ISSN 2706-6827 Vol. 3, Issue 17: 38-43, DOI: 10.25236/IJFS.2021.031705

On Operating Efficiency of Advanced Manufacturing Industry Based on Three-Stage DEA Model -- Taking Wuxi as an Example

Yanbin Wang

Jiangsu Vocational College of Information Technology, Wuxi, Jiangsu 214000, China

Abstract: *This paper selects other major cities in the Yangtze River Delta economic circle as the comparison object to Wuxi with the Three-stage DEA model, analyzing the operating efficiency of listed companies in advanced manufacturing industry, so as to more clearly understand the current situation about the operating efficiency of advanced manufacturing industry in Wuxi. According to the studies, a significant impact of the external environment on the operating efficiency of advanced manufacturing enterprises has been found, and the operating efficiency of advanced manufacturing industry in major cities around the Yangtze River Delta is at a high level. However, the reduction of scale efficiency has become the main factor restricting the growth efficiency of advanced manufacturing industry without the influence of external environmental factors. The study puts forward the suggestions on the creation of a good market environment, construction service and ecological system based on this with the improvement of transportation infrastructure and no blind investment, promoting the deep integration of manufacturing industry and digital technology.*

Keywords: *Advanced manufacturing industry, Three-stage DEA model, Operating efficiency, Yangtze River Delta economic circle*

1. Research Background

November 14, 2020, general secretary Xi Jinping put forward on the Symposium of Comprehensively Promoting the Development of the Yangtze River Economic Belt that "we must strengthen the main position of enterprise innovation, creating an advanced manufacturing cluster with international competitiveness and an industrial chain supply chain with independent control, safety and efficiency serving the whole country". As it hurtles towards the construction of Taihu Lake Bay Science and Innovation Belt, the industrial chain optimization and upgrading of key industrial clusters of advanced manufacturing industry in Wuxi is also accelerating. In recent years, many leading enterprises in clusters have achieved supporting docking at a higher level through innovative service platforms such as the Internet of Things and integrated circuits.

At present, the research on advanced manufacturing industry mainly focuses on the characteristics, output level and system construction, which is less from the perspective of business efficiency. DEA model is accessible to deal with the problem of operating efficiency. Lu Liwen et al. explain the root causes of low development efficiency of some cities with the development efficiency of 108 prefecture level and above cities in the Yangtze River Delta Economic Belt calculated by the DEA model including unexpected output, analyzing the input factors, the redundancy of unexpected output and the deficiency of expected output. Wu Jie et al. carry out the measurement with the DEA model to the green development efficiency. Liu Jiaguo et al. try DEA model for their study on investment efficiency. Chen Mingxin uses DEA model to study the growth efficiency of digital economy. However, there may be some deviation in efficiency measurement, which is a big defect in using the traditional DEA model to deal with the efficiency problem, due to it is assumed that all decision-making units are in the same external environment without the influence of environmental factors and random errors on the measurement results.

2. Research Method of Three-stage DEA

(1) First Stage: Initial Efficiency Analyzed by the Traditional DEA Model

In the first stage, the DEA model in this paper will be divided into input orientation and output

ISSN 2706-6827 Vol. 3, Issue 17: 38-43, DOI: 10.25236/IJFS.2021.031705

orientation with the original input-output data for initial efficiency evaluation. This paper selects the input-oriented BCC model for any decision-making unit, and the dual BCC model under input orientation can be expressed as:

$$min\,\theta-\varepsilon(\hat{e}^{T}S^{-}+e^{T}S^{+})$$
$$s.t.\begin{cases}\sum_{j=1}^{n}X_j\lambda_j+S^{-}=\theta X_0\\ \sum_{j=1}^{n}Y_j\lambda_j-S^{+}=Y_0\\ \lambda_j\geq 0,S^{-},S^{+}\geq 0\end{cases}$$

$j=1,2,\cdots,n$ refers to the decision-making unit, X,Y are input and output vectors.

If $\theta=1,S^{+}=S^{-}=0$, the decision-making unit DEA is valid;

If $\theta=1,S^{+}\neq 0$, or $S^{-}\neq 0$, the decision-making unit weak DEA is effective;

If $\theta<1$, decision-making unit none DEA is in effect.

(2) Second Stage: Environmental Factors and Statistical Noise eliminated by SFA-like Regression

Fried believes that the performance of decision-making unit is affected by management inefficiency, environmental factors and statistical noise, so it is necessary to eliminate these three effects.

The SFA regression equation constructed according to the idea of Fried et al. (taking input orientation as an example) is as follows:

$$S_{ni}=f(Z_i;\beta_n)+\nu_{ni}+\mu_{ni};i=1,2,\cdots,I;n=1,2,\cdots,N$$

S_{ni} is the relaxation value input by the n-th term of the i-th decision-making unit;

Z_i is the environment variable, and β_n is the coefficient of environmental variable;

$\nu_{ni}+\mu_{ni}$ is a mixed error term; ν_{ni} refers to random interference, and μ_{ni} indicates the management inefficient;

$\nu\sim N(0,\sigma_{\nu}^{2})$ is a random error term, which represents the influence of random interference factors on input relaxation variables;

μ is management inefficiency, which indicates the impact of management factors on input relaxation variables. It is assumed that it follows a normal distribution truncated at zero, which is $\mu\sim N^{+}(0,\sigma_{\mu}^{2})$.

The purpose of SFA regression is to eliminate the influence of environmental factors and random factors on efficiency measurement, so as to adjust all decision-making units in the same external environment. The formula of adjustment is as follows:

$$X_{ni}^{A}=X_{ni}+[\max(f(Z_i;\hat{\beta}_n))-f(Z_i;\hat{\beta}_n)]+[\max(\nu_{ni})-\nu_{ni}]\quad i=1,2,\cdots,I;n=1,2,\cdots,N$$

X_{ni}^{A} is the input after adjustment;

X_{ni} is the input before adjustment;

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$[\max(f(Z_i;\hat{\beta}_n)) - f(Z_i;\hat{\beta}_n)]$ is the adjustment of external environmental factors;

$[\max(\nu_{ni}) - \nu_{ni}]$ is to put all decision-making units under the same luck level.

(3) Third Stage: DEA model after adjustment

The relative efficiency value can be calculated again with the BCC model after the original input data is replaced by the input data adjusted in the second stage.

3. Index Selection

(1) City

This paper tries to make clearer about the current condition of operating efficiency of advanced manufacturing industry in Wuxi with nine cities selected in the Yangtze River Delta Economic Circle as the comparison object, finding their own development orientation through comparative analysis, so as to put forward improvement suggestions.

(2) Input Index

This paper selects listed companies belonging to integrated circuit industry from the listed companies in the selected cities, taking the total assets and the number of employees as the main input variables to obtain the sample data.

(3) Output Index

This paper takes the main business income and net profit as the main output variables.

(4) Environment Index

In terms of the demand side, the consumption level can directly affect the development of urban advanced manufacturing industry, which can react upon the consumption mode at the same time. In addition, the construction of transportation infrastructure makes it more convenient to effectively promote the convenience of market transactions with the frequent flow of talents and goods. Thus, this paper takes the per capita GNP as the urban economic development level, the total retail sales of social consumer goods as the consumption level, and the highway network density as the traffic convenience.

4. Empirical Research and Analysis

(1) First Stage: Results and Analysis of Traditional DEA Model

In this stage, a basic BCC model can be used to calculate the input-output efficiency of advanced manufacturing industry in 9 major cities around the Yangtze River Delta in 2019 with DEAP 2.1, as shown in Table 4-1:

Table 4-1: Efficiency Value of Advanced Manufacturing Industry in the First Stage of Major Cities in the Yangtze River Delta

City	Comprehensive technical efficiency	Pure technical efficiency	Scale efficiency	Return to scale
Wuxi	0.959	0.964	0.994	irs
Shanghai	0.989	1.000	0.989	drs
Nanjing	1.000	1.000	1.000	-
Suzhou	0.540	0.899	0.600	irs
Changzhou	0.757	1.000	0.757	irs
Nantong	0.818	0.890	0.919	irs
Hangzhou	1.000	1.000	1.000	-
Ningbo	1.000	1.000	1.000	-
Hefei	0.849	1.000	0.849	irs
Average	0.879	0.973	0.901	

As it is shown in Table 4-1, the average comprehensive technical efficiency of advanced manufacturing industry in major cities around the Yangtze River Delta in 2019 is 0.879, 0.973 of the average pure technical efficiency and 0.901 of the average scale efficiency with the influence of

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external environmental factors and random factors. The gap from the efficiency frontier is narrowed, which means that the advanced manufacturing efficiency of the selected major cities in the Yangtze River Delta is at a high level. The advanced manufacturing industries in Nanjing, Hangzhou and Ningbo are at the frontier of efficiency, with 1 of the comprehensive technical efficiency. There is a certain degree of technical inefficiency in the other six cities.

(2) Second Stage: SFA Regression Results

The random frontier regression analysis can be carried out with Frontier 4.1, taking the relaxation variables of each input variable in the first stage as the explained variables and three environmental variables as the explanatory variables. The results are shown in Table 4-2:

Table 4-2: SFA Parameter Estimation of External Environment Variables

Variable	Relaxation variable of employee number input	Relaxation variable of total asset input
Constant term	89.47***	-3289.36***
Economic development level	-0.7**	2.07***
Urban consumption level	-1.1*	12.08***
Traffic convenience level	-54.19*	-76025.85***
σ2	14323.37***	3.82E+10***
γ	0.05	0.9999***
log value	-55.69***	-116.26***
LR test of the one-side error	3.56	3.97

Note: *, * *, * * * respectively indicate significant at 10%, 5% and 1% significance levels

It can be seen from Table 4-2 that most of the SFA regression coefficients of environmental variables can pass the test of significance level, in which the relaxation variable of total asset input γ is 0.9999, indicating that it is mainly dominated by management inefficiency. The relaxation variable of employee number input γ is 0.05, indicating that it is dominated together by management inefficiency and random interference.

(3) Third Stage: Adjusted DEA Results and Comparative Analysis

The results of the second stage are used to adjust the original input data, and the adjusted input value and original output are substituted into the BCC model for calculation. The improved efficiency value and return to scale are shown in table 4-3:

Table 4-3: Comparison of Efficiency Values between the First Stage and the Third Stage of Advanced Manufacturing Industry in Major Cities around the Yangtze River Delta

City	Comprehensive technical efficiency	Pure technical efficiency	Scale efficiency	Return to scale
Wuxi	0.947	0.949	0.999	irs
Shanghai	1.000	1.000	1.000	-
Nanjing	1.000	1.000	1.000	-
Suzhou	0.578	0.999	0.578	irs
Changzhou	0.603	1.000	0.603	irs
Nantong	0.885	0.998	0.886	irs
Hangzhou	1.000	1.000	1.000	-
Ningbo	0.751	0.955	0.786	irs
Hefei	0.691	0.985	0.701	irs
Average	0.828	0.987	0.839	

It shows in the Table 4-1 after excluding the influence of environmental variables and random factors that the comprehensive technical efficiency and scale efficiency of major cities in the Yangtze River Delta are decreased from 0.879 and 0.901 to 0.828 and 0.839 respectively, and the pure technical efficiency is increased from 0.973 to 0.987. The comprehensive technical efficiency of advanced manufacturing industry in three cities has increased, while four cities has decreased. The pure technical efficiency of advanced manufacturing industry in two cities has increased, while three cities has decreased. The scale efficiency of advanced manufacturing industry in two cities has increased, while five cities has decreased.After the investment adjustment, Wuxi's efficiency ranking in major cities around the Yangtze River Delta rose from fifth to fourth, which is very close to the efficiency frontier.

5. Measures and Suggestions

(1) Better Market Environment, Construction Service and Ecological System

A good market environment is the premise for promoting the quality and efficiency improvement of advanced manufacturing industry. First of all, it should further deepen the reform of "release, control and service", strengthening the construction of a law-based government and an honest government. Laws, regulations and subsidies that hinder fair competition in market supervision and administrative licensing should be abrogated with the remove of administrative monopoly and regional barriers, so as to create a legal environment conducive to stimulating entrepreneurship and ensuring law-abiding innovation of enterprises. The second is to optimize the market environment of fair competition with the deepening supply side structural reform. The decisive role of the market in resource allocation should be stressed, improving the efficiency of resource allocation of manufacturing industry, so as to promote the flow of high-quality production factors to advanced manufacturing industry. The third is to make a better innovation ecological environment with the exploration of the integrated development of new technologies, new business forms and new models with traditional manufacturing industry, so as to improve the innovation cooperation environment.

(2) Improved Transportation Infrastructure without Blind Investment

According to the second stage of SFA regression results, the improvement of urban traffic convenience can help to save employees and asset investment. The construction of urban transportation infrastructure can make the flow of talents and goods more convenient and frequent, so that it can shorten the time distance between enterprises with industrial clusters, industrial chains and the convenience of market transactions, which is conducive to the rational and efficient allocation of human resources and capital by local advanced manufacturing enterprises. Therefore, the government should focus on solving the problems of unreasonable allocation and poor connection of transportation infrastructure. Combine government services and market cultivation closely with marketized means based on the fully construction of transportation infrastructure, so as to improve the operation efficiency of advanced manufacturing enterprises.

(3) Deep Integration of Manufacturing and Digital Technology

Currently, the depth of integration of manufacturing industry and digital technology in Wuxi needs to be further improved under the condition of reshaping the traditional form of real economy with digital economy, sharing economy and industrial cooperation. Artificial intelligence, cloud computing, big data and other industries have developed rapidly on the consumer side and technology side, rather than the combination and application with manufacturing processes. Digital talents in Wuxi are more distributed in software and Internet industries. The unreasonable resource allocation and low efficiency may be produced without enough employees responsible for informatization in manufacturing enterprises. They do not have a good understanding and technical mastery of artificial intelligence, which is difficult to help manufacturing enterprises realize complete intelligent transformation. Therefore, the government needs to provide accurate, personalized and intelligent services for the manufacturing industry with comprehensive talents vigorously introduced and cultivated. They can create more third-party institutions such as the Internet of Things Innovation and Promotion Center with both their understanding of the technical processes of manufacturing enterprises and the general technology knowledge of artificial intelligence.

Fund Project

Soft Science Research Project of Wuxi Association for Science and Technology "Research on the Status Quo and Development Countermeasures of Advanced Manufacturing Industry in Wuxi" (No.KX-20-C026)

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ISSN 2706-6827 Vol. 3, Issue 17: 38-43, DOI: 10.25236/IJFS.2021.031705

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About the author

Wang Yanbin, male (1990.7 -), Han nationality, from Wuxi, Jiangsu, master, lecturer, research direction: internal control/risk management