Manufacturing and Service Operations Management (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/msom.2022.030304
ISSN 2616-3349 Vol. 3 Num. 3

Green Total Factor Productivity Measurements and Spatial Association Network Characteristics of Manufacturing Industry in Shandong Province, China

Shenglei Song, Xiuyan Yu

College of Management, Shandong University of Technology, Zibo, Shandong, 255000, China

Keywords: Green Total Factor Productivity, DEA, Social Network Analysis, Spatially Linked Networks

Abstract: The level of green total factor productivity in manufacturing industry is an important basis for testing the green development of manufacturing industry in Shandong province. Based on this, this paper measures the green total factor productivity of manufacturing industry in Shandong province from 2010 to 2019 using the super-efficient SBM model containing non-expected output and the global Mamquist (GML) index, and analyzes the structural characteristics of the spatially linked network of manufacturing industry in Shandong province in 2019 using social network analysis in three dimensions: overall, individual and cohesive subgroups. The purpose is to provide a reference for the high-quality development of manufacturing industry in Shandong Province.

1. Introduction

As a major manufacturing province in China, Shandong Province has a complete range of industries and has formed a relatively complete system, but in general, it shows the characteristics of "high energy consumption, high emissions and high pollution" in a sloppy industry. General Secretary Jinping Xi clearly pointed out in the report of the 20th National Congress that "we should promote green development and harmonious coexistence between human beings and nature", which requires enterprises to actively deal with environmental pollution and green production. Therefore, green total factor productivity, which is used to reflect the level of regional green development and show the status of regional high-quality green development, was born[1]. Then, what is the level of green total factor productivity of manufacturing industry in Shandong Province, and what characteristics does the space have become an important issue to promote the green development of manufacturing industry in Shandong Province.

Many studies have been done by domestic and foreign scholars around the measurement of green total factor productivity, generally using parametric and non-parametric methods. However, when using the parametric method for measurement, pollution emissions and energy consumption need to be included in the production system, but price information is difficult to obtain, so most scholars currently use the nonparametric method for measurement[2]. For example, Chung[3] et al. proposed Malmquist-Luenberger productivity index based on the directional distance function. This approach decomposes into efficiency changes and technological changes, overcoming the shortcomings of the original Malmquist index. Tone[4] proposed the SBM model, which relies on the reference set, i.e., the metric is determined only by its reference set and is independent of the entire data set statistics. Genzhong Li[5] et al. used the DEA-SBM function to explore the relationship between industrial structure and green total factor productivity based on sample data from 2008-2019 from nine provinces and two cities in the Yangtze River Economic Belt.

Based on this, this paper establishes a green total factor productivity estimation model to measure the green total factor productivity developed by cities in Shandong Province based on panel data from 2010-2019, and analyzes its spatial correlation characteristics in order to provide a reference for the high-quality development of manufacturing industry in Shandong Province.

2. Indicator Selection and Research Methodology

2.1 Indicator Selection

Green total factor productivity measures generally use capital, labor and energy as input indicators, economic growth as desired output indicators, and environmental pollution situation as non-desired output indicators. In this paper, we refer to the studies of Shuru Liu et al[6] and Haijie Wang et al[7], and consider the current development of Shandong Province. The total fixed assets of industrial enterprises above the scale of each city (million yuan) are selected as capital input indicators, and labor and energy inputs are selected as the annual average number of all employees of industrial enterprises above the scale of the city (10,000 people) and electricity consumption of industrial enterprises above the scale (million kilowatt hours), respectively. Output indicators include desired output and non-desired output, among which, desired output is chosen to be expressed by the total industrial output value above scale (million yuan); non-desired output is measured by industrial wastewater emissions (million tons) and sulfur dioxide emissions (million tons). The data are all obtained from the 2010-2019 China Urban Statistical Yearbook, Shandong Provincial Statistical Yearbook and statistical yearbooks of various cities. For the existence of a small amount of missing data, the interpolation method was used to supplement them.

2.2 Research Methodology

2.2.1 SBM model

SBM is a new slack variable-based efficiency measure, a non-radial (non-radial) non-angle (non-oriented) DEA model. Since there are non-desired outputs in the green total factor productivity measure, the non-desired output super-efficiency SBM model is chosen to calculate green total factor productivity (GML)[8], and the green total factor productivity (GML) is decomposed into green technical efficiency (EC) and green technical progress (BPC)[9] using the Mamquist (GML) index, and further the green total factor productivity of manufacturing industry in Shandong province analysis was conducted.

2.2.2 Social Network Analysis Method

Social network analysis is used to model social relationships, which can discover the social relationships among actors within a group, describe the structure of social relationships, and study the impact of this structure on group function or individuals within the group. In this paper, we analyze the spatial association characteristics of green total factor productivity in each municipality of Shandong Province through three aspects: overall network structure, individual centrality and cohesive subgroup analysis. Before applying the social network analysis method, we need to calculate the gravitational matrix with the help of the gravitational model to examine the spatial correlations between cities and regions, so as to construct a spatial correlation network for the high-quality development of green total factor productivity in Shandong province. When applying the gravitational model, the gravitational value higher than or equal to the mean value of the row in which it is located is recorded as 1, indicating that there is a correlation between the manufacturing industries of the two cities, and the gravitational value lower than the mean value is recorded as 0, indicating that there is no correlation between the manufacturing industries of the two cities. The formula is shown as follows.

$$F_{ij} = K_{ij} \frac{GML_j * GML_j}{D_{ij}^{b}} \tag{1}$$

$$K_{ij} = \frac{GML_j}{GML_j + GML_j} \tag{2}$$

Where F_{ij} is the gravitational strength between manufacturing industries in regions i and j; GML_i, GML_j represent the green total factor productivity of manufacturing industries in regions i and j, respectively; Dij is the linear distance between regions i and j; b is the distance decay coefficient, which takes the value of 2; K is the gravitational coefficient.

3. Research Results and Analysis

3.1. Green Total Factor Productivity Analysis in Manufacturing

3.1.1 Overall Analysis

MAXdea software was used to measure the green total factor productivity of manufacturing industries in each city of Shandong Province. Then the average values of green total factor productivity and its decomposition indexes were calculated for each city for 10 years, and the results are shown in Table 1.

Table 1: Manufacturing GML index and its decomposition in Shandong Province, 2010-2019

DMU	GML	EC	BPC	DMU	GML	EC	BPC
Provincial Capital Economic Circle							
Jinan	1.044	1.009	1.035	Liaocheng	1.011	0.996	1.015
Zibo	0.986	0.91	1.083	Binzhou	1.034	1.112	0.929
Taian	0.937	0.906	1.035	Dongying	1.109	0.999	1.11
Dezhou	1.086	1.085	1.001	Average	1.028	1.000	1.028
Jiaodong Economic Circle							
Qingdao	1.095	1.008	1.087	Weihai	0.972	0.911	1.067
Yantai	0.969	0.896	1.081	Rizhao	0.992	0.973	1.019
Weifang	1.02	0.996	1.024	Average	1.009	0.956	1.055
Lunan Economic Circle							
Zaozhuang	0.928	0.866	1.071	Linyi	0.992	0.964	1.029
Jining	0.992	0.985	1.007	Heze	1.043	1.053	0.99
				Average	0.988	0.965	1.024
Total average	1.008	0.973	1.036				

As can be seen from Table 1, the provincial capital economic circle has higher green total factor productivity compared to the other two economic circles. In the Jiaodong and Lunan economic circles, only Qingdao, Weifang and Heze have a green total factor productivity productivity index greater than 1, and the growth of the green total factor productivity index in these cities mainly depends on green technological progress. The GML indexes in the provincial capital economic circle are greater than 1 except for Tai'an and Zibo, which indicates an overall upward trend of green total factor productivity in the provincial capital economic circle from 2010 to 2019. Jinan, Liaocheng, and Dongying EC are less than 1, but the GML index is greater than 1, which indicates that their green total factor productivity growth mainly relies on green technological progress. Zibo, Tai'an, Yantai, Rizhao, Weihai, Jining, Zaozhuang, and Linyi have a GML index less than 1, a BPC index greater than 1, and an EC index less than 1, indicating that the decline in green technical efficiency is the fundamental driver preventing the rise of green total factor productivity.

The overall GML index of Jiaodong Economic Circle, Provincial Capital Economic Circle and the three economic circles achieve positive growth. From the decomposition term, we can see that the progress of green technology level promotes the growth of green total factor productivity, while the backwardness of technical efficiency inhibits the growth of green total factor productivity, so Jiaodong Economic Circle and Provincial Capital Economic Circle should strengthen the investment of scientific research funds and strengthen technological innovation to promote the growth of green technical efficiency.

3.1.2 Trend Analysis

(1) As can be seen from Figure 1, the average index of green total factor productivity of each economic circle is on an upward trend, and the changes of each economic circle also roughly coincide with the average level, indicating that the development of green total factor productivity in Shandong Province is relatively balanced, and it is in a state of growth though fluctuating.

(2) As can be seen in Figure 2 and Figure 3, the green total factor productivity grew in all years except 2014 and 2018, and 2014 did not increase but its GML index was around 1, which indicates that the degree of negative growth was not high in 2014. However, the green total factor productivity index in 2018 is around 0.6 for all economic circles, which is a high degree of negative growth compared to other years. By comparing the green technical efficiency and green technology level it can be found that the main reason for the decrease in 2018 may be the decrease in the green technological progress index. This may be due to the tightening of the policy for green development in cities and towns in 2018, which makes the desired output and non-desired output fail to change in the same proportion, resulting in the decline of the green technological progress index. Therefore, cities and regions should strengthen green technology innovation and increase green innovation investment to improve green technology and promote green technology progress.

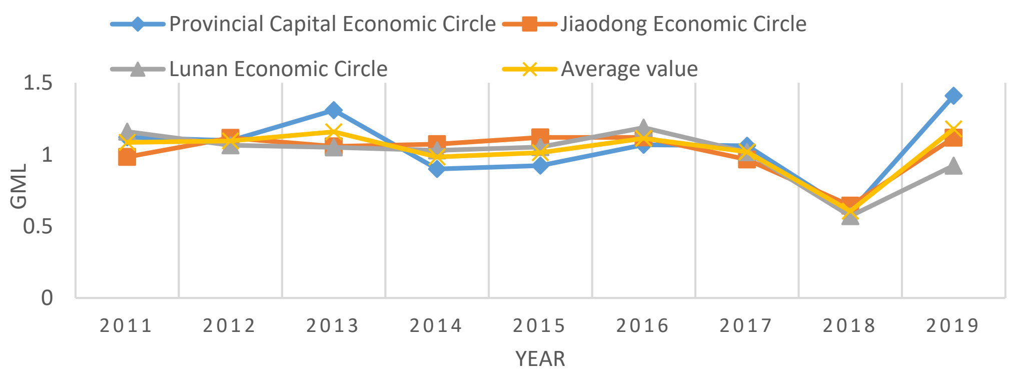

Figure 1: Change of green total factor productivity index by economic circle in Shandong Province

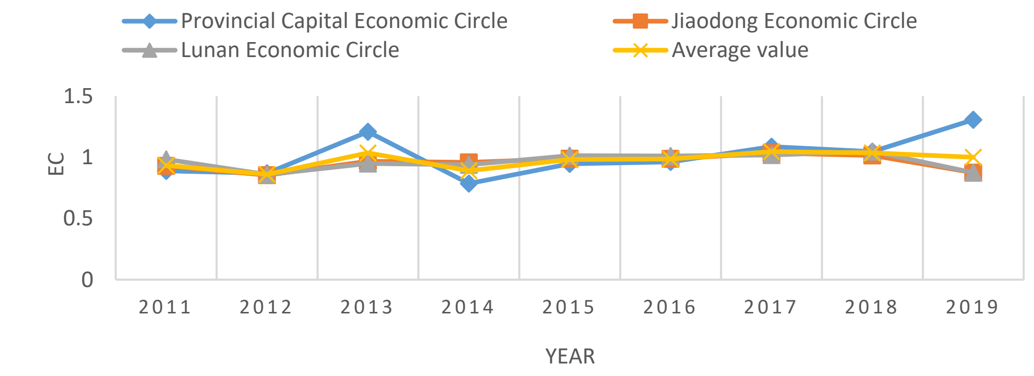

Figure 2: Changes in Green Technology Efficiency Index by Economic Circle in Shandong Province

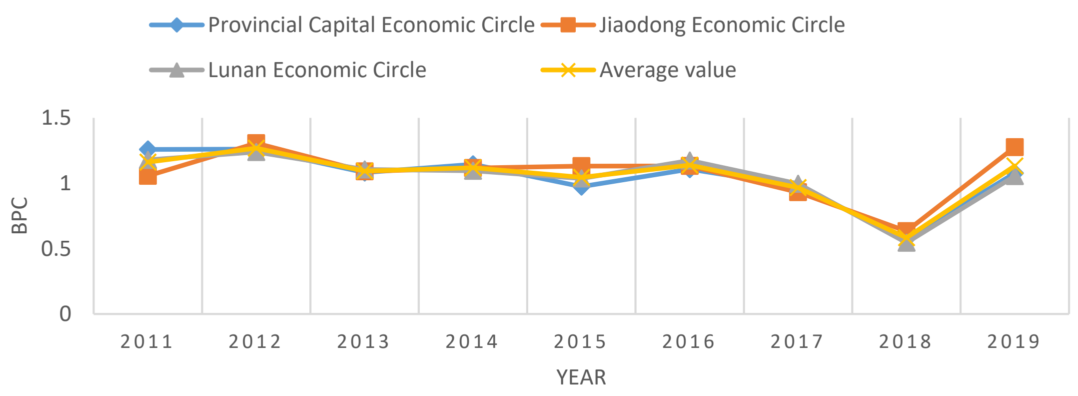

Figure 3: Change of Green Technology Progress Index by Economic Circle in Shandong Province

3.2. Spatial Association Feature Analysis

In this paper, we construct the gravitational matrix through the gravitational model, and then use the social network analysis method to analyze the whole, individual and cohesive subgroups in three dimensions, the research focuses on the social network analysis, so the results of the gravitational model are not repeated.

3.2.1 Overall Network Structure Analysis

The overall structural characteristics of the green total factor productivity spatial correlation network of manufacturing industry in Shandong Province in 2019 were analyzed using Ucinet 6.645 software, and the results of the analysis are shown in Table 2.

Table 2: Overall structural characteristics of the spatial correlation network of green total factor productivity in manufacturing industry in Shandong Province, 2019

Network Density	Network relevance	Network Efficiency	NetworkRating Degree
0.304	1	0.7143	0

The density of manufacturing association network in Shandong Province in 2019 is 0.304, indicating that the manufacturing industries in Shandong Province are more closely connected with each other, but there is some room for progress in the collaborative development of manufacturing industries in different cities. Shandong Province should actively promote the exchange between manufacturing industries in different cities and build a spatially connected network for the coordinated progress of different cities in the province. The result of network correlation degree is 1, which indicates that the accessibility of manufacturing network of various cities in Shandong province is good; the network efficiency is 0.7143, which indicates that its spatial correlation network is relatively stable; the network hierarchy degree is 0, which indicates that there is no rigid hierarchical structure between the development of green total factor productivity of various cities in Shandong province. Overall, under the conditions of accelerated regional integration process and convenient transportation, the manufacturing association network in Shandong Province is relatively stable and well connected, without a strict hierarchical structure.

3.2.2 Individual Centrality Analysis

With the help of Ucinet 6.645, the degree centrality, proximity centrality and intermediary centrality of the manufacturing spatial association network in Shandong province were measured to reveal the power held by cities in the network in Shandong province, and the results are shown in Table 3.

Table 3: Centrality indicators of manufacturing spatial association network in Shandong Province

City Sorting	pointcentrality	out-degree	in-degree	City Sorting	betweennesscentrality	City Sorting	closenesscentrality
Zibo	9	5	9	Zibo	53.695	Zibo	0.714
Taian	8	5	8	Weifang	48.805	Weifang	0.625
Weifang	8	5	7	Taian	36.511	Taian	0.625
Dongying	7	3	7	Qingdao	32.667	Linyi	0.625
Linyi	6	6	2	Linyi	23.179	Dezhou	0.625
Dezhou	6	6	3	Zaozhuan	17.862	Dongying	0.577
Qingdao	6	5	4	Rizhao	15.483	Jinan	0.556
Jinan	5	5	5	Liaocheng	14.317	Rizhao	0.536
Jining	5	4	5	Yantai	14	Qingdao	0.536
Liaocheng	5	5	5	Dongying	13.26	Binzhou	0.536
Binzhou	5	4	5	Jinan	12.91	Liaocheng	0.5
Heze	4	4	3	Binzhou	11.167	Jining	0.5
Zaozhuang	4	4	4	Dezhou	9.611	Zaozhuan	0.484
Rizhao	4	4	3	Jining	5.143	Yantai	0.455
Yantai	4	4	2	Heze	1.393	Weihai	0.455
Weihai	4	4	1	Weihai	0	Heze	0.429

The point centrality of the provincial capital economic circle is higher than that of the Jiaodong economic circle and the Lunan economic circle, indicating that the provincial capital economic circle has a stronger ability to receive and radiate outward and has a certain spatial spillover effect. The betweenness centrality of cities in Shandong province varies widely, and the central plain is generally higher than the periphery. The top four cities in betweenness centrality are Zibo, Weifang, Tai'an and Qingdao, which control the transfer of resource factors in the network. The reason for this is that these cities are in the hub position of communication and exchange with other cities. The top four cities in the closeness centrality ranking are Zibo, Weifang, Tai'an and Linyi, which indicates that these four cities can quickly make connections with other cities in the manufacturing linkage network, play the role of central actors, and can transfer resource elements more quickly.

3.2.3 Co-hesive Subgroup analysis

Table 4: Block model analysis results

Plate	Receiving relationship matrix (pcs)				Number of members (pcs)	Number of received off-plate relations (pcs)	Number of relationships outside the spillover plate (pcs)	Expected internal relationship ratio (%)	Actual internal relationship ratio (%)	Plate Type
	1	2	3	4						
1	1	3	4	3	2	19	10	6.67	9.1	Net Income Plate
2	8	6	7	7	6	10	22	33.33	21.43	Net Spillover Plate
3	7	5	4	7	5	16	19	26.67	17.39	Brokerage Plate
4	4	2	5	2	3	17	11	13.33	15.38	Two-way spillover plate

Plate I contains Jinan and Tai'an cities, located in the central and western part of Shandong Province, belonging to the provincial capital economic circle; plate II contains Qingdao, Zibo, Dongying, Zaozhuang, Yantai, Weifang, the plate in the entire Shandong Province, the high level of economic development; plate III contains Jining, Linyi, Dezhou, Liaocheng, Heze, its economic development level is behind the plate II cities, but the rapid economic development momentum. Plate IV contains Weihai City, Rizhao City and Binzhou City, which are located in the coastal area and have more convenient external exchanges. The economically developed cities in Shandong province are basically located in Plate I and II, and most of the cities in the Lunan Economic Circle are located in Plate III. As can be seen from Table 4, the number of intra-plate relations is smaller than the number of plate spillover relations, which indicates that the spatial spillover effect of green total factor productivity in manufacturing industry in Shandong Province is dominated by inter-plate spillover.

The actual internal relationship proportion of plate I is higher than the expected internal proportion, and the number of outward-receiving relationships of the plate is much larger than the number of overflowing plate relationships, so plate I is a net income plate. The expected internal proportion of plate II is 33.33%, which is much larger than the actual internal proportion of 21.43%, while the number of outward radiating relations of this plate is much larger than the number of receiving relations of the plate, so plate II is a net spillover plate. The expected internal proportion of plate III is 26.67% and the actual internal proportion is 17.39%. The number of relationships outside the receiving board and the number of relationships outside the overflowing board are essentially the same, so this plate is a Brokerage Plate. The actual internal proportion of plateIV exceeds the desired internal proportion, and this board receives the number of relationships from other boards while overflowing relationships to other boards. Therefore, plate IV is a two-way spillover plate.

As can be seen from Figure 4, the number of relationships issued by plate I is mainly concentrated in plate II, plate III and plate IV. Plate I is located in the central region of Shandong Province, which is close to other plates and convenient for communication. Plate II is a net spillover plate, the most economically developed among the four plates, and has a significant spillover effect on the development of green total factor productivity in other plates. Plate III belongs to the brokerage Plate, located in the coastal area of Shandong Province and the border with other provinces, playing an intermediary role between the plates, should give full play to its advantages, and actively promote the flow of factors between the plates. The province should maintain the perspective of "the province's cities and towns as a whole" to promote the integrated development of green total factor productivity among various cities and plates.

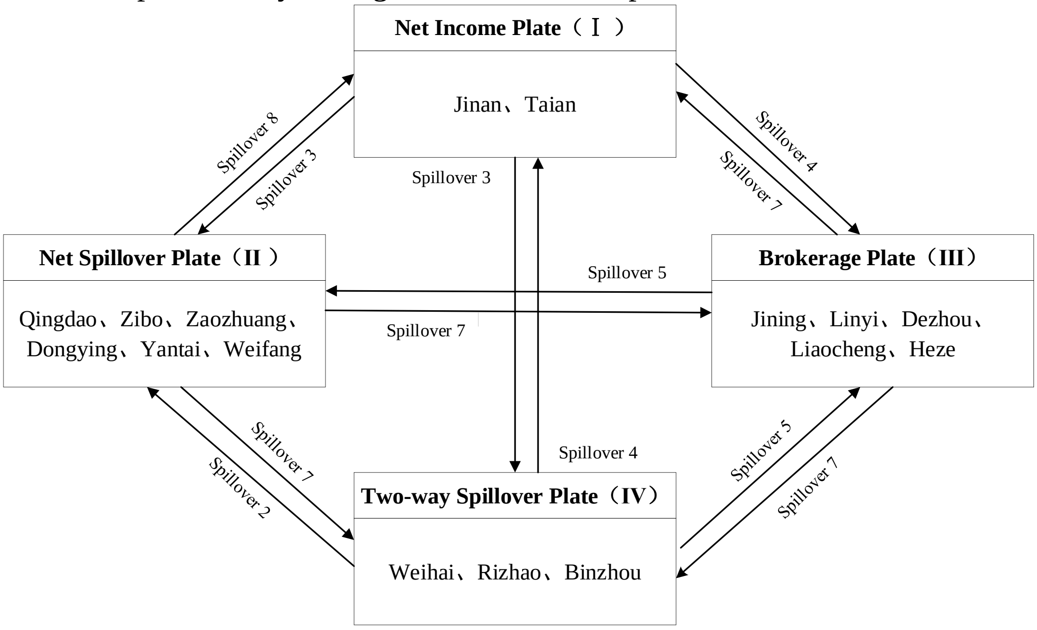

Figure 4: Inter-plate transmission relationship of manufacturing spatial association network in Shandong Province

4. Conclusion and Policy Recommendations

4.1. Conclusion

This paper takes the manufacturing industry of prefecture-level cities in Shandong Province as the research object, and focuses on their green total productivity and spatial network distribution characteristics, using a combination of GML index, modified gravity model and social network analysis to study them. The research results are as follows.

①Green total factor productivity in each economic circle of Shandong Province from 2010 to 2019 shows an upward trend, the progress of green technology level is the main driving force for the rise of green total factor productivity, and the decline of green technical efficiency is the fundamental motive force inhibiting the rise of green total factor productivity.

② The structure of the spatially linked network of green total factor productivity in manufacturing industry in Shandong Province in 2019 is stable, with good network accessibility and closer links among cities, while a hierarchical network hierarchy is not formed.

③Zibo, Weifang, Tai'an, Qingdao and Linyi as the central actors of the network can quickly transfer manufacturing resource factors, have strong control over other cities and have greater power in the network.

④Jinan and Tai'an belong to the Net Income Plate, most cities in northeastern Shandong province belong to the net spillover segment. Some cities in western Shandong province belong to the broker segment, the two-way spillover segment includes Weihai, Rizhao, and Binzhou.

4.2. Policy Recommendations

① Relevant departments should strengthen science and technology innovation. Green technology progress is the main driver of green total factor productivity progress, and although technology in Shandong Province has risen in recent years, the upward trend is slow. In the next stage of development, the government should dig deeper into the development of green technological progress, create a suitable research environment for research institutions, and establish a perfect incentive mechanism to promote the improvement of green technology level.

② The government needs to develop a differentiated development strategy. For the different situations of four plates in Shandong province, make differentiated development strategies. Plate II and plate IV should actively give full play to their own advantages and actively carry out external development and exchanges according to their unique geographical advantages.

③ The local municipalities manufacturing industry to enhance the development of close, give full play to the role of the central actor of the provincial capital economic circle, maintain close ties with the peripheral cities, and promote the synergistic and high-quality development of the economic circles and cities in Shandong Province.

References

[1] Xiufeng Ren, Lan Qiu. Research status and development of green total factor productivity measurement methods. Green Technology, 2020 (02): 226-228.

[2] Donglan Xu, Fengyun Li, Du Lv. The measurement method and application of green total factor productivity. Journal of Qingdao University of Science and Technology (Social Science Edition), 2016, 32 (04): 30-35.

[3] Y. Chung, R. Fare, S. Grosskopf. Productivity and undesirable outputs: a directional distance function approach. Journal of Environmental Management, 1997 (3): 229-240.

[4] Tone K. A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research, 2001, 130: 498-509.

[5] Genzhong Li, Hongliang Zhu. Study on industrial structure upgrading and green total factor productivity in Yangtze River Economic Zone. Operations Research and Management, 2021, 30 (05): 227-231.

[6] Shuru Liu, Xiaoyang Jia, Jiqiang Dang. A study on green total factor productivity measurement and influencing factors of Chinese industry. Ecological Economics, 2020, 36 (11): 46-53.

[7] Haijie Wang, Jie Li, Xiaobo Zhang. Study on green total factor productivity measurement and influencing factors of manufacturing industry in Yellow River Basin. Fujian Forum (Humanities and Social Sciences Edition), 2021 (10): 127-139.

[8] Gang Cheng. Data Envelopment Analysis Methods and MaxDEA Software. Intellectual Property Press, 2014.

[9] J. T. Pastor, C. A. Knox Lovell. A global malmquist productivity index. Economics Letters, 2005 (88): 266-271.