) studied the diversified agglomeration, specialized agglomeration and innovation efficiency of pharmaceutical manufacturing industry, and concluded that diversified agglomeration can significantly improve the innovation efficiency of pharmaceutical manufacturing industry. Specialized agglomeration is not conducive to the improvement of innovation efficiency of pharmaceutical manufacturing industry [12]. Li and Liu (2019) used the super-SBM model to measure the impact of relevant incentive policies on the innovation efficiency of high-end manufacturing industry in China from 2012 to 2017 [13]. Cheng(2020) studied the energy saving potential of manufacturing industry in Jiangsu Province of China, and used the multiple linear regression model with risk analysis to study the impact of technical factors on energy saving potential and manufacturing transformation and upgrading [14].

In the field of environmental regulation, scholars have carried out extensive and in-depth research, scholars based on different perspectives or with different research methods come to conclusions are also widely divergent. Wang et al.(2021) studied the impact of environmental regulation on the spatial spillover effect of regional innovation, and concluded that innovation output, environmental regulation and R&D internal expenditure are innovation spillovers [15]. Pan et al.(2021) studied the impact of environmental regulatory policy on cleaner production technology innovation, and used regional pollution intensity and R&D investment scale explain the heterogeneity effect between them [16]. Based on the panel data of manufacturing enterprises, Li et al. (2021) analyzed the impact of environmental regulation on the efficiency of technological innovation in China's manufacturing industry from the regional, industrial and enterprise levels. It is believed that the three environmental regulation tools have different effects on the efficiency of technological innovation in manufacturing industry, and on the whole, environmental regulation has a restraining effect on the efficiency of technological innovation in China [17]. Zhou et al.(2021) used that spatial capacity model to study the impact of environmental regulation on cities, and thought that environmental regulation has a significant positive impact on urban innovation significant positive [18]. Environmental regulation on the efficiency of the impact can be divided into three main types: promoting [19-21], inhibiting [22, 17] and "U" shaped relationship [23]. This paper puts forward the hypothesis that environmental regulation promotes production efficiency, and verifies the correctness of the hypothesis by empirical conclusions.

In the study of the impact of environmental regulation on pharmaceutical manufacturing industry, most scholars focus on the impact of environmental regulation on high-tech industry or industrial industry, and the model construction and analysis point of view are also different. Zhang (2021) used non-radial SBM model to measure the industrial green efficiency of each province, and then made Tobit regression on environmental regulation and green efficiency. The conclusion is that environmental regulation has a significant positive impact on industrial green efficiency, and environmental regulation has a certain lag [24]. Based on the SBM model and the panel Tobit model, Yi et al.(2020) studied the impact of government R&D subsidies and environmental regulation on the green innovation efficiency of manufacturing industry in the Yangtze River Economic Zone, and concluded that both of them are conducive to improving the green innovation efficiency of manufacturing industry in the Yangtze River Economic Zone [25]. Qiu et al.(2021) used feasible generalized least squares (FGLS) and dynamic generalized method of moments (GMM) to study the impact of environmental regulation and foreign direct investment on green total factor productivity of industrial sectors in 30 provinces of China [26]. Similarly, Xu et al.(2021) also studied the impact of environmental regulation and foreign direct investment on China's green total factor productivity [27]. By establishing a panel Poisson fixed effect model, Cai et al.(2020) studied the incentive effect of environmental regulations on green technology innovation of listed companies in heavy pollution industries in China [28]. Zhao et al.(2021) used SYS-GMM and DIF-GMM to study the impact of environmental regulation and technological innovation on the green transformation of manufacturing industry in the Yangtze River Economic Zone [29]. This paper will study the impact of environmental regulation on pharmaceutical manufacturing industry, and consider the spatial effects of the two, which enriches the existing research results.

Based on the above analysis, this paper will make the following innovations in the existing research: First, in terms of theory, this paper will study the direct effect and spatial spillover effect of environmental regulation on total factor productivity of pharmaceutical manufacturing industry, which enriches the research results in the field of cleaning in pharmaceutical manufacturing industry; Second, this paper constructs the Metafrontier Malmquist-Luenberger index which considers the undesired output mixed distance EBM model to measure the total factor productivity of pharmaceutical manufacturing industry, and the calculation results are more accurate and effective; Third, this paper considers the mediating effect of environmental regulation on pharmaceutical manufacturing industry from three aspects of green technology, production technology and industrial structure, and considers the heterogeneity of eastern, central and western regions, then comprehensively analyzes the impact of ERI on HTFP.

The rest of this article follows: The second part is the research hypothesis, the third part is selection of data indicators and the establishment of models, the fourth part is the empirical results, the fifth part is the discussion of empirical results, the sixth part proposed the policy suggestion according to the empirical conclusion.

2 Research Hypothesis

Generally speaking, high-tech industry is considered to be a pollution-free and efficient industry, especially its knowledge-intensive and technologically advanced characteristics [30, 31]. However, it cannot be ignored that there is a certain waste of resources in the high-tech industry from the perspective of production mode, and its production mode is still dominated by "traditional resources-input-consumption-waste discharge" [11]. In 2020, the Ministry of Environmental Protection issued the Second National Pollution Source Census Bulletin, which included the pollution discharge of oxygen demand and ammonia nitrogen emissions in the industrial water pollution part pharmaceutical manufacturing enterprises COD, BOD5 up to tens of thousands or even hundreds of thousands, wastewater into the water consumption of dissolved oxygen [32], and contains high concentration of cyanide, phenols, antibiotics and other substances, with refractory and biological toxicity [33]. At the same time, the chemical reaction of pharmaceutical manufacturing industry is often accompanied by inorganic waste gas, organic waste gas, chemical comprehensive waste gas and other emissions. These waste gases are complex, difficult to collect and control, and may even be inhaled through breathing and skin, endangering health [34]. Therefore, the pharmaceutical manufacturing industry has a problem of environmental pollution that cannot be ignored.

As the environment as a kind of public goods with externalities, often rely on the role of government to guide. Environmental regulation is an important tool for effectively control of environmental pollution, which will achieve green transformation of pharmaceutical manufacturing industry, and improve production efficiency [29]. The impact mechanism of environmental regulation on total factor productivity of pharmaceutical manufacturing industry is shown in Fig.1.

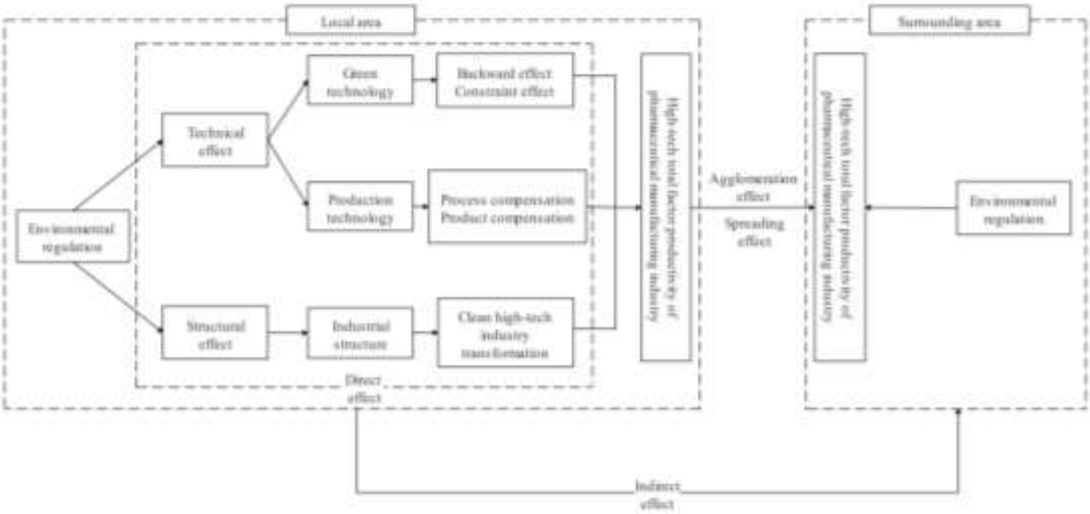


Fig. 1 The mechanism of ERI on HTFP

From the regional impact of environmental regulation on total factor productivity of pharmaceutical manufacturing industry, it is mainly divided into compensation effect and cost effect [35], in which compensation effect is divided into process compensation and product compensation. The compensation effect is similar to the reverse effect. The strict environmental regulation makes the environmental cost of enterprises increase, which forces the highly polluting enterprises to upgrade the green technology and innovate the production technology, so as to reduce the pollution of enterprises [36, 37]. The compensation process mainly improves the original process technology of enterprises, forms a recycling system and creates new value from the technical aspect; Product compensation mainly uses raw materials alternately from the perspective of resource utilization, reduces the cost of pollution treatment, and realizes waste recycling. The above compensation effect and reverse effect are reflected in the promotion effect. The cost effect of inhibition has a greater impact on areas with backward economic development and weak capital base, which is mainly manifested in that strict environmental regulation will occupy part of the funds invested in innovation by enterprises [38-40]. It will tend to choose areas with more relaxed environmental regulations for transfer, and the surrounding areas will become the ground for pollution, thus having a negative impact on the pharmaceutical manufacturing industry in the surrounding areas [41].

Based on the above analysis, increasing environmental regulation will strengthen the screening ability of local enterprises, that is, through green transformation or enterprise withdrawal, to form a "clean" industrial agglomeration in the local area. Environmental regulation continuously optimizes the layout of clean industry in regional pharmaceutical manufacturing industry through structural effect, so as to improve the total factor productivity of pharmaceutical manufacturing industry [42].

To sum up, this paper puts forward Hypothesis 1: Environmental regulation (ERI) has a significant role in promoting the pharmaceutical manufacturing total factor productivity (HTFP).

From the perspective of the impact of environmental regulation on the total factor productivity of pharmaceutical manufacturing industry in the surrounding areas, it is mainly reflected in the cost effect and imitation effect. The above analysis of the cost effect of environmental regulation on the surrounding areas of the inhibitory effect, that is, for the areas with weak economic foundation, strict environmental regulation increases the crowding-out effect of enterprise funds, enterprises will choose the surrounding areas with less environmental regulation to transfer [40].

However, the transfer of enterprises cannot bring cleaner production mode, and the surrounding areas become the pollution bearing ground, which inhibits the green development of pharmaceutical manufacturing enterprises in the surrounding areas. But for the areas with strong economic foundation, environmental regulation accelerates the technological innovation and transformation of local enterprises, and the surrounding areas learn and master the technology and mode of enterprise transformation through learning effect or imitation effect, so as to improve the innovation ability of the surrounding areas and improve the total factor productivity of pharmaceutical manufacturing industry in the surrounding areas [43].

Therefore, this paper proposes that Hypothesis 2: Environmental regulation (ERI) will have a significant role in promoting the total factor productivity of the pharmaceutical manufacturing industry (HTFP) in the surrounding areas, and at the same time, the improvement of HTFP in the surrounding areas will also promote the improvement of HTFP in the region.

Based on the above analysis, environmental regulations will not only affect the local HTFP, but also have an impact on the HTFP in the surrounding areas. The impact of environmental regulation on pharmaceutical total factor productivity can be divided into two paths: first, from the perspective of technical effect, environmental regulation can compensate for the upgrading of clean technology and production process of local enterprises, thus improving local HTFP. At the same time, through the learning effect of technical knowledge and the spillover effect of innovation, it can affect the HTFP of surrounding areas. From the perspective of structural effect, environmental regulation promotes the transformation of clean industry in local pharmaceutical manufacturing industry, improves the degree of industrial cluster, and provides a structural basis for the demonstration effect of local economies of scale. For the surrounding areas, on the one hand, the cost effect inhibits the sustainable development of pharmaceutical manufacturing industry in economically weak areas, on the other hand, the formation of clean industrial clusters in pharmaceutical manufacturing industry has formed a good demonstration effect for the surrounding areas [43], and the surrounding areas can promote the sustainable development of pharmaceutical manufacturing industry through learning effect.

Therefore, based on the above analysis, this paper proposes Hypothesis 3: Green technology, production technology and industrial structure play an intermediary role in the impact of environmental regulation (ERI) on total factor productivity of pharmaceutical manufacturing industry (HTFP).

3 Method and Data

This part is the selection of data indicators and the establishment of models. Section 3.1 refers to the selection of data indicators. Section 3.2 is the calculation process of HTFP. Section 3.3 is the establishment of spatial econometric model.

3.1 Indicator selection

This paper studies the effect of environmental regulation on total factor productivity of pharmaceutical manufacturing industry. According to the availability and accuracy, we select the panel data of 30 provinces in China except Hong Kong, Macao, Taiwan and Tibet from 2004 to 2019 to study. In the heterogeneity analysis, 30 provinces in China are divided into eastern, central and western regions [44, 45], with Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan in the eastern region, Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan in the central region and Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang in the western region.

The data selected in this paper are all from *China Statistical Yearbook*, *China Environmental Yearbook*, *China High-tech Industry Statistical Yearbook*, *China Environmental Statistical Yearbook*, *China Industrial Statistical Yearbooks*, *China Health Statistical Yearbooks* and provincial statistical yearbooks.

This paper takes the logarithm of environmental regulation (ERI) as the core explanatory variable, and the logarithm of total factor productivity of pharmaceutical manufacturing industry (HTFP) as the dependent variable. According to Levinson(1996) and Yuan and Chen(2019), the ratio of operation cost of industrial wastewater treatment facilities to industrial wastewater discharge, the ratio of operation cost of industrial waste gas treatment facilities to industrial, the ratio of waste gas emissions and the comprehensive utilization rate of industrial solid waste, using entropy method [46] to get the environmental regulation index (ERI)[47, 48]. The total factor productivity of pharmaceutical manufacturing industry (HTFP) is measured by data envelopment analysis method. The Metafrontier Malmquist-Luenberger index based on the mixed distance EBM model is constructed to measure the HTFP from 2004 to 2019. See Section 3.2 for the specific calculation process.

The control variables selected in this paper are the degree of foreign development (*Open*), the level of labor force (*Labor*), assets (*Capital*), operating conditions (*Income*) and profitability (*Profit*). Among them, the degree of opening to the outside world is expressed by the total import and export volume of goods of foreign-funded enterprises. The level of labor force is expressed by the average number of employees in industries above scale. Assets, operating conditions and profitability were the total assets of foreign-funded enterprises, the main business income and total profits to show.

This paper considers the intermediary conduction mechanism from the technical effect and the structure effect, the technical effect subdivides into the green technology and production technology. The green technology (*lnIngrva*) is represented by a logarithmic value of the number of green invention applications. Production technology (*lnRD*) is expressed as a logarithmic value of the R&D personnel. The industrial structure (*lnStructure*) is expressed by the logarithmic value of the ratio of the sales output value of the pharmaceutical manufacturing industry to the total industrial output value.

The descriptive statistical analysis of the variables selected in this paper is shown in Table 1.

Table 1 Descriptive statistical analysis of each variable

Variable	Obs	Mean	Std. Dev.	Min	Max
HTFP	480	5.706003	0.757746	4.026174	8.498085
ERI	480	2.056451	0.5237284	0.2196788	4.003557
Open	480	5171258	1.06E+07	414.6523	5.92E+07
Labor	480	276.8299	299.4936	9.28	1568
Capital	480	5149.61	8200.662	11.02	45972.24
Income	480	6252.461	10539.65	11.76	52626.73
Profit	480	415.9898	686.194	1	3723.16
lnIngrva	480	6.489516	1.779569	0	10.38186
lnRD	480	7.076806	1.574959	1.791759	9.830272
lnStructure	480	1.774423	0.7397528	-1.083482	4.380657

3.2 Measurement of HTFP

This paper constructs the Metafrontier Malmquist-Luenberger index under the mixed distance EBM model to measure the total factor productivity of pharmaceutical manufacturing industry. Before measuring, we need to build an input-output index system. And that construct system is shown as Table 2.

Table 2 Input-output index system

Level Ⅰ indicators	Level Ⅱ indicators	Level Ⅲ indicators
Input indicators	Labor input	Annual Average Employees

		Number of health technicians per thousand population
	Infrastructure input	Number of beds in medical and health institutions
	Scale input	Number of Enterprises
	Guarantee input	Per capita medical expenses of outpatients
		Per capita medical expenses of inpatients
Output indicators	Expected output	Revenue
		Profits
	Unexpected output	Incidence of category A and B infectious diseases (1/100,000)
		Mortality rate of category A and B infectious diseases (1/100,000)

Because the input-output system in this paper contains undesirable outputs, the following Undesirable-EBM function considering undesirable outputs is established:

$$
\lambda^{*} = \min \frac{\theta - \varepsilon_x \sum_{p=1}^{P} \frac{w_p^- s_p^-}{x_{pk}}}{\varphi + \varepsilon_y \sum_{q=1}^{Q} \frac{w_q^+ s_q^+}{y_{qk}} + \varepsilon_b \sum_{m=1}^{M} \frac{w_m^{b-} s_m^{b-}}{b_{mk}}}
$$

$$
\begin{aligned}
s.t.\ & \sum_{j=1}^{J} x_{pj}\delta_j + s_p^- = \theta x_{pk},\ p = 1,\ldots,P \\
& \sum_{j=1}^{J} y_{qj}\delta_j - s_q^+ = \varphi y_{qk},\ q = 1,\ldots,Q \\
& \sum_{j=1}^{J} b_{mj}\delta_j + s_m^{b-} = \varphi b_{mk},\ m = 1,\ldots,M \\
& \delta_j \ge 0, s_p^- \ge 0, s_q^+ \ge 0, s_m^{b-} \ge 0
\end{aligned}
$$

Where x_{pk}, y_{qk} and b_{mj} are the inputs, expected outputs and undesirable outputs of decision making unit *K*, respectively, and *P*, *Q* and *M* are the quantities of inputs and outputs. φ is the programming parameter of the radial part of the output index, ε_x, ε_y and ε_b represent the importance degree of the non-radial part of the input index, the expected output index and the unexpected output index in the efficiency value respectively, w_p^-, w_q^+ and w_m^{b-} represent the relative importance degree of each input index, the expected output index and the unexpected output index respectively, and $\sum_{p=1}^{P} w_p^- = 1$, $\sum_{q=1}^{Q} w_q^+ = 1$, $\sum_{m=1}^{M} w_m^{b-} = 1$. s_p^-, s_q^+ and s_m^{b-} are the slack variables of input index, expected output and undesirable output respectively, and the radial programming parameters of undesirable output are consistent with the expected output.

According to Guo et al.(2017), the analysis framework of common frontier and group frontier can be constructed to study the total factor productivity of pharmaceutical manufacturing industry under different frontiers [49], while this paper uses the efficiency value under common frontier as the basis of subsequent analysis, so here, only the model of measuring the efficiency value of common frontier is shown. According to Hayami and Ruttan(1971), the efficiency value can be obtained as follows [50]:

$$\min \alpha^{Metafrontier} = \frac{\theta - \varepsilon_x \sum_{p=1}^{P} \frac{w_p^- s_p^-}{x_{pk}}}{\varphi + \varepsilon_y \sum_{q=1}^{Q} \frac{w_q^+ s_q^+}{y_{qk}} + \varepsilon_b \sum_{m=1}^{M} \frac{w_m^{b-} s_m^{b-}}{b_{mk}}}$$

$$\begin{aligned} s.t.\ & \sum_{j=1}^{J_M} x_{pj}\delta_j + s_p^- = \theta x_{pk},\ p = 1,\ldots,P \\ & \sum_{j=1}^{J_M} y_{qj}\delta_j - s_q^+ = \varphi y_{qk},\ q = 1,\ldots,Q \\ & \sum_{j=1}^{J_M} b_{mj}\delta_j + s_m^{b-} = \varphi b_{mk},\ m = 1,\ldots,M \\ & \delta_j \geq 0, s_p^- \geq 0, s_q^+ \geq 0, s_m^{b-} \geq 0,\ j = 1,\ldots,J_M \end{aligned}$$

J_M is the number of DMUs under the common front and δ is the intensity variable of the common front. According to Pastor and Lovell(2005), the Malmquist index can be constructed as follows [51]:

$$HTFP_t^{t+1} = \sqrt{\frac{1 - D_t^m(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}{1 - D_t^m(x^t, y^t, b^t; y^t, -b^t)} \times \frac{1 - D_{t+1}^m(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}{1 - D_t^m(x^t, y^t, b^t; y^t, -b^t)}}$$

$HTFP_t^{t+1}$ means the total factor productivity of pharmaceutical manufacturing industry in the period from *t* to *t+1*, and $HTFP_t^{t+1}$ is greater than 1, indicating that the total factor productivity of pharmaceutical manufacturing industry in that year is in an upward trend; $HTFP_t^{t+1}$ is less than 1, indicating that the total factor productivity of pharmaceutical manufacturing industry is declining in that year. In order to ensure the validity of the follow-up measurement results, this paper uses the cumulative $HTFP_t^{t+1}$ as the research basis, and its economic significance is the increase of total factor productivity of pharmaceutical manufacturing industry in period t relative to the base 2003.

3.3 Spatial econometric model

Before the establishment of spatial econometrics, we need to establish a panel data regression model. Then we need to build a spatial weight matrix, use the spatial autocorrelation test, and we can establish a spatial econometrics model.

The panel data regression model is as follows:

$$HTFP_{it} = \beta + \alpha_1 ERI_{it} + \rho X_{it} + \lambda z_i + \varepsilon_{it}$$

In the formula, $HTFP_{it}$ represents the value of the dependent variable in the *t* year of *i* province, *ERI* is the core explanatory variable, and *X* is the control variable, z represents the enterprise effect that does not change with time. ε denotes a random perturbation term. α_1 is the regression coefficient of the core explanatory variable *ERI*, ρ is the regression coefficient of the control variable, and β is the constant coefficient.

The panel regression assumes that there is no difference among individuals, which is inconsistent with the actual situation. Therefore, considering the certain differences of economic subjects, individual effects can exist as fixed effects and random effects [52].

The fixed effect model is as follows:

$$HTFP_{it} = \alpha_2 ERI_{it} + \rho X_{it} + \lambda z_i + u_i + \varepsilon_{it}$$

The random effect model is as follows:

$$HTFP_{it} = \alpha_3 ERI_{it} + \rho X_{it} + \lambda z_i + u_i + \varepsilon_{it}$$

Fixed effects and random effects are the same in the form of models, but random effects assume that u_i is independent of X_{it} and z_i, that is, individual effects are independent of explanatory variables, while fixed effects assume that u is dependent on at least one explanatory variable. So according to Hausman(1978), we need to introduce F test, LM test and Hausman test to determine whether there are individual effects, and whether individual effects are related to explanatory variables [53].

In order to further discuss the existence of spatial autocorrelation, this paper uses Moran's I index to test the existence of spatial autocorrelation [54]. According to Cliff and Ord (1973), the global and local Moran's I index are formulated as follows [55]:

$$Global\ Moran's\ I = \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \times \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_{it} - \bar{x})(x_{jt} - \bar{x})}{\sum_{i=1}^{n}(x_{it} - \bar{x})^2}$$

$$Local\ Moran's\ I = \frac{n(x_{it} - \bar{x})\sum_{j=1}^{n} W_{ij}(x_{jt} - \bar{x})}{\sum_{i=1}^{n}(x_{it} - \bar{x})^2}$$

Where x_{it} is the observed value of HTFP and ERI in the year *t* of province *i*, and W_{ij} is the spatial weight matrix. The global Moran index is between -1 and 1, with values greater than 0 indicating positive spatial autocorrelation and values less than 0 indicating negative spatial autocorrelation. When the local Moran index is greater than 0, it shows that there is "H-H" or "L-L" accumulation area in this area;

When it is less than 0, it indicates that there is an "H-L" or "L-H" accumulation area in this area.

In this paper, 0-1 adjacency matrix (W1) and geographical distance matrix (W2) are used as the spatial weight matrix to test the spatial autocorrelation.W1 is used to establish the follow-up spatial econometric model, and W2 is used as the alternative weight matrix to test the robustness of the model.

According to You and Lv (2018), the 0-1 adjacency matrix (W1) is formulated as follows [56]:

$$W_{ij}^{1}=\begin{cases}1, adjacent\\0, other\end{cases}$$

According to Wang et al.(2019), the geographical distance matrix (W2) is formulated as follows [57]:

$$W_{ij}^{2}=\frac{1}{|d_{ij}|}$$

Where d_{ij} is the distance between *i* province and *j* province.

On the basis of verifying the spatial autocorrelation of variables, this paper will establish a spatial econometric model to study the spatial spillover effect of ERI on HTFP. In the existing research, spatial econometric models are mainly divided into spatial lag model (SAR), spatial error model (SEM) and spatial Durbin model (SDM). SAR only considers the spatial lag of the dependent variables, but does not consider the influence of the spatial lag of the explanatory variables [58]. SEM considers the case when the error term has spatial autocorrelation, but does not consider the effect of the spatial lag term of explanatory variables [59]. SDM takes into account both the dependent variable and the spatial lag of the explanatory variable, and the spatial spillover effect of the variable on the surrounding areas [60].

The SAR model is as follows:

$$HTFP_{it} = \alpha_4 ERI_{it} + \alpha_5 W * HTFP_{it} + \rho X_{it} + \varepsilon_{it}$$

The SEM model is as follows:

$$\begin{cases} HTFP_{it} = \alpha_6 ERI_{it} + \rho X_{it} + \varepsilon_{it} \\ \varepsilon_{it} = \gamma W * \varepsilon_{it} + \nu_{it} \end{cases}$$

The SDM model is the following:

$$HTFP_{it} = \alpha_7 W * ERI_{it} + \alpha_8 ERI_{it} + \alpha_9 W * HTFP_{it} + \rho X_{it} + \delta W * X_{it} + \varepsilon_{it}$$

According to Elhorst(2012), this paper uses LR test to test the rationality of SDM model. LR test is to see whether SDM will degenerate into SAR and SEM models, which is to select the optimal spatial econometric model [61].

4 Empirical Results

Based on the panel data of 30 provinces in China from 2004 to 2019, this paper studies the spatial spillover effects of environmental regulation (ERI) on total factor productivity of pharmaceutical industry (HTFP) by establishing a spatial econometric model. Section 4.1 discusses the spatiotemporal characteristics of ERI and HTFP. Section 4.2 studies the effect of ERI on HIFP through panel data regression. Section 4.3 studies the spatial spillover effect of ERI on HTFP through spatial Durbin model. Section 4.4 further analyzes the intermediary transmission mechanism, regional heterogeneity, endogeneity and robustness of the two.

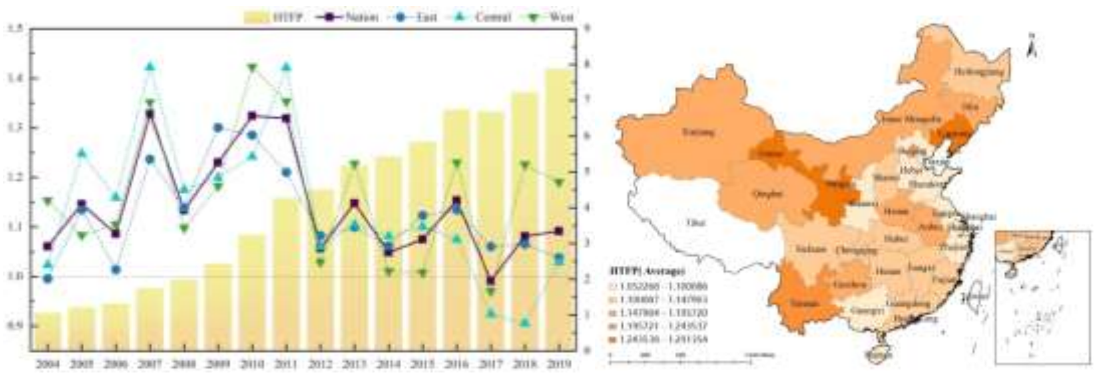
4.1 Temporal and spatial characteristics of ERI and HTFP

The HTFP index calculated by the Metafrontier Malmquist-Luenberger index under the mixed distance EBM model is the change rate from t to $t+1$, and has cumulative characteristics during the study period. Considering the accuracy of temporal-spatial analysis and the stability of the overall change, the annual average value of HTFP is used in Section 4.1, and the cumulative value of HTFP is used in the subsequent measurement process.

Fig.2(a) describes the time trend of annual average change of HTFP and the change of cumulative value of HTFP in the whole country and the three major regions of east, middle and west. From the images, we can see that the average annual value of HTFP from 2004 to 2019 is greater than 1 except 2017, which indicates that HTFP is gradually increasing over time during the study period. In addition, HTFP reached the maximum (1.3241) in 2010, and then HTFP developed steadily. From 2004 to 2019, the annual average of HTFP in China was 1.1422, that is, the average growth rate was 14.22%, and the cumulative HTFP was 4.1758. The trend of time change in the three regions is similar to that of the whole country, and the overall trend of time change in the three regions is small.

According to Fig.2(b), the spatial distribution of HTFP decreased from west to east, and from high to low, it was the west (1.1652), the middle (1.1357) and the east (1.1239). During the study period, the pharmaceutical industry in the western region has developed rapidly, while the eastern region has a strong level of development and is difficult to upgrade, so it is in a stable development trend. Within the region, in the eastern region, Beijing, Shanghai and Liaoning are at a higher level of development, but there is a big gap between their surrounding provinces and central cities; In the central region, the development of each province is relatively average, and the development difference between the surrounding provinces and the central cities is relatively small; In the western region, there is a big gap in the development of various provinces, Ningxia, Gansu and Yunnan are developing faster, while Shaanxi and Guangxi are developing slower.

To sum up, it is important to consider the aggregation of provinces and the heterogeneity of regions in the study of the effect of ERI on HTFP.



(a) (b)

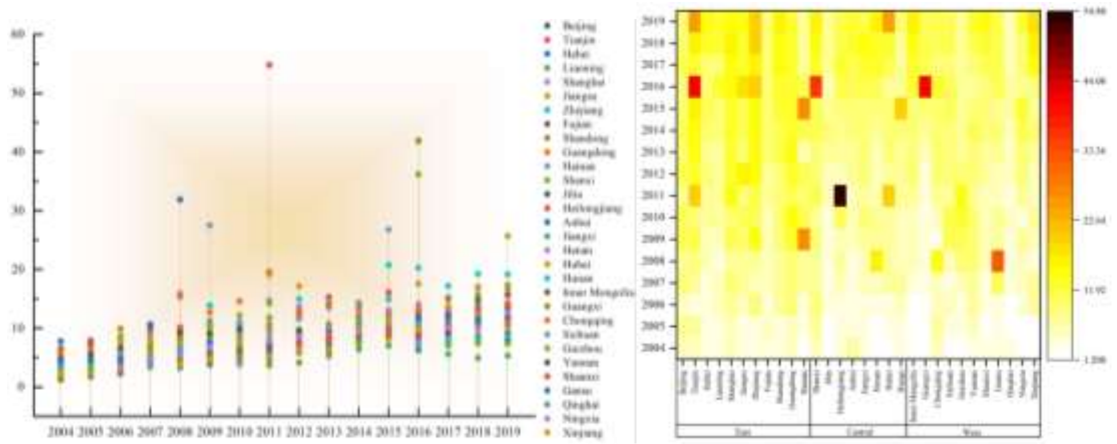
Fig. 2. Temporal and spatial characteristics of HTFP

Fig.3(a) and Fig.3(b) describe the temporal and spatial variation characteristics of environmental regulation (ERI). Fig.3(a) describes the change trend and aggregation characteristics of each province over time. Fig.3(b) describes trends in the spatial dynamics of ERI by region and province from 2004 to 2019.

From Fig.3(a), the overall ERI of the whole country shows a gradual upward trend over time, indicating that during the study period, the intensity of environmental regulation is increasing. Except for some provinces, most provinces show the spatial agglomeration characteristics of "from agglomeration to decentralization". Before 2014, the difference of ERI in each province is small, but after 2014, the development of ERI in each province is more dispersed. The differences in energy utilization, industrial pollution and resource allocation in each province continue to show, which leads to the different intensity of environmental regulation.

From Fig.3(b), the ERI of each region and province shows a gradual upward trend over time, which is consistent with the overall change of the whole country. From the regional point of view, the average ERI from 2004 to 2019 is the eastern (10.2144), the central (8.6867) and the western (7.8871), and the eastern ERI is far more than that of the central and western regions, which shows that the eastern region has strengthened environmental regulation while developing its economy. This is closely related to the eastern industrial structure, pollution prevention and control, environmental input and so on. For example, in the eastern region, Tianjin (14.4987) and Zhejiang (12.5606) are in the leading position, while Fujian (7.1645), Liaoning (7.6985) and Hebei (7.8748) are relatively low; In the central region, Shanxi (11.5473) ranks first, while Jilin (5.5154) ERI is not only at the lowest level in the central region, but also relatively backward in the whole country. There is a large range of "high-high" spatial aggregation of ERI in the eastern and central regions, while the ERI in the western region is generally low, which shows a "low-low" aggregation characteristics.

Therefore, in the follow-up study, we not only need to consider the local impact of ERL, but also need to determine whether there is a spatial spillover effect, so as to more comprehensive analysis of the impact of ERI on HTFP.



(a) (b)

Fig. 3. Temporal and spatial characteristics of ERI

4.2 Empirical results of panel data regression

Before studying the spatial spillover effects of ERI on HTFP, we need to establish a panel data regression model. The effect of ERI on HTFP was discussed. In this paper, ERI is taken as the core explanatory variable and HTFP as the explained variable. By constructing mixed panel regression model (OLS), fixed effects model (FE) and random effects model (RE), the optimal regression model is selected. Table 3 is the regression results of the three models. Model-1, Model-2 and Model-3 are the regression results of mixed OLS, fixed effects and random effects, respectively. Through the F test, LM test and Hausman test, the fixed effects model (Model-2) is the best model, and the goodness of fit of Model-2 is the best, which is 0.552, indicating that the explanatory degree of explanatory variables to HTFP is 55.2%.

Table 3 Results of baseline regression of HTFP by ERI

Model	(1) OLS	(2) FE	(3) RE
ERI	0.686***	0.751***	0.791***
	(0.0618)	(0.0491)	(0.0493)
Open	-5.42e-09	2.32e-08*	-4.81e-09
	(1.01e-08)	(1.31e-08)	(1.14e-08)
Labor	-0.000276	0.000494	-0.000377
	(0.000190)	(0.000349)	(0.000265)
Capital	7.70e-05***	8.27e-05***	6.43e-05***
	(2.66e-05)	(2.30e-05)	(2.29e-05)
Income	-9.83e-05***	-7.52e-05***	-6.58e-05**
	(3.23e-05)	(2.58e-05)	(2.62e-05)
Profit	0.000697**	0.000481**	0.000679***
	(0.000315)	(0.000233)	(0.000237)
Constant	4.329***	3.748***	4.007***
	(0.128)	(0.118)	(0.132)
F test		18.26***	
LM test			700.11***
Hausman test		21.23***	
Observations	480	480	480

R-squared	0.285	0.552	0.535

Notes: *, **, ***indicate significance at the 10%, 5% and 1% level, and the standard errors are in parentheses

From a fixed effect (Model-2), the regression coefficient of ERI to HTFP was 0.751, which was significant at the level of 1%. HTFP will rise by 0.751%, which shows that the increase of environmental regulation has significantly promoted the improvement of total factor productivity in the pharmaceutical industry, proving that Hypothesis 1. On the one hand, according to the "compensation effect" and stricter environmental regulations, pharmaceutical enterprises that fail to meet the standards upgrade pollution prevention, they have to control technology, improve energy efficiency, reduce pollution emissions, which will improve the total factor productivity of pharmaceutical. On the other hand, according to the "reverse effect", pharmaceutical enterprises face the deepening environmental regulation and the increasing cost of pharmaceutical enterprise governance. It will make some enterprises continuously improve production efficiency under the pressure of environmental regulation, and upgrade production technology, industrial structure, resource energy consumption, environmental pollution and other aspects, so as to improve the total factor productivity of pharmaceutical.

From the impact of control variables on HTFP, Open, Capital and Profit are significantly positive at the level of 10%, 1% and 1%, respectively. When Open, Capital and Profit increase by 1%, HTFP will increase by 2.32e-08, 8.27e-05 and

0.000481. The effect of Income on HTFP was significantly negative at 1% level, while the effect of Labor on HTFP was positive but not significant. This shows that opening to the outside world, the stock of assets and the profits of the whole industry are important factors to promote the development of pharmaceutical industry, while business income and the number of employees of industrial enterprises have less effect on improving HTFP.

4.3 Empirical Results of Spatial Econometric Model

Through the analysis of temporal and spatial characteristics of ERI and HTFP, this paper needs to further discuss whether there is spatial spillover effect of ERI on HTFP. This part is divided into two parts. First, build the space weight matrix test and see whether there is spatial autocorrelation between ERI and HTFP. Second, if there is spatial autocorrelation between ERI and HTFP, the corresponding spatial econometric model is selected to study the spatial spillover effect of ERI on HTFP.

4.3.1 Spatial Autocorrelation Test

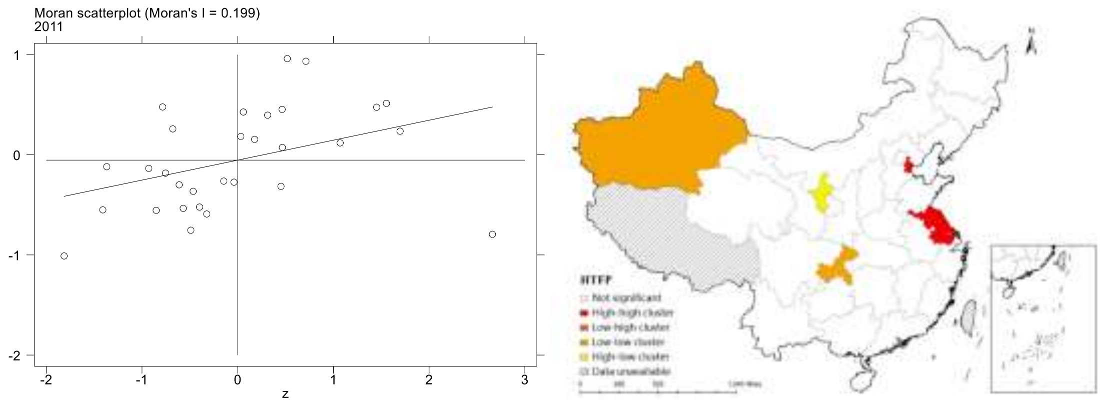
Considering the accuracy and feasibility of the follow-up regression results, this paper constructs 0-1 adjacency matrix (W1) and geographical distance matrix (W2) as the basis of the follow-up study. In this paper, we test the spatial autocorrelation of HTFP and ERI by global Moran index. The value of global Moran index is between -1 and 1, and any value greater than 0 indicates the existence of positive spatial autocorrelation of the variable, and any value less than 0 indicates the existence of negative spatial autocorrelation of the variable. The global Moran exponents for W1 and W2 matrices are shown in Table 4. The results show that HTFP and ERI have significant positive spatial autocorrelation.

Table 4 Global Moran index results of HTFP and ERI

Year	HTFP(W1)	HTFP(W2)	ERI(W1)	ERI(W2)
2004	0.237***	0.056***	0.298***	0.07***
2005	0.281***	0.051**	0.306***	0.066***
2006	0.325***	0.104***	0.286***	0.058***
2007	0.162**	-0.002	0.269***	0.05**
2008	0.179**	0.043**	0.27***	0.046**
2009	0.201**	0.006	0.263***	0.044**
2010	0.242***	0.072***	0.254***	0.04**
2011	0.127*	0.013*	0.249***	0.039**
2012	0.256***	0.097***	0.258***	0.039**
2013	0.285***	0.112***	0.262***	0.039**
2014	0.236***	0.114***	0.267***	0.039**
2015	0.187**	0.095***	0.273***	0.039**
2016	0.223***	0.106***	0.277***	0.039**
2017	0.215**	0.089***	0.278***	0.037**
2018	0.207**	0.096***	0.279***	0.035**
2019	0.242***	0.084***	0.278***	0.034**

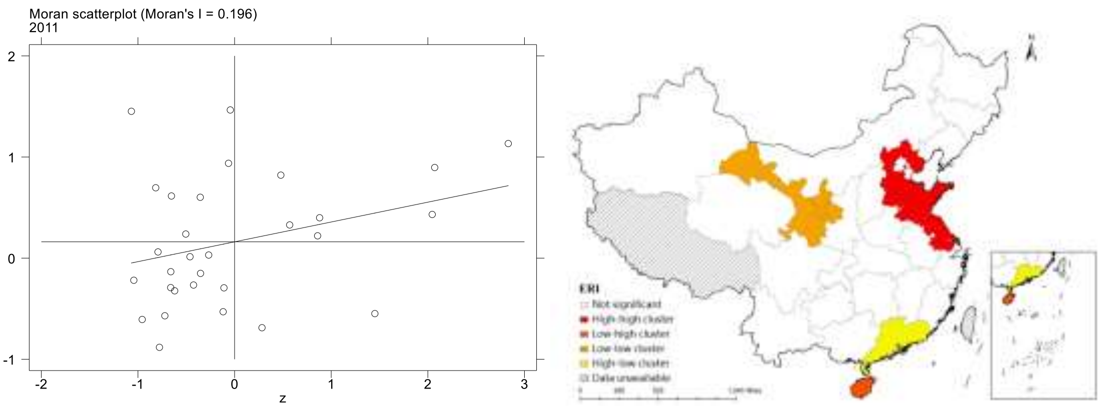
In order to further analyze the spatial aggregation of each province, this paper calculates the local Moran index, draws the local Moran index scatter plot and the local autocorrelation LISA plot. The Moran scatter plot and LISA cluster plot of 2011 are drawn based on W1 matrix. Fig.4 (a) and Fig.4 (b) are the Moran scatter plot and LISA of HTFP, respectively. Fig.5 (a) and Fig.5 (b) are Moran scatter plot and LISA cluster plot of ERI, respectively.

From the Moran scatter diagram of HTFP and ERI, it can be seen that most provinces are concentrated in the first quadrant and the third quadrant, which indicates that there are obvious "high-high" or "low-low" aggregation in HTFP and ERI. From the LISA cluster map of HTFP and ERI, it can be seen that there is a "high-high" cluster of HTFP in Beijing and Jiangsu, a "low-low" cluster in Xinjiang and Chongqing, and a "high-low" cluster in Ningxia. ERI in Hebei, Shandong and Jiangsu have "high-high" aggregation, Gansu and Ningxia have "low-low" aggregation, Guangdong has "high-low" aggregation and Hainan has "low-high" aggregation.



(a) (b)

Fig. 4. Moran scatter plot and LISA aggregation plot of HTFP



(a) (b)

Fig. 5. Moran scatter plot and LISA aggregation plot of ERI

4.3.2 Regression Results of Spatial Econometric Model

In the above research, due to the existence of "compensation effect" and "inversion effect", increasing environmental regulation has a significant role in promoting the total factor productivity of the pharmaceutical industry. However, due to the significant spatial autocorrelation between ERI and HTFP, there are obvious "high-high" or "low-low" aggregation characteristics in the region, so it is very important to study the spatial spillover of ERI to HTFP. In the process of establishing the spatial econometric model, HTFP is taken as the explained variable, ERI is taken as the core explanatory variable, and 0-1 adjacency matrix (W1) is taken as the spatial weight matrix to establish the spatial autoregressive model.

Tabel 5 is the regression results of three spatial econometric models. Model-4, Model-5 and Model-6 are the regression results of SAR, SEM and SDM, respectively. The results of LR test show that the spatial Durbin model (Model-6) is the optimal model. In addition, the goodness of fit of Model-6 was the best, which is 0.7603, indicating that the explanatory degree of explanatory variables to HTFP was 76.03%.

Table 5 Result of spatial econometric model

Model	(4) SAR	(5) SEM	(6) SDM
W*HTFP	0.674***	0.820***	0.460***
	(0.0320)	(0.0216)	(0.0455)
ERI	0.196***	-0.00539	0.101**
	(0.0428)	(0.0441)	(0.0430)
Open	3.29e-08***	4.61e-08***	2.86e-08***
	(9.01e-09)	(7.79e-09)	(8.61e-09)
Labor	0.000247	-9.17e-05	0.000271
	(0.000240)	(0.000223)	(0.000235)
Capital	5.11e-05***	3.83e-05**	3.79e-05**
	(1.59e-05)	(1.52e-05)	(1.60e-05)
Income	-8.31e-05***	-9.64e-05***	-7.92e-05***

	(1.77e-05)	(1.78e-05)	(1.80e-05)
Profit	0.000526***	0.000692***	0.000537***
	(0.000160)	(0.000165)	(0.000166)
W*ERI			0.553***
			(0.0662)
W*Open			-6.48e-08***
			(1.28e-08)
W*Labor			9.75e-05
			(0.000295)
W*Capital			-3.80e-05*
			(2.13e-05)
W*Income			0.000115***
			(2.78e-05)
W*Profit			-0.000597***
			(0.000232)
sigma2_e	0.0954***	0.0925***	0.0843***
	(0.00635)	(0.00621)	(0.00554)
Log-likelihood	-149.6041	-165.076	-100.635
LR test for SAR			97.94***
LR test for SEM			128.88***
Observations	480	480	480

R-squared	0.6597	0.1202	0.7603
Number of ID	30	30	30

In this paper, the results of spatial Durbin model are used as the basis for the follow-up analysis.

First, the coefficient of HTFP spatial lag is 0.460, which is significant at 1% level. This shows that every 1% increase of HTFP in surrounding areas will increase HTFP by 0.46% in this area, which proves Hypothesis 2. The spatial lag term of HTFP is significantly positive, which also verifies the existence of spatial autocorrelation of HTFP, and the existence of "high-high" or "low-low" aggregation in each province. Under the national strategy of overall development of pharmaceutical industry, governments in various regions have intensified their policy efforts to support the development of pharmaceutical manufacturing industry in their respective regions from the perspectives of capital investment, talent attraction and infrastructure construction. Relying on the local resources to build the pharmaceutical manufacturing city, gradually deepen the degree of cluster industrialization, improve the competitiveness of pharmaceutical manufacturing enterprises in scale and innovation, so as to drive the development of HTFP in surrounding cities as a central city.

Second, the regression coefficient of ERI's influence on local HTFP is 0.101, which is significant at 5%. This shows that environmental regulation has a significant role in promoting the improvement of local HTFP, which proves that Hypothesis 1. For every 1% increase in local ERI, local HTFP will increase by 0.101%. The regression coefficient of ERI on local HTFP was 0.553, which was significant at 1%. This shows that the ERI in the surrounding area has a significant role in improving the local HTFP, which proves that Hypothesis 2. For every 1% increase in ERI in the surrounding area, the local HTFP will increase by 0.553%. The role of environmental regulation on the total factor productivity of pharmaceutical manufacturing industry has a significant positive impact on both local and surrounding areas. On the one hand, according to the "backward effect", strengthening environmental regulation means that polluting pharmaceutical enterprises have high cost, forcing enterprises to carry out technological innovation, so as to improve the total productivity of pharmaceutical factors. On the other hand, environmental regulation will screen out "clean" pharmaceutical enterprises, so that the local formation of "green barriers". The "backward effect" makes the local green clean technology have a good demonstration effect on the surrounding areas, while the local "green barrier" transfers the non-clean enterprises to the surrounding areas to a certain extent, but because this transfer lags behind the "non-clean transfer" to HTFP.

Third, from the control variables on the impact of HTFP point of view, the control variable regression coefficient of the direction and fixed. Open, Capital and Profit have a positive effect on the local HTFP, but have a negative effect on the surrounding HTFP. Labor is positive for HTFP in both local and peripheral areas, but the results were not significant. Income has a negative impact on the local HTFP, but has a positive impact on the surrounding HTFP. The potential reason is that the central city absorbs the resource advantages of the surrounding areas, resulting in a "siphon effect", which leads to the lack of sufficient resources in the surrounding areas to improve the efficiency level of the pharmaceutical industry in the region.

4.4 Further analysis

4.4.1 Mediating transmission mechanism

In this paper, the spatial spillover effect of ERI on HTFP is studied by establishing a SDM. However, the impact of environmental regulation on the development of pharmaceutical manufacturing industry is not a direct relationship between the two, and there is a complex intermediary effect between them. Therefore, in the further analysis, this paper first studies the mediating effect between the two.

This paper divides the mediating effect path into technical effect and structural effect, and the technical effect is divided into green technology and production technology, so this paper selects lnIngrva, lnRD and InStructure as three mediating variables, which correspond to green technology, production technology and structural effect respectively. The results of the mediating effect under the spatial Durbin model are Tabel 6, Tabel 7 and Tabel 8.

Table 6 shows the regression day results with lnIngrva as the mediator. ERI is the core explanatory variables of Model-7, and the dependent variable is lnIngrva. In Model-8, lnIngrva was used as the core explanatory variable and HTFP was used as the dependent variable. ERI and lingrva were used as the core explanatory variables and HTFP as the dependent variable in Model-9.

According to Model-7, the spatial lag coefficient of lnIngrva is 0.785, which is significant at 1% level. For every 1% increase in local lnIngrva, the surrounding lnIngrva will increase by 0.785%. The regression coefficient of ERI on local lnIngrva was 0.151, which was significant at 1% level. The regression coefficient of the influence of ERI in surrounding areas on local ln Ingrva is 0.297, significant at 1% level. This shows that increasing environmental regulation not only improves the local green technology level, but also improves the green technology level of the surrounding areas, and green technology has the effect of diffusion to the surrounding areas.

According to Model-8, the spatial lag coefficient of HTFP is 0.407, the regression coefficient of lnIngrva to local HTFP is -0.131, and the regression coefficient of lnIngrva to local HTFP in surrounding areas is 0.402, all of which are significant at the level of 1%. The effect of lnIngrva on HTFP in the local area is negative, while the effect on the surrounding area is positive, and the effect on the surrounding area is greater than that on the local area, which indicates that the "diffusion effect" of the surrounding area was greater than the "backward effect" of the local area. In general, lnIngrva still promotes the improvement of HTFP.

According to Model-9, the spatial lag coefficient of HTFP is 0.329, the regression coefficients of ERI and InIngrva to local HTFP are 0.0535 and -0.142, respectively, and the regression coefficients of ERI and InIngrva to local HTFP are 0.350 and 0.329, respectively. Except the effect of ERI on local HTFP was not significant, the other response coefficients were significant at 1% level. When the mediating variable lnIngrva is added, the significance of the effect of ERI on local HTFP becomes smaller, and the effect of lnIngrva on local HTFP becomes larger, which indicates that the existence of the mediating variable ln Ingrva really needs to be considered. From the point of view of variable spatial hysteresis coefficient, the effects of ERI and lnIngrva on HTFP in surrounding areas decreased slightly after adding lnIngrva. Both ERI and lnIngrva act on HTFP, that is, peripheral ERI has a direct effect on local HTFP and an indirect effect through the action of lnIngrva.

Through the above analysis, we can get the intermediate transmission path of lnIngrva: the increase of environmental regulation in the region and surrounding areas promotes the improvement of local green technology, thus promoting the improvement of HTFP in the region and surrounding areas, which proves that Hypothesis 3.

Table 6 Mediating effects of green technology

Model	(7) lnIngrva	(8) HTFP	(9) HTFP
W*Y	0.785***	0.407***	0.329***
	(0.0232)	(0.0497)	(0.0533)
ERI	0.151***		0.0535
	(0.0407)		(0.0426)

lnIngrva		-0.131***	-0.142***
		(0.0484)	(0.0477)
Open	-4.28e-08***	3.04e-08***	2.59e-08***
	(8.17e-09)	(8.63e-09)	(8.51e-09)
Labor	0.000903***	0.000270	0.000311
	(0.000224)	(0.000234)	(0.000230)
Capital	-1.20e-05	2.08e-05	1.62e-05
	(1.54e-05)	(1.60e-05)	(1.58e-05)
Income	8.28e-05***	-7.02e-05***	-6.18e-05***
	(1.71e-05)	(1.81e-05)	(1.78e-05)
Profit	-0.000634***	0.000547***	0.000498***
	(0.000158)	(0.000166)	(0.000163)
W*ERI	0.297***		0.350***
	(0.0634)		(0.0720)
W*lnIngrva		0.402***	0.329***
		(0.0525)	(0.0534)
W*Open	1.61e-08	-4.32e-08***	-5.04e-08***
	(1.23e-08)	(1.27e-08)	(1.26e-08)
W*Labor	-0.000567**	0.000233	1.27e-05
	(0.000281)	(0.000288)	(0.000286)
W*Capital	4.82e-05**	-6.81e-05***	-6.61e-05***

	(2.07e-05)	(2.16e-05)	(2.12e-05)
W*Income	-4.23e-05	9.77e-05***	0.000106***
	(2.65e-05)	(2.74e-05)	(2.70e-05)
W*Profit	0.000109	-0.000347	-0.000382*
	(0.000222)	(0.000230)	(0.000226)
sigma2_e	0.0767***	0.0817***	0.0786***
	(0.00513)	(0.00535)	(0.00512)
Observations	480	480	480
R-squared	0.8816	0.7775	0.7964
Number of ID	30	30	30

Table 7 represents the regression result of 1nRD as a mediation variable. Model-10 takes ERI as the core explanatory variable and lnRD as the dependent variable. Model-11 takes 1nRD as the core explanatory variable and HTFP as the dependent variable. Model-12 uses ERI and InRD as the core explanatory variables and HTFP as the dependent variable.

According to Model-10, the spatial lag coefficient of lnRD is 0.368, which is significant at the level of 1%. For every 1% increase in local lnRD, InRD in surrounding areas will increase by 0.368%. The regression coefficient of ERI to local lnRD was 0.155, which was significant at 1%. The regression coefficient of ERI to local InRD in the surrounding area was 0.570, which was significant at 1%. This shows that increasing environmental regulation not only improves the local technological innovation, but also improves the technological innovation of the surrounding areas, and technological innovation has the effect of diffusion to the surrounding areas.

According to Model-11, the spatial lag coefficient of HTFP is 0.425, the regression coefficient of lnRD to local HTFP is 0.135, and the regression coefficient of lnRD to local HTFP in surrounding areas is 0.259, all of which are significant at 1% level. LnRD has a positive impact on HTFP in the region and the surrounding areas, technological innovation not only directly improves HTFP, but also indirectly improves HTFP through technology spillovers in the surrounding areas.

According to Model-12, the spatial lag coefficient of HTFP is 0.319, the regression coefficients of ERI and InRD to local HTFP are 0.0602 and 0.119 respectively, and the regression coefficients of ERI and InRD to local HTFP are 0.423 and 0.139 respectively in surrounding areas, except that ERI has no effect on local HTFP. Other regression coefficients were significant. All were significant at 1% level. After adding the mediator variable lnRD, the significance of the effect of ERI on local HTFP becomes smaller. It indicates that the existence of the mediator variable lnRD really needs to be considered. From the variable space lag coefficient. After lnRD was added, the effects of ERI and lnRD on HTFP decreased slightly, which indicated that the peripheral ERI and lnRD affected HTFP together, that is, the peripheral ERI not only had a direct impact on local HTFP, but also had an indirect impact through the role of lnRd.

Through the above analysis, we can get the intermediary transmission path of InRD: the increase of environmental regulation in the region and surrounding areas promotes the improvement of local production technology, thus promoting the improvement of HTFP in the region and surrounding areas, which proves Hypothesis 3.

Table 7 Mediating effects of production technology

Model	(10) lnRD	(11) HTFP	(12) HTFP
W*HTFP	0.368***	0.425***	0.319***
	(0.0527)	(0.0516)	(0.0561)
ERI	0.155**		0.0602
	(0.0711)		(0.0430)
lnRD		0.135***	0.119***
		(0.0279)	(0.0272)
Open	-1.76e-08	3.02e-08***	2.75e-08***
	(1.43e-08)	(8.70e-09)	(8.46e-09)
Labor	0.000705*	1.59e-05	9.95e-05
	(0.000395)	(0.000238)	(0.000232)
Capital	1.41e-05	4.90e-05***	3.44e-05**
	(2.68e-05)	(1.60e-05)	(1.57e-05)
Income	3.21e-05	-0.000103***	-8.61e-05***

	(3.01e-05)	(1.80e-05)	(1.76e-05)
Profit	-0.000600**	0.000740***	0.000656***
	(0.000279)	(0.000168)	(0.000164)
W*ERI	0.570***		0.423***
	(0.104)		(0.0701)
W*lnRD		0.259***	0.139***
		(0.0469)	(0.0498)
W*Open	1.99e-08	-5.68e-08***	-6.34e-08***
	(2.16e-08)	(1.30e-08)	(1.26e-08)
W*Labor	0.000322	0.000239	-2.03e-06
	(0.000495)	(0.000295)	(0.000289)
W*Capital	-8.08e-07	-1.14e-05	-3.09e-05
	(3.57e-05)	(2.13e-05)	(2.09e-05)
W*Income	9.40e-05**	5.14e-05*	8.07e-05***
	(4.73e-05)	(2.85e-05)	(2.80e-05)
W*Profit	-0.000347	-0.000318	-0.000392*
	(0.000392)	(0.000238)	(0.000231)
sigma2_e	0.237***	0.0859***	0.0808***
	(0.0155)	(0.00564)	(0.00527)
Observations	480	480	480
R-squared	0.7042	0.7692	0.7926

Number of ID	30	30	30

Table 8 shows the regression results with InStructure as the mediating variable. In Model-13, ERI is used as the core explanatory variable and InStructure is used as the dependent variable. In Model-14, InStructire was used as the core explanatory variable, and HTFP was used as the dependent variable. In Model-15, ERI and InStructure were used as core explanatory variables, and HTFP was used as dependent variable.

According to Model-13, the spatial lag coefficient of InStructure is 0.610, which is significant at the 1% level. For every 1% increase in the local 1nStructure, the surrounding area InStructure will increase by 0.610%. The regression coefficient of the effect of ERI on local InStructure is 0.00901. The regression coefficient of the influence of ERI in surrounding areas on local InStictire is 0.175, which is significant at the level of 1%. This shows that the environmental regulation of surrounding areas has a certain degree of impact on the changes of pharmaceutical industrial structure, while the impact of local environmental regulation is not significant.

According to Model-14, the spatial lag coefficient of HTFP is 0.636, the regression coefficient of InStructure to local HTFP is 0.262, and the regression coefficient of InStructure to local HTFP is 0.147. But the latter is not significant. This shows that HTFP in this area is mainly affected by InStructure in this area, while InStructure in surrounding areas is not significant.

According to Model-15, the spatial lag coefficient of HTFP is 0.433, the regression coefficients of ERI and InStructure to local HTFP are 0.0971 and 0.248, respectively. The regression coefficients of HTFP were 0.510 and -0.0800 respectively. The regression coefficients of HTFP were significant except for the effect of InStructure in the surrounding areas on the local HTFP.

Through the above analysis, we can get the intermediary transmission path of InStructure: the improvement of environmental regulation in surrounding areas promotes the upgrading of local pharmaceutical industrial structure, thus promoting the improvement of local HTFP, which proves that Hypothesis 3.

Table 8 The mediating effect of industrial structure

Model	(13) lnStructure	(14) HTFP	(15) HTFP
W*HTFP	0.610***	0.636***	0.433***
	(0.0399)	(0.0351)	(0.0468)
ERI	0.00901		0.0971**
	(0.0278)		(0.0432)
lnStructure		0.262***	0.248***
		(0.0721)	(0.0697)
Open	1.99e-09	3.82e-08***	2.89e-08***
	(5.77e-09)	(8.90e-09)	(8.65e-09)
Labor	0.000547***	0.000259	0.000166
	(0.000157)	(0.000245)	(0.000237)

Capital	8.17e-06	4.76e-05***	3.32e-05**
	(1.08e-05)	(1.66e-05)	(1.60e-05)
Income	2.40e-05**	-0.000103***	-8.46e-05***
	(1.20e-05)	(1.83e-05)	(1.78e-05)
Profit	-0.000428***	0.000742***	0.000653***
	(0.000111)	(0.000172)	(0.000166)
W*ERI	0.175***		0.510***
	(0.0376)		(0.0680)
W*lnStructure		0.147	-0.0800
		(0.0978)	(0.0989)
W*Open	-3.66e-08***	-4.78e-08***	-5.55e-08***
	(8.57e-09)	(1.34e-08)	(1.29e-08)
W*Labor	-0.000824***	0.000918***	0.000345
	(0.000198)	(0.000302)	(0.000299)
W*Capital	2.97e-05**	-4.14e-05*	-4.94e-05**
	(1.44e-05)	(2.23e-05)	(2.16e-05)
W*Income	1.42e-05	9.70e-05***	0.000112***
	(1.85e-05)	(2.84e-05)	(2.75e-05)
W*Profit	-9.98e-05	-0.000500**	-0.000541**
	(0.000156)	(0.000240)	(0.000232)
sigma2_e	0.0376***	0.0885***	0.0822***

	(0.00251)	(0.00588)	(0.00539)
Observations	480	480	480
R-squared	0.5795	0.6665	0.7702
Number of ID	30	30	30

4.4.2 Heterogeneity analysis

Due to the differences of temporal and spatial variation characteristics of ERI and HTFP in the eastern, central and western regions, the spatial spillover effects of ERI on HTFP will also be different in different regions. Therefore, this paper takes into account the spatial agglomeration and geographic location heterogeneity of provinces in different regions, establishes a spatial Durbin model, and discusses the impact of ERI on HTFP in the eastern, central and western regions.

Tabel 9 is the regression result of heterogeneity analysis. Model-6 is the regression result of the whole country, which is used as the control group of heterogeneity analysis. Model-16, Model-17 and Model-18 are the regression results of the eastern, central and western, respectively.

According to the spatial lag coefficient of HTFP, the influence degree of HTFP in the surrounding areas on local HTFP from high to low is central (0.609), eastern (0.336) and western (0.241), which are all significant at the level of 1%.

According to the regression coefficient of the impact of local ERI on local HTFP, the impact degree of central (0.181) and western (0.248) is greater than the national level, and both are significant at 1% level. But the local ERI in the east is not significant. This shows that under the strict environmental regulation, the cost of the eastern region has not effectively promoted the transformation of production structure and the development of green technology, and the screening effect of clean enterprises is not significant, which is related to the technical basis and infrastructure conditions of the eastern region itself.

From the regression coefficient of the impact of ERI on local HTFP in the surrounding areas, the impact of eastern (0.899) and central (0.119) is positive, and both are significant at the level of 1% and 10%, respectively. But in the western region, the effect was negative (-0.0350) and not significant. This shows that for the western region, the increase of environmental regulation in surrounding areas will force the local industry to become the undertaker of pollution, leading to the development of local industrial structure towards non-clean pollution industries, thus reducing the local HTFP.

From the regression coefficient of the influence of control variables, the three regions also show different degrees of influence, different directions of action and different levels of significance.

To sum up, for the adjustment of environmental regulation in different regions, it is necessary to improve environmental regulation in the eastern and central regions, while in the western region, it is necessary to strengthen local ERI, weaken the transfer effect of environmental regulation on "polluting enterprises", and pay attention to the improvement of industrial technology, rather than the transfer of polluting industries.

Table 9 Result of heterogeneous regression

Model	(6) Nation	(16) East	(17) Central	(18) West
W*HTFP	0.460***	0.336***	0.609***	0.241***
	(0.0455)	(0.0754)	(0.0464)	(0.0778)
ERI	0.101**	0.00630	0.181***	0.248***
	(0.0430)	(0.0872)	(0.0504)	(0.0697)
Open	2.86e-08***	2.28e-08**	-1.33e-07***	-1.01e-07*
	(8.61e-09)	(9.08e-09)	(4.32e-08)	(5.64e-08)
Labor	0.000271	-0.000788***	0.00217***	0.000117
	(0.000235)	(0.000295)	(0.000465)	(0.00125)
Capital	3.79e-05**	2.45e-05	-4.15e-06	0.000425***
	(1.60e-05)	(1.73e-05)	(5.25e-05)	(0.000117)
Income	-7.92e-05***	-6.79e-05***	0.000126**	-0.000268***
	(1.80e-05)	(1.89e-05)	(5.31e-05)	(0.000103)
Profit	0.000537***	0.000752***	-0.00109***	0.00116
	(0.000166)	(0.000187)	(0.000378)	(0.000716)
W*ERI	0.553***	0.899***	0.119*	-0.0350
	(0.0662)	(0.116)	(0.0631)	(0.118)
W*Open	-6.48e-08***	-4.22e-08***	1.76e-07***	1.65e-07

	(1.28e-08)	(1.21e-08)	(5.19e-08)	(1.33e-07)
W*Labor	9.75e-05	0.000235	-0.00155***	0.00605***
	(0.000295)	(0.000302)	(0.000483)	(0.00190)
W*Capital	-3.80e-05*	-3.04e-06	5.75e-07	-0.000347
	(2.13e-05)	(2.07e-05)	(5.99e-05)	(0.000304)
W*Income	0.000115***	5.76e-05**	-6.43e-05	0.000497**
	(2.78e-05)	(2.57e-05)	(6.79e-05)	(0.000225)
W*Profit	-0.000597***	-0.000616***	0.000855**	-0.00117
	(0.000232)	(0.000220)	(0.000413)	(0.00121)
sigma2_e	0.0843***	0.0821***	0.0254***	0.0837***
	(0.00554)	(0.00900)	(0.00340)	(0.00897)
Observations	480	176	128	176
R-squared	0.7603	0.545	0.709	0.460
Number of ID	30	11	8	11

4.4.3 Endogenous discussion

Although the use of spatial econometric model can better study the spatial spillover effect of ERI and HTFP, there may be endogenous problems caused by the omission of variables and the results of bias, so this paper uses GS2SLS spatial econometric tool variable method to alleviate the endogenous problems that may exist in the model.

Based on Hering and Poncet(2014), this paper uses *Ventilation* as the instrumental variable of environmental regulation [62]. According to Jacobson (2003), the air flow coefficient is equal to the product of the boundary layer height and the wind speed [63]. In this paper, based on the global network of ten meters wind speed and boundary layer height data in the ERA-Interim database of the European Center for Medium-Range Weather Forecasts, the air circulation coefficient of each network in the corresponding year is calculated, and then the air circulation coefficient of each province is obtained according to the longitude and latitude matching of each provincial capital city.

When air pollutant emissions are the same, cities with low air ventilation coefficient tend to use more stringent environmental regulation tools. The calculation process of environmental regulation itself includes environmental pollution, so it can be considered that there is a correlation between environmental regulation and air circulation coefficient. Moreover, the air circulation coefficient only depends on natural phenomena such as climate conditions, and there is no other mechanism with the total factor productivity of the pharmaceutical industry, so the air circulation coefficient as an instrumental variable, which has exogeneity.

Table 10 is the result of the GS2SLS instrumental variable method. From the results, Ventilation coefficient and environmental regulation (ERI) are significantly negative at the level of 5%, with a coefficient of -0.256. The results are in agreement with the theoretical expectation.

The spatial lag coefficient of ERI is 0.0106, but the result is not significant, which indicates that local environmental regulation is endogenous, while the environmental regulation of surrounding areas is not endogenous, indicating that there is no two-way causal relationship between ERI of surrounding areas and local HTFP.

Table 10 Results of instrumental variable method

Model	(19) HTFP
Ventilation	-0.256**
	(0.109)
Open	2.92e-08
	(3.39e-08)
Labor	0.00104***
	(0.000315)
Capital	9.78e-05
	(9.15e-05)
Income	2.51e-05
	(0.000137)
Profit	-0.00354***
	(0.00126)
W*ERI	0.0106
	(0.0172)
W*e.ERI	-1.946**

	(0.841)
Constant	5.167***
	(0.180)
Pseudo R2	0.2838
Wald test of spatial terms	5.78*
Observations	30

4.4.4 Robustness test

In order to test the robustness of the model established in this paper, the following methods are used to compare the robustness of the results by replacing the control variables and the spatial weight matrix. Table 11 shows the results of the robustness test. Model-6 was the control group, Model-20 replaced the control variable Open with Open2, Model-21 replaced the control variable Capital with Capital2, and Model-22 replaced the 0-1 adjacency matrix (W1) with the geographical distance matrix (W2). As a result, the magnitude and significance of the regression coefficients changed only slightly, but not in direction. Therefore, the spatial econometric regression results obtained in this paper are robust.

Table 11 Robustness Test Result

Model	(6) HTFP-W1	(20) Open2	(21) Capital2	(22) HTFP-W2
W*HTFP	0.460***	0.470***	0.413***	0.412***
	(0.0455)	(0.0454)	(0.0478)	(0.0879)

ERI	0.101**	0.0937**	0.0827*	0.0172*
	(0.0430)	(0.0435)	(0.0435)	(0.0439)
T		1.37e-08***	8.03e-07	
		(4.95e-09)	(1.56e-06)	
Open	2.86e-08***		3.09e-08***	2.11e-08**
	(8.61e-09)		(8.83e-09)	(8.32e-09)
Labor	0.000271	0.000446*	0.000223	0.000310
	(0.000235)	(0.000245)	(0.000228)	(0.000234)
Capital	3.79e-05**	4.29e-06		2.50e-05
	(1.60e-05)	(1.75e-05)		(1.57e-05)
Income	-7.92e-05***	-5.62e-05***	-5.69e-05***	-6.90e-05***
	(1.80e-05)	(1.69e-05)	(1.50e-05)	(1.77e-05)
Profit	0.000537***	0.000569***	0.000621***	0.000466***
	(0.000166)	(0.000169)	(0.000166)	(0.000161)
W*ERI	0.553***	0.515***	0.469***	0.580***
	(0.0662)	(0.0674)	(0.0698)	(0.153)
W*T		-2.47e-08***	4.78e-06**	
		(7.58e-09)	(1.91e-06)	
W*Open	-6.48e-08***		-3.75e-08***	-8.33e-08**
	(1.28e-08)		(1.28e-08)	(3.31e-08)
W*Labor	9.75e-05	-0.000209	0.000445	-0.00167**

	(0.000295)	(0.000309)	(0.000297)	(0.000814)
W*Capital	-3.80e-05*	4.25e-05*		-5.97e-05
	(2.13e-05)	(2.17e-05)		(4.86e-05)
W*Income	0.000115***	4.78e-05**	5.20e-05**	0.000168***
	(2.78e-05)	(2.30e-05)	(2.19e-05)	(4.48e-05)
W*Profit	-0.000597***	-0.000556**	-0.000579**	-5.44e-05
	(0.000232)	(0.000239)	(0.000229)	(0.000454)
sigma2_e	0.0843***	0.0863***	0.0842***	0.0807***
	(0.00554)	(0.00567)	(0.00551)	(0.00523)
Observations	480	480	480	480
R-squared	0.393	0.349	0.342	0.561
Number of ID	30	30	30	30

5 Discussion

By constructing a spatial econometric, this paper study the impact of the environmental regulation on the total factor productivity of the pharmaceutical industry. The empirical results show that: (1) ERI and HTFP show "high-high" or "low-low" spatial clustering characteristics, and local HTFP has a positive role in promoting HTFP in surrounding areas; (2) ERI has a significant positive impact on HTFP in local and surrounding areas, but there are differences in the performance of the three regions; (3) ERI affects HTFP in local and surrounding areas through the mediating effect of green technology, production technology and industrial structure.

The above three conclusions will be discussed in this section.

5.1 The spatial clustering characteristics of HTFP

In Section 4.3.1, the global Moran index is used to verify the existence of positive spatial autocorrelation of HTFP, and the Moran scatter plot and LISA aggregation plot are plotted. It is shown that HTFP has the spatial agglomeration characteristics of "high-high" or "low-low" aggregation. For example, from Fig.4(a) and Fig.4(b), HTFP shows "high-high" aggregation of provinces such as Tianjin and Jiangsu, and "low-low" aggregation of provinces such as Xinjiang and Chongqing. China's pharmaceutical manufacturing industry has a good momentum of development, under the influence of policies, resources and other factors, the overall showing a more obvious regional characteristics. In recent years, remarkable industrial clusters have been formed in the Yangtze River Delta, Dawan District and Bohai Rim, mainly relying on regional innovation-driven, industrial support, economic base and other advantages. The improvement of HTFP in the surrounding areas will promote the improvement of local HTFP to a certain extent Tianjin and Jiangsu, as representatives of the Bohai Rim and Yangtze River Delta, show the characteristics of "high-high" aggregation.

As an emerging industrial cluster, Sichuan-Chongqing region has a "low-low" aggregation in the results, the main reasons are: (1) there is a short-term effect of R&D investment on the growth of enterprises, but the R&D investment of enterprises needs long-term accumulation; (2) The innovation output cycle of pharmaceutical products is longer than that of other industries, and the innovation achievements may not be obvious in a short time; (3) There is innovation spillover effect in pharmaceutical manufacturing industry, and technology leaders provide technology to transferees involuntarily, which makes technology leaders fail to receive corresponding returns. Xinjiang borders Qinghai, Gansu and Inner Mongolia, and its geographical location is located in the westernmost part of China, far from the industrial cluster cities, forming a "low-low" agglomeration situation.

5.2 Spatial agglomeration characteristics of ERI

For example, from Fig.5(a) and Fig.5(b), the provinces with "high-high" ERI are Hebei, Shandong and Jiangsu, and the provinces with "low-low" ERI are Gansu and Ningxia. Hebei and Shandong are traditional provinces with large industrial and resource reserves, and also have severe environmental conditions, which require more stringent environmental regulation. So these industrial clusters have formed a "high-high" cluster.

In Jiangsu Province, which is close to the traditional industrial agglomeration area, the environmental regulation has also appeared the characteristics of "high-high" agglomeration. The main reasons are as follows: (1) Jiangsu is located in the border area of traditional industries, and there may be some enterprises using the layout of other places to avoid supervision, which aggravates the environmental pollution in the adjacent areas, so more stringent environmental regulation is needed; (2) Environmental regulation in Jiangsu has "marginal effect", and the environmental benefits brought by the same environmental input cost will be lower than other provinces, so more targeted and effective environmental governance measures should be taken to improve the efficiency of environmental regulation. However, Gansu and Ningxia are far away from traditional industrial clusters and heavy industrial clusters, and the intensity of environmental regulation is relatively small, thus forming the "low-low" aggregation characteristics of environmental regulation.

5.3 Effect of ERI on HTFP

ERI has a significant role in promoting HTFP in local and surrounding areas, through the intermediary effect of green technology, production technology and industrial structure. In the eastern region, ERI had no significant effect on local HTFP, but had significant effect on HTFP in the surrounding areas; In the central region, ERI has a significant positive impact on HTFP in local and surrounding areas; In the western region, ERI has a significant positive impact on the local HTFP, and has a negative impact on the HTFP of the surrounding areas, but not significant. The following will be combined with the intermediary effect, analysis of the role of different regional differences.

In the eastern region, the pharmaceutical manufacturing industry clusters are widely distributed, at the same time, some areas are affected by the traditional industrial layout, and the efforts of environmental regulation are increasing. Environmental regulation promotes the development of green technology and the adjustment of production technology through the backward effect, improves the content of scientific and technological innovation of enterprises, and promotes the pharmaceutical manufacturing industry. Taking the Yangtze River Delta as an example, strengthening environmental regulation has promoted the formation of innovative achievements of local enterprises and the expansion of pharmaceutical industry structure. Pharmaceutical enterprises set up branches around them to liaise with local enterprises and exchange labor force. Peripheral enterprises will gradually absorb some advanced technology and management of enterprises in the Yangtze River Delta, in order to enhance the innovation ability of the surrounding pharmaceutical enterprises and produce innovative results. And that spillover effect of ERI and innovation achievement make the influence of ERI on local HTFP not significant, but the influence on HTFP of surrounding area is significant.

In the central region, the development of pharmaceutical manufacturing industry is relatively average, it is difficult to form many industrial clusters. The high-quality development of manufacturing industry has some drawbacks, such as the large proportion of low-end industries in the value chain, the slow start of cross-provincial and cross-sectoral innovation platform construction, and the imperfect mechanism of regional coordinated development. The central region has a good foundation for development, and environmental regulation has improved green technology and production technology to a certain extent. Compared with the eastern region, the central region pays more attention to the comprehensive coordination and resource flow of small regions in the scale of urban agglomeration or central city circle. The convergence of industrial structure is common, the complementarity between industries is not strong, and the regional comparative advantage is difficult to give full play to. Therefore, for the central region, environmental regulation needs to promote the upgrading of manufacturing industrial structure from the perspective of structural effect, and give full play to the role of ERI in promoting HTFP in local and surrounding areas.

In the western region, the pharmaceutical manufacturing industry has developed rapidly. As an important energy production base, the western region has brought serious pollution problems to the local environment due to its low technical level, so it is necessary to strengthen the environmental regulation in the western region. Environmental regulation forces enterprises to speed up innovation and improve total factor production through the cost of compliance. On the other hand, environmental regulation will increase production costs and squeeze R&D investment, which will have a negative impact on total factor productivity. The economic foundation of the western region is relatively weak, environmental regulation will be to a certain extent. Squeeze R&D investment, so that the western region as a whole has the fundamental problem of insufficient technological innovation. Therefore, the impact of ERI on local HTFP in the western region is smaller than that in the whole country, and has a negative impact on HTFP in the surrounding areas.

6 Conclusions and Policy Recommendations

In this paper, the direct effect and spatial spillover effect of ERI on HTFP are studied by establishing fixed effect model and spatial Dubin model. The main conclusions are as follows:

First, increasing environmental regulation has a significant role in promoting the total factor productivity of pharmaceutical manufacturing industry. For every 1% increase in ERI, HTFP will increase by 0.751%.

Second, ERI and HTFP have significant positive spatial autocorrelation, and there are "high-high" aggregation and "low-low" aggregation characteristics. Environmental regulation has a significant positive impact on the total factor productivity of pharmaceutical manufacturing industry in local and surrounding areas. For every 1% increase in ERI, the local HTFP will increase by 0.101%, and the surrounding HTFPs will increase by 0.553%.

Third, in the further analysis, environmental regulation has an impact on HTFP through the intermediary effects of green technology, production technology and industrial structure. At the same time, the influence effect of ERI on HTFP shows heterogeneous characteristics in the eastern, central and western regions.

Based on the above empirical results, this paper puts forward the following policy recommendations from the perspective of the whole country and the three major regions:

Firstly, for the whole country, facing the urgent requirements of clean industry transformation, it is necessary to combine the development characteristics and advantages of each region, strengthen regional cooperation and promote collaborative governance. Accelerate the construction of integrated demonstration zones, radiate the development of surrounding areas, and promote the coordinated development of pharmaceutical manufacturing industry. At the same time, it is necessary to build a scientific research platform to improve the ability of independent innovation. Encourage and guide enterprises, colleges and universities and other innovative subjects to make full use of their scientific research advantages. Actively build a platform for cultivating and sharing scientific research achievements, optimize the scientific research and innovation environment by means of strategic cooperation, and expand the transformation and application of scientific and technological achievements, so as to improve green technology and production technology.

Secondly, for the eastern region, we need to effectively use the regional economic environment, infrastructure, technological innovation, industrial clusters and other advantages to optimize the industrial structure of pharmaceutical manufacturing industry and develop environmental protection industry. With the concept of green development, we should promote green pharmaceutical manufacturing industry, develop green circular economy, and constantly improve the scientific and technological content and clean content of the industry. At the same time, we need to standardize the market order and improve the trading mechanism. Drawing on mature experience, we should actively cultivate a platform for property rights trading of environmental resources, promote the implementation of market-oriented environmental and economic policy mechanisms such as green insurance and green credit, and promote the level of total factor productivity of pharmaceutical manufacturing industry with a mild environmental regulation system.

Thirdly, for the central region, we should focus on technological transformation and technological innovation, vigorously promote the transformation and upgrading of traditional industries, accelerate the transformation of green and clean industries and the development of pharmaceutical manufacturing industries, improve the productivity of all manufacturing workers, upgrade the level of industrial development, and promote the transformation of central speed to central quality. At the same time, we should improve the industrial complementarity of the central region, expand the small regional urban agglomeration to large-scale industrial clusters, and give full play to the advantages of each region, so as to improve the promoting effect of environmental regulation on improving the total factor productivity of pharmaceutical manufacturing industry.

Finally, for the western region, the role of environmental regulation in promoting the development of pharmaceutical manufacturing industry is limited, the backward effect to improve the technological innovation of enterprises is insufficient in terms of funds, and the environmental regulation of surrounding areas will make the region a pollution-bearing area, which requires the government to increase financial support for clean transformation enterprises, such as reducing taxes and costs. Implement restrictive policies on enterprises, increasing the cost of cross-regional transfer of polluting enterprises, limiting the number of cross-regional transfer of polluting enterprises, and increasing government investment in R&D, fundamentally solving the problem of transformation of pollution enterprises, so as to improve the total factor productivity of pharmaceutical manufacturing industry.

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Conflicts of Interest

The author(s) declare no competing interests.

Author Contributions

Conceptualization, Q.W. and S.Z.; Methodology, Q.W. and S.Z.; Software, Y.L. and F.L.; Validation, Q.W., Y.L. and Y.W.; Formal Analysis, Q.W. and Y.L.; Investigation, Y.W. and F.L.; Resources, Q.W. and S.Z.; Data Curation, Q.W., Y.L. and Y.W.; Writing – Original Draft Preparation, Q.W., Y.L., Y.W. and S.Z.; Writing – Review & Editing, Q.W., Y.L., F.L. and S.Z.; Visualization, Q.W. Y.W. and F.L.; Supervision, Q.W. and S.Z.; Project Administration, Q.W. and S.Z.; Funding Acquisition, S.Z.

Data Availability Statement

The data selected in this paper are all from China Statistical Yearbook, China Environmental Yearbook, China High-tech Industry Statistical Yearbook, China Environmental Statistical Yearbook, China Industrial Statistical Yearbooks, China Health Statistical Yearbooks, provincial statistical yearbooks and the ERA-Interim database of the European Center for Medium-Range Weather Forecasts.

The data that support the findings of this study are available from [www.cnki.net], but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of [www.cnki.net].