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Research on the Economic Green Development Efficiency of the Regions in Jiangsu Province, China—Based on Three-Stage DEA Model

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Abstract: By referring to relevant policies, theories and analysis methods, the paper uses the three-stage DEA model to further measure and evaluate the efficiency of green development of Jiangsu Province and the selected regions in the province, while identifying the environmental factors of the progress and the corresponding influences. The paper makes multi-angle analyses of the multi-period green development level of the cities and regions in Jiangsu Province. Based on all the results of data analyses and empirical research, this paper sorts out and summarizes the different economic green development levels, different changing paths of economic green development efficiency, different performances of the scale efficiency, pure technical efficiency, and technical efficiency, different changes of the returns to scale, and corresponding improvement paths of the areas in Jiangsu Province. Finally, this paper puts forward policy suggestions from three perspectives: the synergy capacity of green development among areas in Jiangsu Province, the improvement path associated with the change of their returns to scale, and the specific methods to improve the efficiency of economic green development of different types of regions.

1. Introduction

As China's economy continues to develop and people's living standards gradually improve, there is an increasing demand for the quality of economic development and concerns about green development. The transformation of regional economic structures and the improvement of independent development capabilities, as well as the sharing of resources, linkage of industries, and market connectivity between regions, are essential to building a harmonious and win-win ecological environment system. Scientifically assessing the efficiency of green development of Jiangsu Province is the key to promoting the acceleration of economic transformation, enhancing the green competitiveness of the economy, and realizing a pattern of green development in Jiangsu Province. It has practical meaning for promoting economic green development in Jiangsu Province according to local conditions. [12][13]

Based on the fact that areas in Jiangsu Province have different levels of green development and stages of economic development, the study selected sample data for various prefecture-level cities to compare and analyze the efficiency of economic development in the three major regions in Jiangsu Province. Overall, this paper carried out a comprehensive evaluation and research of the green development path of regional economies in Jiangsu Province, and proposed corresponding suggestions, which is conducive to promoting the sustainable development of regional economies and promoting the construction of an ecological civilization.

Regarding empirical research methods, this paper applied the three-stage DEA model to calculate the efficiency of economic green development. The traditional DEA model or the improved DEA model does not consider the impact of environment and random error on the efficiency value, which may not truly reflect the green development efficiency of regional economy in Jiangsu Province. Based on the traditional DEA model, Fried et al. (2002)[18] began to study how to introduce environmental factors and random noise into the model, which is mainly divided into three steps, so it is called three-stage DEA model by scholars. Compared with the traditional DEA model, the three-stage DEA model eliminates the interference of environmental factors and random factors, and can more accurately evaluate DMU efficiency. Therefore, the three-stage DEA model has obvious advantages in the field of assessing environment-related efficiency. In the following stage of this paper, a three-stage DEA based on traditional DEA and stochastic frontier analysis (SFA) proposed by Fried et al. (2002)[18] was adopted to eliminate the impact of environmental factors and random errors on efficiency, so as to obtain relatively real values of the efficiency of economic green development of the regions in Jiangsu Province.

2. Literature Review

Relevant research fields at home and abroad mainly focus on the measurement and evaluation of the efficiency of regional economic green development, and the evaluation and recommendations of policy theories. The measurement and evaluation of the efficiency of economic green development has attracted much attention from scholars in recent years. The green development of regional economy involves many aspects such as economic development mode, environmental construction, and social structure, and China has put forward requirements for regional economic development and ecological civilization construction. In the research on concepts such as "green development" and "green economy", some literature divided the measurement indicators into three categories: society, environment, and economy, and mostly took a large area or a single city as a case. While some literature in China pointed out that the key to achieving high-quality economic development is to increase total factor productivity, but similar related indicators did not consider the impact of resource and environmental constraints on economic output. Based on the fact, many scholars in China have taken into account the symbiotic relationship between energy consumption, environmental pollution, and economic growth, and in the constructed models, factors such as pollutant emissions that have an impact on the environment were regarded as input factors of production.

From the perspective of model selection, the non-parametric data envelopment analysis (Data Envelopment Analysis, DEA) model proposed by American scholar Charnes et al. It has obvious advantages [19], so it is widely used in the field of measurement and evaluation of environment-related efficiency by many researchers in China and worldwide. For example: Yang et al. (2018) evaluated the efficiency of China’s industrial waste gas control based on the DEA model [20]; Zheng et al. (2017) used the super-efficiency DEA model to measure the efficiency of air pollution control in 29 provinces and cities in China and the impact of voluntary and mandatory environmental policies on the efficiency of air pollution controlling [16]; Ying et al. (2018) used the DEA-Malmquist model to measure the emission efficiency of air pollution in Zhejiang Province [21].

Generally speaking, the traditional DEA model or the improved DEA model does not consider the influence of the environment and random errors on the efficiency value, and the real level of governance may not be reflected. For this reason, Fried et al. (2002) proposed a three-stage DEA model [18], and the three-stage DEA model has obvious advantages in evaluating the efficiency of environmental governance. At present, there are many studies [7][14][15] using the three-stage DEA model to evaluate the efficiency of regional environmental governance; for example, Wang et al. (2022) [15] conducted a series of studies on the efficiency of urban smog control in the Yangtze River Delta based on the three-stage DEA model. In view of these, this paper used the three-stage DEA model to measure the efficiency of economic green development of the regions in Jiangsu Province, from 2010 to 2019, aiming to effectively eliminate the influence of environmental variables and random errors, so as to accurately measure the efficiency to provide a scientific basis for formulating policies.

From the perspective of influencing factors, many domestic scholars have included factors and variables such as environmental pollution and environmental regulation (Xiao, 2019) [6] into the evaluation system to analyze the different geographical conditions in China. The economic green development efficiency of regions with different development types and economic structures, such as Zhang et al. (2021) [1] and Han et al. (2022) [5]. Moreover, from the perspective of the measurement method of economic green development efficiency, many domestic scholars use "three wastes", carbon dioxide, and comprehensive indices such as green GDP (Wang et al., 2014) [8] etc. as output indicators, labor force, capital, technology, energy (Zhang et al., 2017) [9] etc. as input indicators to measure the efficiency of green economic development in China.

Regarding the improvement path, foreign research often focuses on the improvement and continuous requirements of the monitoring methods of the government and relevant departments, and emphasizes the importance of negative data (R Adarina1, Yu Gazukina1, K Yankovskaya1, 2019) [22]. On the basis of relevant calculation methods, indicators in the evaluation model and the results obtained, foreign literature put forward revision opinions on unreasonable indicators, looking for indicators that reflect negative information, pointing out the green development symptoms of relevant regions within the selected time span, and using this to find possible universal optimization scheme in the region. Among them, regarding "green development" and "green economy", foreign literature gives greater weight to social welfare and puts forward higher requirements for improvement in terms of its research process and improvement path, and at the same time regards regional industrial development as the focus of improvement and improvement, put forward requirements for the supervisory role of the government. On the basis of using similar methods and based on the country's overall deployment and requirements, as well as factors such as different geographic locations, economic development levels, and green development time cycles in different regions, on the one hand, Chinese scholars have combined regional development types and endowment structures, and put forward proposals and suggestions for the green development of specific industries in order to promote the green development of the regional economy. On the other hand, they tended to combined national policies and overall requirements, integrate the government's ideas, guidance methods, and ongoing work related to green development in the region, and put forward feasible policies to make reasonable suggestions.

3. Research Methods

As is mentioned above, in this paper, the three-stage DEA based on traditional DEA and stochastic frontier analysis (SFA) proposed by Fried et al. (2002)[18] was adopted to eliminate the impact of environmental factors and random errors on efficiency, so as to obtain relatively accurate values of the economic green development efficiency of the regions in Jiangsu Province.

3.1. Stage 1: Traditional DEA Model

In this stage, the BCC model with variable returns to scale assumption was used to conduct traditional DEA analysis on the initial input-output data of the decision variables. The BCC model is constructed based on the CCR model that calculates constant returns to scale and can be used to calculate efficiency values with variable returns to scale. The BCC model can be expressed as follows:

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

where $j = 1,2,\ldots,n$ represents the decision making unit (DMU); X, Y are input and output variables; S^+ is the slack variable; S^- is the output slack variable; β_j is the weight variable; ε is non-Archimedean infinitesimal quantity; $\hat{e}, e$ are the weights of input redundancy and output shortfall. If $\theta = 1, S^+ = S^- = 0$, the DMU is DEA efficient; If $\theta = 1, S^+ \neq 0$ or $S^- \neq 0$, the DMU is weakly DEA efficient; If $\theta < 1$, the DMU is DEA inefficient.

3.2. Stage 2: Stochastic Frontier Model

Input slack in the first stage is affected by environmental factors, management inefficiency and statistical noise. In order to remove the influence of unnecessary factors on efficiency, the stochastic frontier analysis (SFA) regression model is established with external environment variables as explanatory variables and input slack variables as explained variables. All input variable values can be adjusted at the same environmental level. The model is as follows:

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

where S_{ni} is the slack value of the nth input of i DMUs; $f(Z_i;\lambda_n)$ is the corresponding stochastic frontier function; $Z_i = (Z_{1i}, Z_{2i}, \cdots, Z_{ki})$ is the environmental variable of the ith DMU; λ_n is the coefficient of the corresponding environmental variable; $V_{ni} + \mu_{ni}$ is the mixed error term; V_{ni} is the random error, and $V_{ni} \sim N(0, \sigma^2{}_{vi})$; μ_{ni} is the management inefficiency, and $\mu_{ni} \sim N^+(0, \sigma^2{}_{\mu i})$; V_{ni} and μ_{ni} are independent of each other. In order to separate the random error from management inefficiency, Frontier4.1 is first used for maximum likelihood estimation (MLE) to find the estimated values of λ_i, σ^2. With reference to the formula proposed by Luo (2012)[10] and Chen et al. (2014)[11] to separate the management inefficiency term, the estimators of V_{ni} and μ_{ni} are obtained.

Based on the above estimation results, the adjustment formula of input variables of each DMU can be expressed as follows:

$$X_{ni}^A = X_{ni} + [\max(f(Z_i;\hat{\lambda}_n)) - f(Z_i;\hat{\lambda}_n)] + [\max(V_{ni}) - V_{ni}], i = 1,2,\cdots, I; n = 1,2,\cdots, N \tag{3}$$

where X_{ni}^A is the adjusted input variable after homogenization; X_{ni} is the input variable before adjustment; $\max(f(Z_i;\hat{\lambda}_n)) - f(Z_i;\hat{\lambda}_n)$ represents the influence of the adjusted environmental factors; $[\max(V_{ni}) - V_{ni}]$ represents the influence of the adjusted random error term. Finally, all DMUs are adjusted to the same state, thus we can now assume that each DMU is in the same state of external environmental and is subject to the same random shocks.

3.3. Stage 3: Adjusted DEA Model

The initial input variable values and output values adjusted by SFA model are again substituted into BCC model for calculation, and more accurate efficiency values are obtained after eliminating random interference and other factors.

4. Variable Selection and Data Resources

4.1. Variable Selection

The evaluation system consists of three main parts—input, output, and environmental variables (see Table 1).

Table 1: Evaluation system of green development efficiency of regional economy in Jiangsu Province, China

Variable Category	Variable Specification	Variable Name	Unit Name	Frequency
Input Variable	Labor Force	*Lab*	10 thousand people	Year
	Land	*Lan*	Square kilometer (km^2)	Year
	Technology	*Tec*	-	Year
	Innovation	*Inn*	100 million yuan	Year
	Capital	*Inv*	100 million yuan	Year
Output Variable	Green GDP Index	*GGI*	-	Year
Environmental Variable	Industrial Structure	*IS*	Percent (%)	Year
	Urbanization Level	*Urb*	Percent (%)	Year
	Human Capital	*HC*	10 thousand people	Year

Input indicators include the following five aspects: (1) Labor force. The local labor force input was explained by the employed population of the whole social society in the region; (2) Land. The area of built-up area (municipal district) in the region was selected to reflect the consumption of land; (3) Technology. Technology mainly refers to the input of secondary utilization and treatment of generated pollutants. Due to the unavailability of some data, the number of wastewater treatment facilities in the region was selected as the representative of technology; (4) Innovation. The fiscal expenditure on science and technology was select to reflect the input of innovation; (5) Capital. The investment in fixed assets of the whole society was selected to reflect the capital input.

In the selection of output indicators, this paper used the entropy method to convert industrial wastewater discharge (in 100 million tons), industrial smoke (dust) emissions (in 10,000 tons), industrial sulfur dioxide emissions (in 10,000 tons), and regional gross domestic product (in 100 million yuan) as undesired output into the comprehensive index of environmental pollution, and then used the ratio of GDP to comprehensive index of environmental pollution—green GDP index as the final output.

There is no unified and recognized standard for the selection of environmental variables, so this paper selected the following indicators as environmental variables: (1) Industrial structure. The proportion of secondary industry in GDP was selected to reflect the industrial structure in the region; (2) Urbanization level. The proportion of urbanization population was selected to measure the urbanization level of a region; (3) Human capital. The number of graduates from higher education institutions in the region over the years was selected to reflect human capital.

Regarding the second stage of the three-stage DEA model, this paper took labor force (number of employed people), innovation (fiscal expenditure on science and technology), land (built-up area of municipal district), capital (investment in fixed assets of the whole society) and technology (number of sewage treatment plants) as explained variables. The explanatory variables include industrial structure (proportion of secondary industry in GDP), human capital (number of graduates from higher education institutions), and urbanization level (urbanization rate). Among them, *IS*, *HC*, and *Urb* represent the variable of industrial structure, human capital and urbanization level respectively. This paper carried out logarithmic processing on the indicators of environmental variables in the second stage, so as to make the gamma value and LR value of all input slack variables pass the one-sided likelihood ratio test of 10% significance and make the data series more stable and easier to eliminate heteroscedasticity. Among them, ln*IS*, ln*HC*, and ln*Urb* represent the corresponding variables after the logarithm of the industrial structure variable, the human capital variable, and the urbanization level variable respectively.

DEA model requires to meet the standard of degree of freedom (DOF), that is, there must be enough DMUs. Therefore, under the premise that each prefecture-level city was regarded as an independent DUM, that is, there were 13 DMUs in total, and based on the principle that it is not appropriate to choose too many input or output variables, the green GDP index, which is highly comprehensive and used to evaluate the green development level of regional economy in Jiangsu Province, was selected as the only output variable. And the standard of DOF which requires $2(M + N) \leq K$ was met.

4.2. Data Resources

The sample time span is from 2010 to 2019. In view of the impact of COVID-19 on various indicators, the data of 2020 and 2021 were not used in this paper.The index data used are from China Statistical Yearbooks, Jiangsu Statistical Yearbooks, Nanjing Statistical Yearbooks, Wuxi Statistical Yearbooks, Changzhou Statistical Yearbooks, Suzhou Statistical Yearbooks, Zhenjiang Statistical Yearbooks, Nantong Statistical Yearbooks, Yangzhou Statistical Yearbooks, Taizhou Statistical Yearbooks, Xuzhou Statistical Yearbooks, Lianyungang Statistical Yearbooks, Huai'an Statistical Yearbooks, Yancheng Statistical Yearbooks, Suqian Statistical Yearbooks, Statistical Yearbooks on Urban and Rural Construction, China Urban Statistical Yearbooks, and statistical bulletin-sheets on National Economic and Social Development.

Among them, the data of fixed assets of the whole society in 2018 and 2019 in each region were calculated. Since the China Statistical Yearbook, the statistical yearbooks of all provinces and cities, and the China City Statistical Yearbooks lack the fixed asset investment data of prefecture-level cities after 2018 required in this paper, and only the growth rate data can be queried.

5. Result Analysis of Empirical Research

5.1. Result Analysis of Stage 1 (Traditional DEA Model)

With the help of DEAP 2.1, the input-oriented BCC model was selected to analyze the green development efficiency of 13 prefecture-level cities in Jiangsu Province from 2010 to 2019. The results are shown in Table 2.

Table 2: The stage-1 results of the technical efficiency of the green development of regional economy in Jiangsu Province, China, from 2010 to 2019

Region	City	2010	2011	2012	2013	2014
Southern Jiangsu	Nanjing	0.479	0.490	0.467	0.382	0.429
	Wuxi	0.698	0.849	0.801	0.805	0.604
	Changzhou	0.709	1.000	1.000	1.000	0.697
	Suzhou	0.417	0.399	0.330	0.317	0.340
	Zhenjiang	1.000	0.680	0.775	0.812	0.939
Central Jiangsu	Xuzhou	0.517	0.623	0.652	0.734	0.661
	Lianyungang	1.000	1.000	1.000	1.000	1.000
	Huai'an	0.869	1.000	1.000	1.000	1.000
Northern Jiangsu	Xuzhou	0.602	0.336	0.314	0.311	0.329
	Lianyungang	1.000	0.749	0.738	0.705	0.467
	Huai'an	0.641	0.570	0.690	0.731	0.721
	Yancheng	1.000	1.000	1.000	1.000	1.000
	Suqian	1.000	1.000	0.684	0.753	0.870
Total Average		0.764	0.746	0.727	0.735	0.697
Average of Southern Jiangsu		0.661	0.684	0.675	0.663	0.602
Average of Central Jiangsu		0.795	0.874	0.884	0.911	0.887
Average of Northern Jiangsu		0.849	0.731	0.685	0.700	0.677

Region	City	2015	2016	2017	2018	2019
Southern Jiangsu	Nanjing	0.394	0.441	0.364	0.369	0.361
	Wuxi	0.536	0.338	0.261	0.260	0.295
	Changzhou	0.647	0.482	0.305	0.387	0.322
	Suzhou	0.313	0.260	0.257	0.262	0.245
	Zhenjiang	0.895	0.616	1.000	1.000	1.000
Central Jiangsu	Xuzhou	0.654	0.482	0.496	0.585	0.528
	Lianyungang	1.000	1.000	1.000	1.000	1.000
	Huai'an	1.000	1.000	1.000	1.000	1.000
Northern Jiangsu	Xuzhou	0.284	0.186	0.198	0.426	0.251
	Lianyungang	0.437	0.277	0.444	0.696	0.655
	Huai'an	0.512	0.651	0.728	0.945	1.000
	Yancheng	1.000	1.000	1.000	1.000	1.000
	Suqian	0.657	0.592	0.674	0.713	0.520
Total Average		0.641	0.563	0.594	0.665	0.629
Average of Southern Jiangsu		0.557	0.427	0.437	0.456	0.445
Average of Central Jiangsu		0.885	0.827	0.832	0.862	0.843
Average of Northern Jiangsu		0.578	0.541	0.609	0.756	0.685

It can be seen from Table 2 that without considering the influence of external environmental factors and random errors, the technical efficiency level of economic green development of Jiangsu Province as a whole and all regions from 2010 to 2019 was relatively high, with large fluctuations, and the values were in the range of 0.400 to 1.000. From 2010 to 2019, there were significant differences in the green development efficiency of the three regions in Jiangsu Province, among which the average efficiency in central Jiangsu reaches 0.860, the average efficiency in northern Jiangsu was close to the average level of the whole province, and the average efficiency in southern Jiangsu was slightly lower than the average level of the whole province. Without eliminating the influence of environmental factors and random errors, the efficiency of economic green development in central Jiangsu was relatively high and remained relatively stable from 2010 to 2019. Overall lower than the provincial level. The average efficiency values of Zhenjiang, Yangzhou, Taizhou, and Yancheng were all higher than 0.850, among which Yangzhou and Yancheng maintain the efficiency value of 1.000 for a long time in ten years, while the average efficiency values of Nanjing, Suzhou and Xuzhou were lower than 0.500.

5.2. Result Analysis of Stage 2 (SFA Model)

By adjusting the initial values of each year, the green development efficiency of regional economy in Jiangsu Province under the same managerial environment was obtained. Firstly, the labor force, innovation, land, technology, and capital slack variables obtained in the stage 1 were explained variables, and the explaining variables include industrial structure, human capital and urbanization rate. Table 3 shows the calculation results of environmental variables and input slack variables, and Frontier 4.1 was used as the analysis tool for this step.

Table 3: The stage-2 SFA regression results

Variable	Labor Force Slack Variable	Innovation Slack Variable	Land Slack Variable	Technology Slack Variable	Capital Slack Variable
Constant term	368.245**	-14.167	642.699***	37.585***	2689.544***
	(1.812)	(-0.787)	(2.758)	(2.638)	(30.407)
ln*Ind*	-112.862**	1.991	-199.302***	-12.184***	-1213.122***
	(-2.156)	(0.431)	(-3.289)	(-3.449)	(-7.748)
ln*Lab*	12.331	-0.214	60.299***	4.641***	308.155*
	(0.65)	(-0.339)	(2.66)	(8.463)	(1.437)
ln*Urb*	11.554*	1.392*	19.216**	1.402**	383.948***
	(1.43)	(1.603)	(1.882)	(1.979)	(2.69)
Sigma-squared	25499.721***	5980.538***	14278.756***	65.43***	1603137.1***
	(9432.42)	(4.473)	(10.27)	(2.99)	(1081242.4)
Gamma	0.971***	0.999***	0.928***	0.922***	0.868***
	(256.029)	(2314.75)	(63.357)	(28.897)	(48.757)
Log Likelihood Function	-643.860	-362.775	-667.538	-308.781	-1005.565
LR	279.506***	449.214***	161.724***	129.652***	115.690***

Note: ***, **, and * indicate significance at the levels of 1%, 5% and 10%, respectively; data in parentheses are t values of variables; gamma represents management inefficiency; log likelihood function represents the value of log likelihood function; LR stands for the result of LR test of the one-sided likelihood error .

In Table 3, each LR passes the 1% significance test, indicating that the data results obtained by

SFA model are reliable; the gamma values of the five input slack variables are 0.971, 0.999, 0.928, 0.922, and 0.868 respectively, and all pass the significance test of 1%, indicating that the efficiency of economic green development is affected by environmental factors such as industrial structure, human capital and urbanization rate. If the regression of environmental variables on slack variables is positive, then there is a positive relationship between them. So, the increase of environmental variables may lead to the increase of input redundancy and the waste of cost input. Conversely, saving input costs has a positive impact on governance efficiency. The specific description of the analyses of the environmental variables is as follows:

(1) Industrial structure. The regression coefficients of this variable on the four input slack variables of labor, land, technology and capital were all negative, and all pass the significance test of 5%. It indicates that the increase in the proportion of the secondary industry would reduce such input redundancy. The proportion of the secondary industry was significantly positively correlated with the green development efficiency, which was contrary to the expected results. The reason for this result may come from the industrial structure of most regions in Jiangsu Province and the specific transformation and development path of the secondary industry in each region, that is, while developing the secondary industry to promote economic development, the overall transformation from the secondary industry with high energy consumption, high pollution, and high emissions to the secondary industry with clean and low energy consumption has been in progress and partly realized, which significantly reduced the level of environmental pollution from the sources [20]. The reason could also be attributed to the absorption capacity of the secondary industry in Jiangsu Province for various inputs, that is, the mainstream type of secondary industry in Jiangsu Province could effectively absorb inputs such as labor, land, capital and technology.

(2) Human capital. The regression coefficients of this indicator for the three input slack variables that pass the significance test were positive, and the corresponding variables of land and technology input pass the significance test of 1%, and the corresponding variables of capital input pass the significance test of 10%. The results show that the increase of human capital would lead to the increase of slack variables in each input, that is, the increase of human capital may increase the redundancy of various inputs in Jiangsu province's economic green development, which was contrary to the expectation. This abnormal result may be due to the fact that the data of human capital in this study were determined by the number of ordinary college graduates in that year. In addition, although this paper selected graduates from ordinary colleges and universities as the representative of the data, the increase in their quantity did not necessarily mean the improvement of the overall quality of human capital. While the quantity of human capital enlarged, the structure of human capital was not optimized, and even develops in reverse. This result could be explained by Zheng's research (2022) on the relationship between human capital structure and environmental pollution [2]. Different stages of economic development mean different factor endowment structures, and the optimal production structure endogenously determined by factor endowment structure is also different. In other words, with economic development, the relation between environmental pollution and human capital structure follows the environmental Kuznets curve. In short, the human capital indicator in this study could not reflect the human capital structure perfectly and accurately, and based on the economic level of the studied region, the increase of the variable value in this region does not optimize the human capital structure, so the analysis had "unexpected" results.

(3) Urbanization level. The regression coefficients of the slack variables corresponding to each input were all positive, and all pass the significance test of 10%, indicating that each slack variable was positively correlated with the urbanization rate. The study of Qiu and Huang (2020) pointed out that the relationship between urbanization level and air pollution shows an "inverted U-shaped" curve [17].

According to the above analysis, it can be seen that the influence relationship of environmental variables on the input slack variables, and the influence of external environmental factors would lead to the deviation of the economic green development efficiency of each city in different environments. Therefore, in order to make the results better reflect the green development efficiency of the city's economy, the study adjusted the initial input variables to make all cities under the same conditions of external environment.

5.3. Result Analysis of Stage 3

Table 4: The stage-3 results of the technical efficiency of green development of regional economy in Jiangsu Province, China, from 2010 to 2019

Region	City	2010	2011	2012	2013	2014
Southern Jiangsu	Nanjing	0.695	0.668	0.700	0.631	0.569
	Wuxi	0.901	0.904	0.924	0.966	0.693
	Changzhou	0.832	1.000	1.000	1.000	0.752
	Suzhou	0.561	0.562	0.519	0.523	0.554
	Zhenjiang	1.000	0.596	0.705	0.752	0.866
Central Jiangsu	Xuzhou	0.662	0.800	0.848	0.942	0.880
	Lianyungang	0.784	1.000	1.000	1.000	1.000
	Huai'an	0.804	0.854	1.000	1.000	0.999
Northern Jiangsu	Xuzhou	0.863	0.452	0.425	0.432	0.473
	Lianyungang	0.906	0.674	0.724	0.669	0.452
	Huai'an	0.667	0.624	0.675	0.715	0.703
	Yancheng	1.000	1.000	1.000	1.000	1.000
	Suqian	1.000	0.771	0.572	0.571	0.614
Total Average		0.821	0.762	0.776	0.785	0.735
Average of Southern Jiangsu		0.798	0.746	0.770	0.774	0.687
Average of Central Jiangsu		0.750	0.885	0.949	0.981	0.960
Average of Northern Jiangsu		0.887	0.704	0.679	0.677	0.648

Region	City	2015	2016	2017	2018	2019
Southern Jiangsu	Nanjing	0.567	0.646	0.659	0.699	0.743
	Wuxi	0.641	0.417	0.379	0.390	0.447
	Changzhou	0.696	0.528	0.390	0.488	0.406
	Suzhou	0.469	0.386	0.381	0.430	0.420
	Zhenjiang	0.818	0.570	1.000	1.000	1.000
Central Jiangsu	Xuzhou	0.994	0.675	0.654	0.672	0.687
	Lianyungang	1.000	1.000	1.000	0.749	0.928
	Huai'an	1.000	1.000	1.000	1.000	1.000
Northern Jiangsu	Xuzhou	0.448	0.268	0.291	0.676	0.394
	Lianyungang	0.437	0.270	0.410	0.621	0.601
	Huai'an	0.487	0.646	0.687	0.910	0.976
	Yancheng	1.000	1.000	1.000	1.000	1.000
	Suqian	0.562	0.503	0.585	0.616	0.402
Total Average		0.701	0.608	0.649	0.712	0.693
Average of Southern Jiangsu		0.638	0.509	0.562	0.601	0.603
Average of Central Jiangsu		0.998	0.892	0.885	0.807	0.872
Average of Northern Jiangsu		0.587	0.537	0.595	0.765	0.675

The input variables had been adjusted according to the formula, and the adjusted input and output data were put into the BCC model through the software DEAP 2.1 for calculation. The results after processing are shown in Table 4 and Table 5.

Comparing the results of the first stage and the third stage, after eliminating the influence of environmental factors and random factors, the economic green development efficiency of each region in Jiangsu Province has changed. After adjustment, the mean value of the technical efficiency level of southern Jiangsu and central Jiangsu as a whole, as well as Nanjing, Wuxi, Changzhou, Suzhou, Nantong, and Xuzhou were higher than the value before adjustment, while the mean value of the technical efficiency level of northern Jiangsu as a whole, as well as Zhenjiang, Yangzhou, Taizhou, Lianyungang, Huai'an, and Suqian was slightly lower than the value before adjustment, among which Nanjing had the most obvious growth. It increased from 0.418 to 0.658, and the decrease was the most obvious in Suqian, which decreased from 0.746 to 0.620. After eliminating the impact of environmental and random factors, in general, the adjusted value of the average scale efficiency of cities in Jiangsu Province was significantly lower than its average pure technical efficiency. Compared with the pre-adjustment level, the pure technical efficiency of southern Jiangsu and central Jiangsu has increased significantly, among which the cities in southern Jiangsu and Nantong in central Jiangsu have increased relatively obviously, Taizhou has increased slightly, Suqian has decreased slightly, and the average level of other areas remained unchanged. The scale efficiency of all regions in Jiangsu had little change, showing a decline in general, among which Suqian had the most obvious decline from 0.746 to 0.631, Yancheng had remained unchanged before and after the adjustment, and Wuxi had a slight increase.

From the regional perspective, the efficiency values of economic green development in central Jiangsu were at the leading level of the whole province except 2010 after adjustment. In 2010, the efficiency value of northern Jiangsu was the highest in the province, but in the medium term, it dropped to the level lower than that of other regions. The technical efficiency of economic green development in southern Jiangsu was close to and slightly lower than the average of the whole province in the early stage, but the gap has increased and remained relatively fixed since 2014.

As for the changing pattern of green development efficiency in different regions of Jiangsu Province within 10 years, observing the relevant data, it can be seen that the changing trend of efficiency indicators in all regions of Jiangsu Province after adjustment was generally more unstable. After the adjustment, the overall trend of the technical efficiency of economic green development in the province basically remained unchanged, and the efficiency value rises on the whole. The change trend of the technical efficiency of economic green development in northern Jiangsu was basically unchanged in each year. The overall trend of the technical efficiency of economic green development in central Jiangsu remained unchanged over the years: from 2017 to 2018, it changed from an increase to a significant decline. The occurrence time and value of the minimum value decreased from 0.795 at the end of 2010 before the adjustment to 0.750 after the adjustment. The efficiency value in this region showed an inverted U-shaped change from 2010 to 2018, and then decreased to 0.675 in 2019. The changes in the technical efficiency of economic green development in southern Jiangsu were quite different before and after the adjustment, and the efficiency value has increased in most years, among which the increase was the most obvious in 2010 and each year after 2016, which led to the overall downward trend in the early stage of the region, and then dropped to the lowest value of 0.509 in 2016, and then showed a significant upward trend.

According to the data of each year, from 2010 to 2019, the scale efficiency of most regions in Jiangsu Province was slightly exaggerated due to the influence of environment and random errors, which covered up the problems exposed in green development to a certain extent. Relatively speaking, the technical efficiency was underestimated, especially of cities in southern and central Jiangsu. It can be seen that after excluding the influence of environment and random error factors, the change of pure technical efficiency was the key factor causing the change of technical efficiency level.

Specifically, from the perspective of the technical efficiency frontier, in the ten years selected by the study, the total number of cities with effective technical efficiency (VRS effective) remained unchanged or decreased before and after the adjustment. It can be seen that the technical efficiency of some cities in the corresponding years was affected by the environment and random errors, and the efficiency value was inflated.

Regarding the states of returns to scales, the vast majority of cities belonged to the type of increasing returns to scale, and the number of such cities after adjustment was higher than that before adjustment except for 2013, 2016 and 2017. Cities with constant returns to scale maintained the same number or decrease in 10 years. A few cities with decreasing returns to scale remained unchanged or lower than the number before adjustment (See Table 5). There were no cities with decreasing returns to scale in Jiangsu Province in 2014 and 2016. Therefore, most cities should take the path of expanding the scale of input factors to achieve the improvement of economic green development efficiency in the past and perhaps at present.

Table 5: The change of economic green development efficiency level and states of returns to scales before and after the adjustment

Year	VRS Efficient		IRS		DRS		CONS	
	Before	After	Before	After	Before	After	Before	After
2010	5	3	4	9	4	1	5	3
2011	5	3	7	9	1	1	5	3
2012	4	4	8	8	1	1	4	4
2013	4	4	7	7	2	2	4	4
2014	3	2	9	11	1	0	3	2
2015	3	3	9	9	1	1	3	3
2016	3	3	10	10	0	0	3	3
2017	4	4	9	9	0	0	4	4
2018	4	3	9	10	0	0	4	3
2019	5	3	8	10	0	0	5	3

Note: "VRS Effective" represents the number of the cities whose technical efficiency was scale effective; "IRS" represents increasing returns to scale; "DRS" represents decreasing returns to scale; "CONS" denotes constant returns to scale. An efficiency value of 1.000 is considered effective, thus a technical efficiency value of 1.000 means being "VRS Effective".

6. Analysis of the Economic Green Development Efficiency of the Regions in Jiangsu Province

Based on the analysis of prefecture-level cities in the three regions in the above parts, we can draw further conclusions by comparing the data and research results.

Firstly, by comparing the efficiency values before and after adjustment and the empirical analysis results obtained by different research objects in the first and third stages of the three-stage DEA model, and further comparing the data of various areas, we can find that the economic development stage of northern Jiangsu was relatively lagging behind, the cities' economic sizes were small. The efficiency values of some cities in northern Jiangsu were low in most years, though the economic green development efficiency of some cities could still reach a certain high value in some years. In the early stage, most environmental indicators and economic indicators of northern Jiangsu as a whole and prefecture-level cities were lower than those of other areas, and the corresponding regional development process had an obvious transformation stage, which might be caused by the problems encountered in the transformation process of traditional industries in the corresponding areas. About central Jiangsu and the cities within, the efficiency values of most areas in central Jiangsu were higher than those of other regions in the province, and high efficiency values of the cities mainly appeared in the early period of the selected period. Compared with other regions in the province, the path of economic green development in central Jiangsu was more stable. In southern Jiangsu, the efficiency values and changes among cities were quite different, which might be affected by various factors such as the economic development level and the main functions of cities in southern Jiangsu. Compared with other cities in the province, the indicator values of all areas in southern Jiangsu were lower in the later period except Zhenjiang. Many cities in southern Jiangsu Province are leading in economy and politics in Jiangsu Province, so their relatively low efficiency values and relatively vague or negative development might be due to the fact that such areas were going through a necessary exploration period on the path of economic green development, and the development of such activities eventually led to the decrease of the values of some indicators of economic green development of the corresponding cities. From the results of data comparison of the prefecture-level cities in the three regions, it can be seen that there were obvious differences in the stage-3 efficiency values of the cities of different sizes. In most cases, the efficiency values of the medium-sized cities in Jiangsu Province were larger, while the efficiency values of the small-sized and the large-sized cities were lower, that is, the relationship between efficiency and city size level often presented an inverted U-shaped. Generally speaking, although large-sized cities have obvious advantages in economic foundation, while attracting more inputs and production factors, they will lead to congestion effect caused by excessive concentration, increasing the pollution level and adversely affecting various environmental indicators. The economic infrastructure and infrastructure of small-sized cities are relatively ordinary, with relatively few inputs and factors, average technology and management capabilities, and relatively average work capacity and efficiency in the field of economic green development. The population size of medium-sized cities is smaller than that of large-scale cities, the factors and inputs of small cities are more sufficient, the industrial structure is relatively concentrated and easy to control, and the efficiency of environmental governance or policy implementation is higher and faster. This conclusion can be clearly reflected by comparing some representative large-sized cities in southern Jiangsu, such as Nanjing and Suzhou, some medium-sized cities in central Jiangsu, and some small-sized city in northern Jiangsu.

Except for the years when the technical efficiency was effective, most places in Jiangsu Province have been in the state of increasing returns to scale in recent years, while some regions have seen decreasing returns to scale in a few years. In this regard, the focus of the development of relevant areas in Jiangsu Province was to reasonably expand input, and at the same time reduce the proportional impact of environmental factors on input redundancy as much as possible, so as to effectively improve the efficiency in the process of economic green development. The results show that in some periods, cities with decreasing returns to scale have changed from this state to constant returns to scale or increasing returns to scale, which can solve the problem of over-saturation of factors and total inputs by means of effective adjustment in industrial structure and input.

According to the efficiency values of economic green development and their changes in the past 10 years, it has been pointed out above that the changes of indicators of some cities in central and southern Jiangsu were similar—the technical efficiency value generally declined or remained at a low level over time. The reason may be that on the basis of their economic advantages, such cities explored feasible paths that could well coordinate green development and economic growth in the middle and late stages. However, the transformation and upgrading of relevant industries in such areas was difficult and took a long time. The 10-year data used in this paper only showed the initial stage of the corresponding urban industrial adjustment process without recording the possible stage of improving the efficiency of economic green development in the later stage of the process, which ultimately leads to the corresponding trend of change showed in the paper. In order to further improve the economic level, the relevant places in northern Jiangsu actively changed the industrial structure, which led to a short-term decline in the efficiency value. In the later stage, based on their own economic development stages, combined with their own characteristics, these places achieved sustained economic growth and significant recovery of green development efficiency through effective actions with their late-mover advantage. This change reflects the transformation process of the traditional industrial structure of some cities in northern Jiangsu. Compared with the industrial development process of the cities in southern and central Jiangsu mentioned above, the process in northern Jiangsu took a shorter time and it can be clearly shown in the charts above. In conclusion, the various changing patterns reflected that each place has changed its industrial structure according to its own characteristics. The places represented by most of the cities in southern Jiangsu preferred to seek further innovation in the unknown path, which means trying to make breakthroughs on the frontier, while the places represented by some cities in northern Jiangsu preferred to seek high-speed catch-up according to the known path, which is more based on their late-mover advantage.

Regarding the analysis of the impact of environmental variables on each input in the second stage of the three-stage DEA model, we can find significant differences among regions in Jiangsu Province by comparing the results of the research objects. From the perspective of the environmental variable of industrial structure, that is, the proportion of secondary industry, the increase of the value of this indicator in different areas would reduce the redundancy of most inputs. The proportion of the secondary industry was significantly positively correlated with the green development efficiency. The secondary industry in most areas of Jiangsu Province is relatively advanced—with clean, environmental protection and low energy consumption, strong absorption capacity of various inputs, and relatively high-quality industrial structure and good industrial vitality.

From the perspective of the environmental variable of human capital, the regression results corresponding to this environmental variable all show certain unexpectedness. Based on the above explanations, the reason for the unexpectedness can be attributed to the economic development level and factor endowment of each object.

From the perspective of the environmental variable of urbanization level, most of the results show that under normal circumstances, the rapid promotion of urbanization would exacerbate pollution, thus having a certain degree of negative impact on the green development of regional economy. The overall urbanization of Jiangsu Province has reached a high level, and excessive input may cause congestion effect, reduced efficiency of input utilization, and over-saturation of input in the short term, which will lead to the deterioration of economic green development to a certain extent.

7. Conclusions and Policy Suggestions

7.1. Analysis Conclusions

The empirical analysis based on the three-stage DEA model shows that the changing paths of economic green development efficiency in various regions of Jiangsu Province were significantly different. In most years, the efficiency value of some prefecture-level cities in northern Jiangsu was relatively low. In the early stage, most environmental indicators and economic indicators in northern Jiangsu as a whole and prefecture-level cities were relatively low compared with other regions. The efficiency values of most regions in central Jiangsu were higher than those in other regions of the province, and the high efficiency values were concentrated in the early stage. There were obvious gaps in efficiency values and changes among cities in southern Jiangsu, and most cities have lower indicators in the later period, and the values tend to be vague or negative. According to the efficiency value and its changes, it can be seen that the industrial development process of many cities in northern Jiangsu and southern Jiangsu may have undergone a transformation stage. The former had a short transformation time and has a significant effect, while the latter had a relatively long transformation time. It requires long-term research to more effectively reflect it. The relationship between technical efficiency and city size often presents an inverted U-shape [17]. Generally speaking, large-sized cities with better economic foundations attract a large amount of investment and production factors, which can easily lead to congestion effects, increase management difficulties, and affect green development. The economic level, infrastructure, input and production factors, technology and management capabilities of small-sized cities are relatively low, and the efficiency of economic green development is often correspondingly low. However, the population size, factors and inputs of medium-sized cities are relatively sufficient and redundant, and they are more flexible and effective in centralized control and adjustment of industrial structure. The implementation cycle of various tasks of economic green development is shorter and the efficiency is higher.

After removing the influence of external environmental factors and random error factors through the second stage of the three-stage DEA model, the adjusted value of the average scale efficiency of cities in Jiangsu Province was significantly lower than its average pure technical efficiency. Compared with the pre-adjustment level, the pure technical efficiency in southern and central Jiangsu has increased significantly, among which the cities in southern Jiangsu and Nantong in central Jiangsu have seen the most obvious increase. The scale efficiency and technical efficiency of each region have changed greatly, and the pure technical efficiency has changed slightly. After adjustment, the improvement path of green economy development efficiency in Jiangsu Province and prefecture-level cities has changed greatly and become more unstable. After the adjustment, the overall changing trend of technical efficiency basically remains unchanged, the efficiency value increases as a whole, and the pure technical efficiency value was relatively high. After adjustment, the comprehensive efficiency value of most years of each object was mainly affected by the scale efficiency. The scale efficiency of most areas in Jiangsu Province was affected by the environment and random errors, which slightly exaggerated the efficiency value, which concealed the problems exposed in green development to a certain extent. Relatively speaking, the phenomenon of insufficiency of technical efficiency concentrated in cities in southern and central Jiangsu. Excluding the influence of environment and random error factors, the change of pure technical efficiency was the key factor that causes the change of technical efficiency.

From the perspective of the adjustment of the efficiency level of economic green development, in most years from 2010 to 2019, most prefecture-level cities in Jiangsu Province belonged to the type of increasing returns to scale after adjustment.

In the second stage of the three-stage DEA model, there were significant differences in the specific impacts of different environmental variables on each input in Jiangsu Province. Due to the special structure of the secondary industry in most areas of Jiangsu Province, the ability to utilize and absorb various inputs was strong, and the clean, environmentally friendly, and low-pollution secondary industry accounted for a large proportion. The proportion of the secondary industry was significantly positively correlated with the efficiency of green development. The unexpected regression results corresponding to the human capital environment variables show that under the economic development level and factor endowment of each object, with the increase of the variable value, the human capital structure of the corresponding region developed in reverse, which had a negative impact on the efficiency of green development [2]. The environmental variables of the level of urbanization generally led to an increase in investment redundancy in Jiangsu Province, which had a negative impact on the economic green development of the corresponding regions.

7.2. Policy Suggestions

In this part, by referring to other research focusing on the economic green development of some other regions in China [3][4][23] while further analyzing the conclusions of this research, this paper extracted applicable points of other materials and summarized some policy recommendations for Jiangsu Province.

The government should strengthen the green development synergy between regions in Jiangsu Province, and try to reduce the differences in pollution control capabilities while balancing the economic development levels of the three major regions. Based on the spillover effect of pollution, coordinated pollution control should insist on strengthening regional cooperation, and strengthen the relevance of inter-regional pollution prevention and control through inter-regional technology sharing, information sharing, method sharing and other measures.

In view of the changes in returns to scale, different regions should choose different methods in different periods to promote the green development of the regional economy. For regions with increasing scale returns in the corresponding period, it is recommended to increase the efficiency of economic green development by increasing technological innovation, actively introducing environmental governance talents, and increasing reasonable and effective investment. For cities with diminishing returns to scale during the corresponding period, the allocation of input resources should be optimized to improve resource utilization, thereby improving governance efficiency.

Areas with relatively backward economic development stage and industrial structure in Jiangsu Province, such as some cities in northern Jiangsu, should pay attention to ecological construction and environmental protection while employing relatively traditional methods to achieve industrial development and economic growth during the period of industrial growth. Moreover, these areas should give full play to the benefits of scale, efficiently allocate various inputs, learn from advanced experience and at the same time adapt to local conditions, effectively implement actions according to the path that suits you, seize the opportunity, and take advantage of the region's late-mover advantages, so as to further improve the efficiency of economic green development.

For the areas in Jiangsu Province whose level of economic development are stable and relevant indicators are in the middle position of Jiangsu Province, they should maintain policy determination, solidly implement relevant measures that are conducive to promoting economic green development, and achieve sustained and steady economic growth under the premise of effective promotion of ecological construction. In the path of improving the efficiency of economic green development, relevant places also need to observe, analyze and adjust factor inputs and industrial allocation in a timely manner according to their own characteristics.

For the areas in Jiangsu Province that are at the forefront of economic development, such as some cities in southern Jiangsu and central Jiangsu, should make full use of its sufficient resources to overcome the reform resistance caused by the large industrial scale and realize further optimization of industrial structure. The formulation and implementation of policies in relevant regions should start from the details, focusing on the optimization of human capital structure, the type of enterprises within the secondary industry, and the absorption capacity of high-quality input factors such as innovation.

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