Scientific Research Publishing

Pharmacology & Pharmacy, 2023, 14, 98-111
https://www.scirp.org/journal/pp
ISSN Online: 2157-9431
ISSN Print: 2157-9423

Study on Carbon Emission Efficiency Evaluation and Influencing Factors of Chinese Pharmaceutical Manufacturing Industry

Ying Cui, Shuzhen Chu*

International Pharmaceutical Business School, China Pharmaceutical University, Nanjing, China
Email: 674246062@qq.com, *1019941160@cpu.edu.cn

How to cite this paper: Cui, Y. and Chu, S.Z. (2023) Study on Carbon Emission Efficiency Evaluation and Influencing Factors of Chinese Pharmaceutical Manufacturing Industry. *Pharmacology & Pharmacy*, **14**, 98-111.
https://doi.org/10.4236/pp.2023.144008

Received: March 13, 2023
Accepted: April 14, 2023
Published: April 17, 2023

Abstract

To measure the carbon emission efficiency of China's pharmaceutical manufacturing industry, explore the factors affecting the carbon emission efficiency of China's pharmaceutical manufacturing industry, and provide reference for improving the carbon emission efficiency of China's pharmaceutical manufacturing industry and promoting the government to formulate macro policies. Based on the data of the pharmaceutical manufacturing industry in 30 provinces of China from 2010 to 2019, and based on the SBM model and ML (Malmquist-Luenberger) index model, the carbon emission efficiency of the pharmaceutical manufacturing industry was calculated and its dynamic change was investigated, and the Tobit model was further used to explore the influencing factors of the carbon emission efficiency of the pharmaceutical manufacturing industry. The carbon emission efficiency of China's inter-provincial pharmaceutical manufacturing industry has steadily improved. The carbon emission efficiency of the eastern region is higher than that of the western region, and that of the western region is higher than that of the central region. The eastern region is dominated by technological progress, and there is room for improvement in technological efficiency. The central and western regions are dominated by technological efficiency. Compared with technological efficiency, technological progress needs to be further improved. Environmental regulation, industrial agglomeration and technological innovation level positively affect carbon emission efficiency, while foreign investment level has no significant impact on carbon emission efficiency.

Keywords

Carbon Emission Efficiency, SBM Model, ML Index, Pharmaceutical Manufacturing, Tobit Model

*Corresponding author.

1. Introduction

Global warming has broken the balance of natural ecosystem and is threatening the survival and development of human beings. The rapid development of industry consumes large amounts of fossil fuels, along with the production of the greenhouse gas carbon dioxide. At the 75th session of the UN General Assembly, China proposed to peak its carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. Over the past 40 years of reform and opening up, great changes have taken place in the scale and structure of energy production and consumption. The course of energy development can be described as magnificent. However, there has not been a fundamental change in China's energy structure that is lower than coal and energy efficiency, and pollution problems in key regions and industries have not been fundamentally solved. Resource and environmental constraints have intensified, carbon peaking, carbon neutralization time window is tight, and technology reserves are insufficient, and it is difficult to promote industrial green and low carbon transformation. Domestic and foreign scholars from the national level (such as the Organization for Economic Cooperation and Development (OECD) economies [1], "One Belt, One Road" countries [2], Central and Western Europe [3], etc.), regional level (such as provinces [4], Yangtze River Delta, Pearl River Delta and the three economic circles of Beijing-Tianjin-Hebei [5], etc.) industry level (railway transportation [6], industrial industry [7], agriculture [8], construction [9], tourism [10], etc.), but there are few studies on the carbon emission efficiency of pharmaceutical manufacturing industry. The pharmaceutical industry provides material basis for protecting people's life and health, such as drugs and medical devices. Meanwhile, as one of the heavily polluting industries, it is urgent to implement the action plan of carbon emission reduction in key areas of the pharmaceutical industry, clarify the target of carbon dioxide emission intensity control, and improve the comprehensive utilization efficiency of resources in the whole industry. Therefore, it is of great significance to study the carbon emission efficiency of Chinese pharmaceutical manufacturing industry and further explore its influencing factors for the reduction of greenhouse gas emission and the prevention and control of air pollution.

2. Literature Review

At present, most scholars use DEA model or stochastic frontier function method to measure carbon emission efficiency. For example, Wang Rong *et al.* [11] chose data envelopment analysis and Malmquist index model to evaluate China's agricultural carbon emission efficiency from static and dynamic perspectives. Caiqing Zhang [12] *et al.* calculated the industrialization, urbanization and carbon emission efficiency of the Yangtze River Economic Belt based on the stochastic frontier model. With the continuous improvement of the theory of super-efficiency DEA model and non-expected output SBM model, many scholars tend to use these two more scientific and effective models when measuring efficiency. For example, Huayong Niu [13] *et al.* calculated the carbon emission efficiency of each province by using the three-stage DEA model of super efficiency. Xiaoye Li [14] *et al.* combined the measurement data Envelopment analysis (SBM-DEA) model based on three-stage relaxation and Malmquist-Luenberger model. The dynamic carbon emission efficiency of China's industrial energy was accurately measured. Kai Tang [15] *et al.* calculated the carbon emission efficiency of 262 Chinese cities from 2003 to 2016 using the super-efficiency SBM model. Song Aifeng [16] *et al.* used a novel super epsilon-based measures (SEBM) carbon emission efficiency evaluation model) analyzed China's carbon emission efficiency from time and space dimensions respectively.

In terms of the research on influencing factors of carbon emission efficiency, existing literatures mainly focus on the relationship between carbon emission efficiency and scientific and technological innovation level, industrial agglomeration level, environmental regulation intensity, foreign investment, industrial structure, economic efficiency of energy consumption, etc. Jiang Pan [17] *et al.* believe that when green technology innovation is taken as a threshold variable, the relationship between environmental regulation and carbon emission rate shows a "U" shape. Zuoren Sun *et al.* [18] believe that industrial agglomeration has a significant impact on urban carbon efficiency, with significant spatial spillover effect. Ruijing Zheng [19] *et al.* believe that scientific and technological innovation is expected to significantly improve carbon emission efficiency in Central and eastern Europe; Shijian Wu [20] *et al.* measured and analyzed the carbon emission efficiency of the three urban agglomerations in the Yangtze River Economic Belt, and believed that FDI only had a positive impact on the carbon emission in the Yangtze River Delta and the middle reaches of the Yangtze River. Qizhen Wang [21] *et al.* discussed the relationship between FDI, technological innovation and carbon emission efficiency, and found that the influence of FDI and technological innovation on carbon emission efficiency presents regional heterogeneity. Other scholars explored the combined effects of various influencing factors on carbon emission efficiency, such as Lin Xueqin [22] *et al.*, who found that productivity level, industrial R&D input and opening-up level had a positive promoting effect on industrial carbon emission efficiency. Based on the above research results, this study uses the SBM model and ML index to measure the carbon emission efficiency, and examines the carbon emission efficiency of 30 provinces in China from five aspects. They include energy consumption from main business income of pharmaceutical manufacturing units, foreign investment, industrial agglomeration, environmental regulation and scientific and technological innovation level.

3. Carbon Emission Efficiency Measurement of China's Pharmaceutical Manufacturing Industry

3.1. Measurement Method

In this paper, the extended model of data Envelopment analysis (DEA), that is, the non-expected output super efficiency SBM model, is used for calculation. The efficiency measurement of the traditional DEA model is not affected by the units of input and output indicators. Because it does not consider the problem of relaxation variables and the actual situation that the input and output will appear redundant, the calculation results will be biased and not accurate enough. Therefore, on the basis of traditional DEA, Tone proposed a SBM model considering the non-radial Angle of relaxation variables. This model directly introduced all relaxation variables into the objective function in a non-ray mode of action, and the evaluation results of efficiency value were more accurate. In order to solve the problem that the efficiency value of many DMU in the results is equal to 1 and its real size cannot be measured, Tone [23] *et al.* introduced the super efficiency SBM model, the formula is shown in (3-1).

$$
\begin{aligned}
&\min \rho = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1+\frac{1}{e_1+e_2}\left(\sum_{r=1}^{e_1}\frac{s_r^+}{y_{rk}}+\sum_{t=1}^{e_2}\frac{s_t^{b-}}{b_{tk}}\right)} \\
&\sum_{j=1,j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leq x_{ik} \\
&\sum_{j=1,j\neq k}^{n} y_{rj}\lambda_j - s_r^+ \geq y_{rk} \\
&\sum_{j=1,j\neq k}^{n} b_{tj}\lambda_j - s_t^{b-} \leq b_{tk} \\
&i=1,2,\cdots,m; r=1,2,\cdots,e_1; t=1,2,\cdots,e_2; j=1,2,\cdots,n\left(j\neq k\right)
\end{aligned} \tag{3-1}
$$

ρ represents the carbon emission efficiency value in the formula. There are m inputs, e_1 expected outputs, e_2 non-expected outputs. x represents input, y represents expected output, b represents non-expected output. $s=\left(s_i^+, s_r^-, s_t^{b-}\right)$ represents the relaxation of input, expected output and unexpected output, λ represents the weight vector.

3.2. Selection and Treatment of Carbon Emission Efficiency Indicators

This paper measures the carbon emission efficiency of China's pharmaceutical manufacturing industry from the perspective of input-output. The input-output indicators are shown in **Table 1**.

Table 1. Index system of carbon emission efficiency.

Type	First-order index	Secondary index	Three-level index
Input	Capital element	Asset investment	Investment in fixed assets of pharmaceutical manufacturing industry
	Elements of labor force	Number of employees	Average employment in pharmaceutical manufacturing
	Energy element	Energy consumption	Energy consumption of pharmaceutical manufacturing industry
Output	Expected output	Economic benefit	Pharmaceutical manufacturing industry main business income
	Undesirable output	Carbon dioxide	CO_2 emissions from pharmaceutical manufacturing

The basic input factors include capital factors and labor factors. The fixed asset investment of pharmaceutical manufacturing enterprises is used as the replacement index of capital factors, and the GDP index is deflated with 2010 as the base period. The average number of employees of pharmaceutical manufacturing enterprises is used as the replacement index of labor factors. Different from ordinary efficiency, energy consumption should also be included in the input index of carbon emission efficiency for analysis. The energy consumption of pharmaceutical manufacturing industry in various provinces is converted through the coefficient relationship between different energy consumption and standard coal. The main business income is used as an alternative indicator of economic benefit, and the GDP index is deflated based on 2010. The annual CO_2 emission of pharmaceutical manufacturing industry in 30 provinces was taken as the index of undesirable output.

The panel data of pharmaceutical manufacturing industry in 30 provinces of China except Hong Kong, Macao, Taiwan and Xizang from 2010 to 2019 were used as research samples. The original data of each index came from the official website of CEADs, China High-tech Industry Statistical Yearbook, China Investment Statistical Yearbook, China Statistical Yearbook, China Industrial Statistical Yearbook and local statistical yearbooks. For individual missing values, interpolation method was used to fill in the data.

3.3. Measurement Result of Static Efficiency of Carbon Emission

MATLABR2022b software is used to calculate the carbon emission efficiency of 30 provinces in China from 2010 to 2019, and the carbon emission efficiency is calculated separately in the eastern, central and western regions. The results are shown in Table 2. Nationally, the carbon emission efficiency of pharmaceutical manufacturing industry showed a fluctuating upward trend from 2010 to 2014, and reached the highest point of 0.936 in 2014. It showed a downward trend from 2015 to 2018, and recovered an upward trend from 2018 to 2019, which may be related to the rapid and vigorous development of generic drugs in pharmaceutical manufacturing industry in recent years. In the process of development, pharmaceutical enterprises pay more attention to economic benefits and ignore the innovation of green technology, thus the energy utilization efficiency began to decline. From the perspective of three regions, the carbon emission efficiency of pharmaceutical manufacturing industry in eastern region is higher than that in western region, and western region is higher than that in central region. The mean carbon emission efficiency of pharmaceutical manufacturing industry in eastern China was 0.931, higher than the national average of 0.914; the mean carbon emission efficiency of pharmaceutical manufacturing industry in western China was 0.924, also higher than the national average; and the mean carbon emission efficiency of pharmaceutical manufacturing industry in central China was 0.879, lower than the national average. The carbon emission efficiency of the pharmaceutical manufacturing industry in the eastern and central regions

Table 2. Carbon emission efficiency of pharmaceutical manufacturing industry in 30 provinces of China.

Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	mean
Beijing	1.001	0.921	1.006	1.009	1.023	1.014	1.028	1.031	1.022	1.025	1.008
Tianjin	0.893	0.897	0.976	0.976	1.001	1.006	0.963	1.003	0.944	0.934	0.959
Hebei	0.872	0.834	0.919	0.907	0.890	0.886	0.905	0.885	0.828	0.877	0.880
Shanxi	0.785	0.742	0.812	0.810	0.801	0.805	0.795	0.833	0.825	0.830	0.804
Nei Monggol	0.837	0.793	0.796	0.826	0.837	0.830	0.833	1.011	0.803	0.794	0.836
Liaoning	0.883	0.862	0.957	0.941	1.002	0.918	0.921	0.918	0.920	0.905	0.923
Jilin	0.839	0.801	0.887	0.882	0.891	0.885	0.886	0.861	0.810	0.825	0.857
Heilongjiang	0.862	0.848	0.907	0.894	0.895	0.878	0.885	0.871	0.850	0.841	0.873
Shanghai	0.891	0.849	0.897	0.930	0.908	0.923	0.945	1.000	0.901	0.871	0.911
Jiangsu	0.891	0.842	0.959	0.943	0.943	0.943	0.909	0.914	0.868	0.875	0.909
Zhejiang	1.021	0.900	1.010	0.969	0.983	1.008	0.942	1.005	0.930	0.973	0.974
Anhui	0.898	0.924	1.016	1.006	1.002	0.994	1.007	1.030	1.061	0.892	0.983
Fujian	0.840	0.792	0.833	0.827	0.817	0.818	0.819	0.802	0.805	0.808	0.816
Jiangxi	0.858	0.857	0.884	0.894	0.918	0.868	0.876	0.895	0.884	1.012	0.895
Shandong	0.973	0.888	1.001	1.009	0.995	1.001	0.945	0.961	0.850	0.870	0.949
Henan	0.905	0.845	0.939	0.916	0.917	0.935	0.890	0.883	0.826	0.843	0.890
Hubei	0.823	0.787	0.859	0.869	0.863	0.863	0.869	0.871	0.863	0.897	0.856
Hunan	0.821	0.805	0.864	0.881	0.902	0.884	0.898	0.911	0.869	0.912	0.875
Guangdong	0.908	0.880	0.910	0.917	0.891	0.866	0.869	0.871	0.854	0.859	0.882
Guangxi	0.865	0.932	0.877	1.000	1.003	1.006	1.000	0.949	0.813	0.888	0.933
Hainan	1.028	1.043	1.033	1.025	1.017	1.023	1.016	1.011	1.061	1.083	1.034
Chongqing	0.837	0.818	0.909	0.895	0.905	0.930	0.907	0.887	0.879	0.886	0.885
Sichuan	0.840	0.808	0.860	0.846	0.840	0.853	0.844	0.834	0.813	0.815	0.835
Guizhou	1.015	1.009	1.001	0.934	0.995	0.992	1.007	1.003	0.921	1.002	0.988
Yunnan	0.966	0.927	1.004	1.005	1.004	0.987	0.999	0.882	0.915	1.002	0.969
Shaanxi	0.963	1.044	0.987	0.976	0.980	0.960	0.959	1.000	1.003	1.003	0.988
Gansu	0.893	0.852	0.965	0.902	1.000	0.963	0.900	0.942	0.898	0.896	0.921
Qinghai	1.003	1.010	1.009	1.013	1.006	1.008	1.005	0.858	0.817	0.836	0.956
Ningxia	1.002	1.016	1.047	1.103	1.058	1.006	1.195	0.836	1.010	1.082	1.036
Xinjiang	0.745	0.779	0.815	0.840	0.783	0.794	0.769	0.755	0.771	0.756	0.781
Eastern region	0.927	0.882	0.955	0.950	0.952	0.946	0.933	0.946	0.907	0.916	0.931
Central region	0.849	0.826	0.896	0.894	0.899	0.889	0.888	0.894	0.874	0.882	0.879
Western region	0.913	0.907	0.950	0.942	0.947	0.939	0.946	0.894	0.892	0.916	0.924
mean	0.899	0.877	0.931	0.931	0.936	0.928	0.926	0.917	0.887	0.903	0.914

shows a W-shaped change trend; The carbon emission efficiency of the pharmaceutical manufacturing industry in the western region shows an overall N-shaped trend. According to the average carbon emission efficiency of the pharmaceutical manufacturing industry in each province in the past ten years, the average carbon emission efficiency of Ningxia Hui Autonomous Region, Hainan Province, Beijing City, Guizhou Province and Shaanxi Province ranks in the top five. Xinjiang Uygur Autonomous Region, Shanxi Province and Fujian Province ranked the bottom.

3.4. Calculation Results of Dynamic Efficiency of Carbon Emission

The calculation result of DEA model is technical efficiency. Since the production frontier referenced by DMU at different time points is different, it represents a relative efficiency and cannot dynamically analyze the change of productivity. Swedish economist Sten Malmquist [24] first proposed the Malmquist index in 1953, which is used to dynamically analyze the changes of productivity and the respective roles of technical efficiency and technological progress in productivity changes. Among them, the changes of production technology reflect the changes of production frontier. Changes in technical efficiency reflect the extent of movement to the forefront of production. Due to the existence of the undesired output problem, a modified Malmquist index appeared again. Chung *et al.* [25] applied the directional distance function containing the undesired output to the Malmquist model and called the resulting Malmquist index the Malmquist-Luenberger index. While the traditional Malmquist index is calculated based on the output distance function, the Malmquist-Luenberger index is calculated based on the directional distance function, which aims to increase the desired output while reducing the undesired output. Under the assumption of constant returns to scale (CRS), ML index can be decomposed into technical efficiency change index (MLEC) and technological progress index (MLTC) [26]. The calculation formulas are shown in (3-2) to (3-5).

$$\mathrm{ML}\left(x^{t+1}, y^{t+1}, z^{t+1}, x^{t}, y^{t}, b^{t}\right)=\sqrt{\frac{E^{t}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}{E^{t}\left(x^{t}, y^{t}, b^{t}\right)} \frac{E^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}{E^{t+1}\left(x^{t}, y^{t}, b^{t}\right)}} \quad (3\text{-}2)$$

$$\mathrm{MLEC}=\frac{E^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}{E^{t}\left(x^{t}, y^{t}, b^{t}\right)} \quad (3\text{-}3)$$

$$\mathrm{MLTC}=\sqrt{\frac{E^{t}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}{E^{t+1}\left(x^{t}, y^{t}, b^{t}\right)} \times \frac{E^{t}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}{E^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}} \quad (3\text{-}4)$$

$$\mathrm{ML}=\mathrm{MLEC} \times \mathrm{MLTC} \quad (3\text{-}5)$$

MATLABR2022b software was used to calculate the ML index and decomposition index of carbon emission efficiency in China from 2010 to 2019, and the three regions were divided into eastern, central and western regions. The results are shown in **Table 3**. From the perspective of the whole country, the ML index

Table 3. ML index and decomposition of carbon emission efficiency of pharmaceutical manufacturing industry in China by region.

	ML (National region)	MLEC (National region)	MLTC (National region)	ML (Eastern region)	MLEC (Eastern region)	MLTC Eastern region)	ML (Central region)	MLEC (Central region)	MLTC (Central region)	ML (Western region)	MLEC (Western region)	MLTC (Western region)
2010-2011	1.017	0.976	1.042	0.984	0.952	1.034	1.021	0.973	1.049	1.048	1.002	1.045
2011-2012	0.975	1.065	0.916	0.986	1.083	0.910	0.990	1.085	0.913	0.953	1.032	0.923
2012-2013	1.015	1.001	1.014	1.007	0.996	1.012	1.012	0.998	1.014	1.026	1.008	1.017
2013-2014	1.002	1.005	0.997	1.001	1.001	1.000	1.007	1.005	1.002	0.999	1.008	0.991
2014-2015	0.998	0.993	1.006	1.000	0.994	1.006	0.991	0.989	1.002	1.002	0.993	1.008
2015-2016	1.010	0.998	1.012	1.000	0.987	1.013	1.008	0.999	1.009	1.022	1.007	1.015
2016-2017	0.984	0.994	0.990	1.007	1.013	0.995	0.997	1.007	0.990	0.951	0.967	0.984
2017-2018	1.001	0.969	1.032	1.003	0.960	1.045	1.010	0.976	1.035	0.992	0.974	1.018
2018-2019	1.000	1.019	0.981	0.998	1.010	0.988	1.000	1.014	0.987	1.001	1.031	0.971
Mean	1.001	1.016	0.985	0.987	0.992	0.995	1.036	1.043	0.994	0.989	1.020	0.969

of the whole study period is relatively stable, with three periods less than 1, and the ML index of other periods greater than 1, indicating that the overall trend is rising from 2010 to 2019. The technical efficiency index can promote the improvement of carbon emission efficiency, and the average growth rate of the technical efficiency index is 1.6%, while the technical progress index is less than 1. It has an inhibitory effect on the improvement of carbon emission efficiency, with an average inhibitory rate of 1.5%. From a regional perspective, the technological progress and efficiency in the eastern region are both less than 1, and the technological progress is slightly higher than the technological efficiency, which means that the eastern region should pay attention to improving the technological progress and efficiency at the same time. It is suggested that the eastern region should further strengthen the resource allocation management and factor use efficiency and accelerate the technological progress at the same time; The technical efficiency of the central region has promoted the improvement of carbon emission efficiency. The average growth rate of technical efficiency is 4.3%, while the technical efficiency of the central region is less than 1, which indicates that the central region should pay more attention to technological progress; The technological efficiency of the western region plays a role in promoting the carbon emission efficiency, while the technological progress index of the western region is less than 1, indicating that the western region needs to further develop innovative technologies.

4. Empirical Analysis of Influencing Factors

4.1. Tobit Model Construction

Due to the non-negative truncation of carbon emission efficiency, the Tobit model is used for regression in this paper. The model construction is shown in

(4-1).

$$\mathrm{EFF}_{it} = \alpha + \beta_1 \mathrm{FDI}_{it} + \beta_2 \mathrm{CR}_{it} + \beta_3 \mathrm{ER}_{it} + \beta_4 \mathrm{NE}_{it} + \beta_5 \mathrm{Inno}_{it} + \varepsilon_{it} \quad (4\text{-}1)$$

In the formula, i represents different regions, t represents different years, and EFF is interpreted as a variable and represents the carbon emission efficiency of the pharmaceutical manufacturing industry. The explanatory variables were the level of foreign investment (FDI), the level of industrial agglomeration (CR) and the intensity of environmental regulation (ER). The unit of economic energy consumption (NE), scientific and technological innovation level (Inno), α is the constant term, ε_{it} is the error term.

4.2. Data Sources and Variable Description

The explained variable is the carbon emission efficiency (EFF) of the pharmaceutical manufacturing industry, which is calculated from the above. Others are explanatory variables. The level of foreign investment (FDI) is measured by the utilization of foreign investment in fixed assets of the whole society, and the GDP index is deflated with 2010 as the base period. Introducing foreign investment will increase the investment in scientific and technological innovation of enterprises, and may introduce foreign advanced pollution treatment technology to improve production efficiency and reduce carbon emissions. The degree of industrial agglomeration (CR) is measured by location entropy method. With high degree of industrial agglomeration, rapid technological exchange and diffusion, and vigorous development of technological intermediary market, resource utilization efficiency and technological innovation level are further improved, so as to improve carbon emission efficiency. Environmental regulation intensity (ER) is expressed by the proportion of the completed investment in pollution control in GDP. Environmental regulation can force enterprises to carry out scientific and technological innovation activities. Innovation and creativity will enable enterprises to improve the production mode, gradually enhance the competitive advantage, eliminate the increased input cost due to environmental control, and improve the efficiency of carbon emission. The level of scientific and technological innovation (Inno) is expressed by the number of patent applications of pharmaceutical manufacturing industry. The ratio of energy consumption per unit of economic energy consumption (NE) to the main business income of the pharmaceutical manufacturing industry indicates that the less energy consumed per unit of economy, the higher the carbon emission efficiency.

4.3. Empirical Results

The descriptive statistics of variables are shown in Table 4, and the regression results of the national Tobit model are shown in Table 5. It can be seen from Table 5 that industrial agglomeration, environmental regulation intensity and technological innovation level have a positive impact on national carbon emission efficiency. The higher the unit economic energy consumption, the lower the carbon emission efficiency. The level of foreign investment negatively affects carbon emission efficiency, but not significantly. The intensity of environmental regulation is the main influencing factor.

4.4. Robustness Test

In order to ensure the validity and robustness of the empirical results, this paper takes the period from 2010 to 2018 as the research object and conducts Tobit regression again by shortening the time window method. The results are shown in Table 6. The results of each variable are still significant, which is consistent with

Table 4. Descriptive statistics of variables.

Variable	Quantity	Mean	Standard deviation	Minimum	Maximum
EFF	300	0.91356	0.07851	0.74200	1.19500
FDI	300	0.00442	0.00481	0.00005	0.02742
ER	300	0.00118	0.00109	0.00002	0.00992
CR	300	0.99405	0.62529	0.13300	3.86100
NE	300	0.32270	0.53860	0.02700	3.09000
Inno	300	0.02024	0.01031	0.00100	0.04980

Table 5. Regression results of Tobit model.

EFF	Coef.	Std. Err.	t	P > t
NE	−0.040***	0.009	−4.200	0.000
ER	22.262***	4.583	4.860	0.000
CR	0.016**	0.007	2.220	0.027
FDI	−1.117	0.902	−1.240	0.217
Inno	1.533***	0.416	3.690	0.000
_cons	0.858	0.014	62.960	0.000

Note: *, ** and *** indicate the significance level under the conditions of 10%, 5% and 1% respectively.

Table 6. Results of Tobit regression robustness test

EFF	Coef.	Std. Err.	t	P > t
NE	−0.044***	0.010	−4.150	0.000
ER	23.123***	4.769	4.850	0.000
CR	0.015**	0.007	2.120	0.035
FDI	−1.227	0.934	−1.310	0.190
Inno	1.697***	0.432	3.930	0.000
_cons	0.857	0.014	61.170	0.000

Note: *, ** and *** indicate the significance level under the conditions of 10%, 5% and 1% respectively.

the conclusions above, indicating the robustness of the results.

5. Research Conclusions and Implications

5.1. Research Conclusion

From the perspective of input and output, the carbon emission efficiency of the pharmaceutical manufacturing industry in 30 provinces in China from 2010 to 2019 was calculated using the expected output super-efficiency SBM model. The ML index and its decomposition index model are used to explore the changing trend and driving factors of carbon emission efficiency values in China, eastern, central and western regions, and Tobit model is used to explore the influencing factors of carbon emission efficiency. It is concluded that the green development of China's pharmaceutical manufacturing industry has been effective and the carbon emission efficiency of China's pharmaceutical manufacturing industry has been steadily improved. The pharmaceutical manufacturing industry is gradually transforming from resource factor type to ecological target type. Technical efficiency can promote the improvement of national carbon emission efficiency, and technological progress and development deserve more attention. The carbon emission efficiency of the eastern part of China is higher than that of the western part, and that of the western part is higher than that of the central part. The central and western parts are dominated by technological efficiency, and technological progress and technological efficiency need to be further improved. Among the influencing factors, the level of environmental regulation, the level of scientific and technological innovation, and the degree of industrial agglomeration have positive effects on carbon emission efficiency. Unit economic energy consumption negatively affects carbon emission efficiency. The level of foreign investment has no significant effect on carbon emission efficiency.

5.2. Implication

Based on the conclusions, this paper puts forward the following suggestions: 1) strengthen the intensity of environmental regulation, strengthen the assessment of ecological environmental protection, improve the environmental accountability mechanism, and promote enterprises to tackle the key core pollution treatment technologies by collecting environmental tax. Use market instruments such as emission trading system to encourage enterprises to carry out environmental innovation. 2) To strengthen scientific and technological innovation, the government should implement the science and technology training based development plan, build the ability of source innovation and set up a special fund to support enterprises to develop green and environmental protection technologies. 3) To speed up the elimination of backward production capacity, the government should scientifically and reasonably set the rectification standards for high-consumption and low-efficiency enterprises that meet the actual situation of the pharmaceutical manufacturing industry, and carry out the transformation, upgrading and merger and reorganization of substandard enterprises. Accurately analyze the equipment operation and energy consumption data of the enterprise, optimize the different nodes in the production process by virtue of intelligent control equipment and internal systems, and reduce the unit energy consumption while helping the factory to improve its capacity. 4) Increase the scale of industrial agglomeration, use diversified media to promote the flow of knowledge elements, and use the effect of scale economies to promote the technological progress of pharmaceutical manufacturing industry. While pursuing the scale advantage, we should beware of the problems of agglomeration but not excellent and high level of overcapacity. 5) Implement the policy of opening to the outside world, raise the threshold of environmental access for pharmaceutical manufacturing enterprises while expanding the opening to the outside world in an orderly manner, and create a negative list system for high-quality foreign investment access. 6) Jointly formulate regional green innovation policies, promote the coordinated development of regional green economy. We will comprehensively use various means such as administration, science and technology, the rule of law, and the market to improve the carbon emission efficiency of the pharmaceutical manufacturing industry and achieve carbon peak and carbon neutrality as soon as possible.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Iram, R., Zhang, J., Erdogan, S., *et al*. (2020) Economics of Energy and Environmental Efficiency: Evidence from OECD Countries. *Environmental Science and Pollution Research*, **27**, 3858-3870. https://doi.org/10.1007/s11356-019-07020-x

[2] Li, Y., *et al*. (2022) Differences of Carbon Emission Efficiency in the Belt and Road Initiative Countries. *Energies*, **15**, Article 1576. https://doi.org/10.3390/en15041576

[3] Zhang, J., Patwary, A.K., Sun, H., *et al*. (2021) Measuring Energy and Environmental Efficiency Interactions towards CO_2 Emissions Reduction without Slowing Economic Growth in Central and Western Europe. *Journal of Environmental Management*, **279**, Article 111704. https://doi.org/10.1016/j.jenvman.2020.111704

[4] Li, L., Cai, Y. and Liu, L. (2020) Research on the Effect of Urbanization on China's Carbon Emission Efficiency. *Sustainability*, **12**, Article 163. https://doi.org/10.3390/su12010163

[5] Li, J., Ma, X. and Yuan, Q. (2019) Regional Carbon Emission Efficiency Evaluation and Impact Factor Analysis. *Journal of Environmental Science*, **39**, 4293-4300.

[6] Liu, H., Zhang, Y., Zhu, Q., *et al*. (2016) Environmental Efficiency of Land Transportation in China: A Parallel Slack-Based Measure for Regional and Temporal Analysis. *Journal of Cleaner Production*, **142**, 867-876. https://doi.org/10.1016/j.jclepro.2016.09.048

[7] Gao, P., Yue, S. and Chen, H. (2020) Carbon Emission Efficiency of China's Industry Sectors: From the Perspective of Embodied Carbon Emissions. *Journal of Cleaner Production*, **283**, Article 124655. https://doi.org/10.1016/j.jclepro.2020.124655

[8] Wang, R. and Feng, Y. (2020) Research on China's Agricultural Carbon Emission

Efficiency Evaluation and Regional Differentiation Based on DEA and Theil Models. *International Journal of Environmental Science and Technology*, **18**, 1453-1464. https://doi.org/10.1007/s13762-020-02903-w

[9] Du, Q., Deng, Y., Zhou, J., *et al.* (2022) Spatial Spillover Effect of Carbon Emission Efficiency in the Construction Industry of China. *Environmental Science and Pollution Research*, **29**, 2466-2479. https://doi.org/10.1007/s11356-021-15747-9

[10] Shen, Q., Sun, T. and Luo, K. (2019) Research on China's Tourism Carbon Emission Efficiency and Its Influencing Factors. *Fresenius Environmental Bulletin*, **28**, 6380-6388.

[11] Wang, R. and Feng, Y. (2021) Research on China's Agricultural Carbon Emission Efficiency Evaluation and Regional Differentiation Based on DEA and Theil Models. *International Journal of Environmental Science and Technology*, **18**, 1453-1464. https://doi.org/10.1007/s13762-020-02903-w

[12] Zhang, C. and Chen, P. (2021) Industrialization, Urbanization, and Carbon Emission Efficiency of Yangtze River Economic Belt—Empirical Analysis Based on Stochastic Frontier Model. *Environmental Science and Pollution Research*, **28**, 66914-66929. https://doi.org/10.1007/s11356-021-15309-z

[13] Niu, H., Zhang, Z., Xiao, Y., Luo, M. and Chen, Y. (2022) A Study of Carbon Emission Efficiency in Chinese Provinces Based on a Three-Stage SBM-Undesirable Model and an LSTM Model. *International Journal of Environmental Research and Public Health*, **19**, Article 5395. https://doi.org/10.3390/ijerph19095395

[14] Li, X., Tang, Y., Liu, P. and Cheng, Z. (2022) Regional Differential Decomposition and the Formation Mechanism of the Dynamic Carbon Emissions Efficiency of Industrial Energy in China. *Frontiers in Environmental Science*, **10**, Article 946596. https://doi.org/10.3389/fenvs.2022.946596

[15] Tang, K., Xiong, C., Wang, Y., *et al.* (2021) Carbon Emissions Performance Trend across Chinese Cities: Evidence from Efficiency and Convergence Evaluation. *Environmental Science and Pollution Research*, **28**, 1533-1544. https://doi.org/10.1007/s11356-020-10518-4

[16] Song, A., Yang, X., Zhang, X., *et al.* (2019) Ecology Environment Research about Carbon Emission Efficiency in China Based on a Novel Super Epsilon-Based Measures (SEBM) Model. *Applied Ecology and Environmental Research*, **17**, 1109-1128. https://doi.org/10.15666/aeer/1701_11091128

[17] Jiang, P., Li, M., Zhao, Y., *et al.* (2022) Does Environmental Regulation Improve Carbon Emission Efficiency? Inspection of Panel Data from Inter-Provincial Provinces in China. *Sustainability*, **14**, Article 10448. https://doi.org/10.3390/su141610448

[18] Sun, Z. and Liu, Y. (2021) Does Industrial Agglomeration Promote Carbon Efficiency? A Spatial Econometric Analysis and Fractional-Order Grey Forecasting. *Journal of Mathematics*, **2021**, Article ID: 5242414. https://doi.org/10.1155/2021/5242414

[19] Zheng, R., Cheng, Y., Liu, H., *et al.* (2022) The Spatiotemporal Distribution and Drivers of Urban Carbon Emission Efficiency: The Role of Technological Innovation. *International Journal of Environmental Research and Public Health*, **19**, Article 9111. https://doi.org/10.3390/ijerph19159111

[20] Wu, S. and Zhang, K. (2021) Influence of Urbanization and Foreign Direct Investment on Carbon Emission Efficiency: Evidence from Urban Clusters in the Yangtze River Economic Belt. *Sustainability*, **13**, Article 2722. https://doi.org/10.3390/su13052722

[21] Wang, Q. and Liu, S. (2022) How Do FDI and Technological Innovation Affect Carbon Emission Efficiency in China? *Energies*, **15**, Article 9209. https://doi.org/10.3390/en15239209

[22] Lin, X., Bian, Y. and Wang, D. (2021) Spatial and Temporal Evolution Characteristics and Influencing Factors of Industrial Carbon Emission Efficiency in Beijing-Tianjin-Hebei Region. *Economic Geography*, **41**, 187-195.

[23] Tone, K. (2002) A Slacks-Based Measure of Super-Efficiency in Data Envelopment Analysis. *European Journal of Operational Research*, **143**, 32-41. https://doi.org/10.1016/S0377-2217(01)00324-1

[24] Malmquist, S. (1953) Index Numbers and Indifference Surfaces. *Trabajos de Estatistica*, **4**, 209-242. https://doi.org/10.1007/BF03006863

[25] Chung, Y., Fare, R. and Grosskopf, S. (1997) Productivity and Undesirable Outputs: a Directional Distance Function Approach. *Journal of Environmental Management*, **51**, 229-240. https://doi.org/10.1006/jema.1997.0146

[26] Chambers, R.G., Chung, Y. and Fare, R. (1996) Benefit and Distance Functions. *Journal of Economic Theory*, **70**, 407-419. https://doi.org/10.1006/jeth.1996.0096