Research Article

Evaluation of the Efficiency of Marine Science and Technology, Green Efficiency of the Marine Economy, and Comprehensive Efficiency in China

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Based on the unexpected output network SBM-DEA model, this study calculates the efficiency of marine science and technology, green efficiency of the marine economy, and comprehensive efficiency in 11 coastal provinces and cities in China from 2006 to 2017. The influencing factors of two-stage efficiency and comprehensive efficiency are tested by a panel tobit model. The results show that (1) the marine comprehensive efficiency in China from 2006 to 2017 is low, with an average of 0.581. The comprehensive efficiency has not achieved DEA effectiveness, because the efficiency of the first stage is less than 1. The green efficiency of the second stage is generally better than that of the first stage; and (2) among the influencing factors, the development level of the marine economy has a significant positive effect on the second-stage efficiency and comprehensive efficiency. Finally, the author suggests optimizing the input-output efficiency of marine scientific and technological resources, accelerating the transformation of marine scientific and technological achievements, and continuing to promote the development of the marine economy to improve the comprehensive efficiency of the marine economy.

1. Introduction

At present, the marine economy has slowed down in China. The growth rate of the marine economy was as high as 18% in 2006. It has slowed significantly since 2012, and it was stable at 6%–7% from 2015 to 2017, indicating that the marine economy had completed high-speed growth and turned to the stage of paying more attention to connotation and quality, as shown in Figure 1. More and more scholars use the green efficiency of the marine economy to measure the connotation quality of the marine economy. The key to improve the green efficiency of the marine economy lies in marine science and technology (Qin et al., 2020) [1]. Marine science and technology will provide new power and support systems for the development of the marine economy towards higher quality (Wang et al. [2]; Liu et al. [3]).


2. Literature Review

The calculation of economic green efficiency has mainly gone through the following stages: the first stage is to measure green efficiency by taking environmental pollution as an input variable. Pittman et al. [4] first introduced environmental factors into the measurement framework and used pollution control costs as the “bad” output price; in the second stage, environmental pollution is regarded as a “bad” output based on radial and angular directional distance functions. Chung et al. [5] used the directional distance function to calculate the efficiency of pulp mills in Sweden for the first time; and the third stage is based on the non-radial and nonangular directional distance functions of relaxation variables. Tone [6] proposed the slack-based measure (SBM) efficiency measurement model, which was improved by Färe et al. [7].

A study on the green efficiency of the marine economy began in the third stage mentioned above. That is, the green

Scientific and technological innovation-driven economic development has always been the focus of scholars at home and abroad. From early classical economics to the neoclassical economic growth theory, the Schumpeterian innovation theory, and the neo-Schumpeterian theory, scholars have conducted in-depth research on economic growth driven by science and technology from different perspectives and levels (Sun et al. [13]).

There are relatively few studies on the marine science and technology driving the green efficiency of the marine economy. The existing literature mainly calculates the green efficiency of the marine economy, takes marine science and technology as one of its influencing factors, and uses static or dynamic econometric models to analyze its impact on the green efficiency of the marine economy (Qin et al. [1]; Ning et al. [14]; Du et al. [15]; Hui et al. [16]).

The existing research puts forward many important views that provide a useful reference for this research, and some documents expand the ideas of this study [17–19]. However, there are still deficiencies: (1) the research perspective of the relevant literature mainly takes marine science and technology as an influencing factor. Few literatures regard the output of marine science and technology as an intermediate input to open the black box of marine science and technology driving the green efficiency of the marine economy; and (2) the selection of inputs and outputs in the measurement of green efficiency is not unified, and the selection and estimation of variables such as labor input, capital input, and unexpected output, and the processing of missing data need to be standardized.

This study takes the output of marine science and technology as an intermediate variable to link marine science and technology with the green efficiency of the marine economy. Based on the unexpected output network SBM-DEA model, this paper calculates the two-stage efficiency and comprehensive efficiency in 11 coastal provinces and cities in China from 2006 to 2017. On this basis, the influencing factors of two-stage and comprehensive efficiency are tested using a panel tobit model [20]. Finally, according to the research conclusions, we explore the path of marine science and technology driving the green efficiency of the marine economy to provide a decision-making reference for promoting the higher quality development of the marine economy in China.

3. Material and Methods

3.1. The Network SBM-DEA Model Considering Unexpected Output. Based on the unexpected SBM-DEA model [6] and the network SBM-DEA model [21] proposed by Tone and the construction ideas of He et al. [22], this study defines the network SBM-DEA model considering unexpected output, which is called the unexpected output network SBM-DEA model.

3.1.1. Unexpected SBM-DEA Model. The number of decision-making units is $N (j = 1, 2, \ldots, N)$, $X$ means input, and the quantity is $n$, $Y^a$ means expected outputs, and the quantity is $m_1$, $Y^b$ means unexpected outputs, and the quantity is $m_2$, $x \in R^n$, $y^a$, $y^b$.

The input-output matrix is expressed as follows:
The input expressed as follows: \( S_a \) represents the expected output relaxation variable, \( S_b \) represents the undesired output relaxation variable, \( \lambda \) represents the weight vector. In the above expression, \( S \) represents the input relaxation variable, \( S^b \) represents the undesired output relaxation variable, and \( \lambda \) represents the weight vector.

3.1.2. Unexpected Output Network SBM-DEA Model. As shown in Figure 2, supposing there are \( m \) subprocesses. \( I_k \) and \( R_k \) are the number of inputs and outputs of the \( k \)th subprocess, respectively. \( (k - 1, k) \) represents the node between subprocess \( k - 1 \) and subprocess \( k \). The input \( x_{i,j}^k \) of subprocess \( k \) produces the expected output \( y_{r,j}^k \) and the unexpected output \( \mu_{p,j}^k \). The intermediate variable connecting department \( k - 1 \) and \( k \) is denoted by \( z_{j}^{(k-1,k)} \). \( \lambda_{j}^{k} \) represents the density vector in the production process of subprocess \( k \).

Assuming that the network production possibility set satisfies a closed set, convex set, joint weak disposability, strong disposability, and joint weak disposability of inputs and expected outputs, it transforms the network environment technology model under the premise of constant return to scale as follows:

\[
\begin{align*}
\text{Min} & \quad \rho^* = \frac{1 - (1/n) \sum_{i=1}^{n} (S_i / x_{i,0})}{1 + (1/m_1 + m_2) \left( \sum_{i=1}^{n} S_i / y_{r,0} + \sum_{j=1}^{m} \left( S_j / y_{r,j}^b \right) \right)} \\
& \quad \text{s.t.} \quad x_{i,0} = X\lambda^k + S_i^k, \\
& \quad y_{r,0} = Y^k\lambda^k - S_i^k, \\
& \quad y_{r,j}^b = Y^k\lambda^k + S_i^b, \\
& \quad S_i^k \geq 0, \quad S_i^b \geq 0, \quad \lambda \geq 0.
\end{align*}
\]

In the above expression, \( S \) represents the input relaxation variable, \( S^b \) represents the expected output relaxation variable, \( S^b \) represents the undesired output relaxation variable, and \( \lambda \) represents the weight vector.

Based on the input relaxation variable \( s_k^k \), the expected output relaxation variable \( s_k^{g_k} \), and the unexpected output relaxation variable \( s_k^{b_k} \), the unexpected efficiency evaluation model of the evaluated unit DMU is expressed as follows:

\[
\begin{align*}
\rho^*_p = \min & \quad \frac{\sum_{k=1}^{3} \omega^k \left[1 - (1/I_k) \left( \sum_{i=1}^{I_k} s_i^k \right) / x_{i,0}^k \right]}{\sum_{k=1}^{3} \omega^k \left[1 + (1/R_k + P_k) \left( \sum_{i=1}^{3} s_i^k \right) / y_{r,0}^k + \sum_{p=1}^{h} \left( s_p^k / u_p^k \right) \right]} \\
& \quad \text{s.t.} \quad x_{i,0}^k = X\lambda^k + s_i^k, \quad k = 2, \\
& \quad y_{r,0}^k = Y\lambda^k - s_r^{g_k}, \quad k = 2, \\
& \quad u_0^k = U\lambda^k + s_p^{b_k}, \quad k = 2, \\
& \quad z^{(k-1,k)} \lambda_{j}^{k-1} = z^{(k-1,k)} \lambda_{j}^{k} \quad (\forall (k-1,k)), \\
& \quad \lambda > 0.
\end{align*}
\]

In the above expression, \( \omega^k \) is a subjectively specified weight, indicating the relative importance of stage \( k \) to the overall efficiency value of the DMU.
free and unconstrained while maintaining continuity between input and output. \( \rho_0^* \) is the unguided overall efficiency of \( DMU_0 \). If and only if if \( \rho_0^* = 1, s_{r^*} = 0, s_{r^{**}}^k = 0 \), and \( s_{p}^{k_{p^*}} = 0 \), the model is technically effective overall. The unguided efficiency value in stage \( k \) is calculated as follows:

\[
\rho_k = \frac{1-(1/I_k)\left(\sum_{i=1}^{I_k} (s_{r^*}^i - s_{r^{**}}^i) / y_{r^*}^i + \sum_{p=1}^{I_p} (s_{p}^{k_{p^*}} / y_{p^*}) / y_{p^*}\right)}{1/\rho_k + P_t(\sum_{i=1}^{I_k} (s_{r^*}^i / y_{r^*}^i) + \sum_{p=1}^{I_p} (s_{p}^{k_{p^*}} / y_{p^*}) / y_{p^*})}, \quad k = 2, 3.
\]

where \( s_{r^*}^i, s_{r^{**}}^i, s_{p}^{k_{p^*}} \) are the optimal solutions of inputs, expected outputs, and unexpected outputs in Model (2).

### 3.2. Selection of Input-Output Variables and Intermediate Variables

#### 3.2.1. Selection of Input Variables in the First Stage

The input indices are mainly considered from three aspects: capital input, labor input, and material resource input. Drawing on the ideas of Wang et al. [24], the capital input is expressed by the funding input of marine scientific research institutions. The labor input is expressed by the number of marine science and technology practitioners in marine scientific research institutions. The material resource input is expressed by the number of marine research institutions. To increase the comparability of data, the annual consumer price index is used to convert the funding input of marine scientific research institutions into comparable prices based on 2005.

#### 3.2.2. Intermediate Variables

The output of marine science and technology is taken as the intermediate variable. It mainly reflects the achievements in four categories: patents, papers, works, and topics. They are expressed by the number of invention patents owned, scientific and technology papers published, scientific and technology works published, and scientific and technology projects of marine scientific research institutions. To meet the requirement of the model on the quantity of inputs and outputs, the entropy method was used to calculate the weight of the four indicators, and finally, the marine scientific and technological output index was obtained, which was used as the final quantitative index.

#### 3.2.3. Selection of Input-Output Variables in the Second Stage

Input indices: marine labor input and marine capital input.

##### Determination of marine labor input

This paper uses the number of sea-related employees in coastal areas. Since the index of sea-related employment in coastal areas is no longer counted in the China Marine Economic Statistical Yearbook (2018), the processing method of missing data by Zhang et al. [25] is adopted. The time trend (logarithm) of coastal provinces is used to carry out OLS regression on the existing sea-related employment (logarithm) in various regions from 2006 to 2016. The data in 2017 were missing, so a used fit value was employed instead.

##### Determination of marine capital input

Since there are no statistics on the marine capital stock, drawing lessons from Ding et al. [26], converting the capital stock of coastal areas was achieved using the proportion of gross ocean product and the gross product of coastal areas. The estimation method of the capital stock of coastal areas was the sustainable inventory method. Drawing on the calculation formula of Zhang et al. [25],

\[
K_t = I_t + (1 - \delta_t)K_{t-1},
\]

where \( K_t \) represents the capital stock in year \( t \), \( K_{t-1} \) represents the capital stock in year \( t-1 \), \( I_t \) represents the investment in year \( t \), \( P_t \) represents the fixed asset price index in year \( t \), and \( \delta_t \) represents the capital depreciation rate in year \( t \), which is set as 9.6\%. According to the initial capital stock in 2000 calculated by Zhang et al. [25], the nominal capital stock
of 11 coastal provinces and cities expressed in current prices was obtained in turn, and then, the fixed asset price index was used to reduce it to the actual capital stock based on 2005.

Output indices: expected and unexpected outputs of the marine economy.

**Expected outputs of the marine economy.** The gross ocean product of 11 coastal provinces and cities was chosen as the quantitative index [27]. To increase the comparability of the data, the annual consumer price index was used to convert the gross ocean product to comparable prices based on data from 2005.

**Unexpected outputs.** In the production process of the marine economy, there will also be unexpected outputs, such as wastewater and solid waste, which will cause direct pollution to seawater. This paper chooses the discharge of solid waste and wastewater from the marine industry as the unexpected outputs of the marine economy. Since there are no indices on the discharge of marine industrial solid waste and discharge of marine industrial wastewater in the existing statistical data, the proportion of gross ocean product in coastal areas to regional gross product was used to convert the discharge of industrial solid waste and industrial wastewater in coastal areas and obtain the discharge of marine industrial solid waste and discharge of marine industrial wastewater. Then, the entropy method was used to calculate the weight of the two indices, and finally, the marine environmental pollution index was obtained as the final quantitative indicator of unexpected outputs. The index system of two-stage efficiency and comprehensive efficiency is shown in Table 1.

3.3. Method of Influencing Factor Analysis. To further analyze the influencing factors of the efficiency, two-stage efficiency and comprehensive efficiency were used as the dependent variables. Indices of influencing factors were chosen to analyze the efficiency value.

### 3.3.1. Tobit Model

Since the dependent variable is the efficiency, and its value range is between 0 and 1, the tobit regression model is selected for analysis.

The dependent variable is the logarithm of the efficiency value. Since the efficiency value range is between 0 and 1, the value range of the dependent variable is less than or equal to 0. The panel tobit regression model is selected for analysis.

\[
y_i^* = x_i' \beta + u_i, \quad i = 1, 2, \ldots, N. \tag{7}
\]

Here, \( \sigma \) is the scale factor, and \( y_i^* \) is a potential dependent variable. The relationship between observed data and potential dependent variables is as follows:

\[
y_i = \begin{cases} 0, & \text{if } y_i^* > 0, \\ y_i^*, & \text{if } y_i^* \leq 0. \end{cases} \tag{8}
\]

All the values of \( y_i \) with positive values are defined as 0. It is said that these data are right intercepted at 0. More generally, they can be intercepted on the left and right of any finite point, that is,

\[
y_i = \begin{cases} c_-, & \text{if } y_i^* \leq c_-, \\ y_i^*, & \text{if } c_- < y_i^* < c_+, \\ c_+, & \text{if } c_+ \leq y_i^*. \end{cases} \tag{9}
\]

After substituting the efficiency value into the above expression, when the potential dependent variable is less than or equal to 0, the value of the dependent variable is the logarithm of the efficiency value; and when the potential dependent variable is greater than 0, the value of the dependent variable is truncated.

3.3.2. Selection of the Influencing Factor Variable. The efficiency of the first stage (InTES), the efficiency of the second stage (InTET), and comprehensive efficiency (InTET) were selected as explained variables.

Based on the existing literature and the actual situation of the marine economy, the following variables were selected as explanatory variables:

1. **Upgrading the marine industrial structure** (ois).
   According to Gang et al. [28], Shao et al. [29], and Ren et al. [30], it is expressed by the ratio of added value of marine tertiary industry to that of marine secondary industry.

2. **Development level of marine education** (edu). It is measured by the proportion of undergraduate and junior college students of marine majors in general higher education in coastal areas.

---

**Table 1:** Index system of the two-stage efficiency and comprehensive efficiency.

<table>
<thead>
<tr>
<th>Stage</th>
<th>First-level indices</th>
<th>Second-level indices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inputs</td>
<td>Funding input</td>
</tr>
<tr>
<td>First</td>
<td>Outputs (intermediate variables)</td>
<td>Number of technology practitioners</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of marine scientific research institutions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of invention patents owned</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of papers published</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of works published</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of projects</td>
</tr>
<tr>
<td>Second</td>
<td>Inputs</td>
<td>Marine labor input</td>
</tr>
<tr>
<td></td>
<td>Expected output</td>
<td>Gross ocean product</td>
</tr>
<tr>
<td></td>
<td>Unexpected outputs</td>
<td>Discharge of marine industrial solid waste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge of marine industrial wastewater</td>
</tr>
</tbody>
</table>

4. Results

4.1. Results of the Efficiency. Based on the unexpected output network SBM-DEA model, this paper uses the Maxdea8 software to calculate the efficiency. The results are shown in Table 2.

### Table 2: Results of two-stage efficiency and comprehensive efficiency.

<table>
<thead>
<tr>
<th>Region</th>
<th>The first-stage efficiency</th>
<th>The second-stage efficiency</th>
<th>Comprehensive efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tianjin</td>
<td>0.248</td>
<td>0.879</td>
<td>0.560</td>
</tr>
<tr>
<td>Hebei</td>
<td>0.495</td>
<td>0.610</td>
<td>0.537</td>
</tr>
<tr>
<td>Liaoning</td>
<td>0.181</td>
<td>0.581</td>
<td>0.380</td>
</tr>
<tr>
<td>Shanghai</td>
<td>0.629</td>
<td>1.000</td>
<td>0.815</td>
</tr>
<tr>
<td>Jiangsu</td>
<td>0.470</td>
<td>0.800</td>
<td>0.627</td>
</tr>
<tr>
<td>Zhejiang</td>
<td>0.230</td>
<td>0.936</td>
<td>0.572</td>
</tr>
<tr>
<td>Fujian</td>
<td>0.329</td>
<td>0.930</td>
<td>0.610</td>
</tr>
<tr>
<td>Shandong</td>
<td>0.421</td>
<td>0.686</td>
<td>0.508</td>
</tr>
<tr>
<td>Guangdong</td>
<td>0.587</td>
<td>1.000</td>
<td>0.794</td>
</tr>
<tr>
<td>Guangxi</td>
<td>0.074</td>
<td>0.780</td>
<td>0.405</td>
</tr>
<tr>
<td>Hainan</td>
<td>0.169</td>
<td>1.000</td>
<td>0.584</td>
</tr>
<tr>
<td>Average value</td>
<td>0.348</td>
<td>0.837</td>
<td>0.581</td>
</tr>
</tbody>
</table>

4.1.1. Characteristic Analysis of Comprehensive Efficiency. Table 2 shows that China’s comprehensive efficiency of the marine economy from 2006 to 2017 was low, with an average of 0.581. There is a large regional gap, among which there are five areas where the efficiency is above the national average, namely, Shanghai, Jiangsu, Fujian, Guangdong, and Hainan, accounting for 45% of the coastal areas. The areas with high comprehensive efficiency evaluation value are mostly marine economically developed areas with strong marine scientific and technological ability. There are six regions where the efficiency is below the national average, namely, Tianjin, Hebei, Liaoning, Zhejiang, Shandong, and Guangxi. The lower comprehensive efficiency of Tianjin and Zhejiang comes from the low efficiency of the first stage. The low comprehensive efficiency of Hebei and Shandong is due to the low efficiency of the second stage, which may be due to the neglect of marine environmental pollution [31]. The efficiency values of two stages in Liaoning and Guangxi are below the average level.

4.1.2. Two-Stage Efficiency Characteristic Analysis. The average efficiency of the first stage in coastal areas from 2006 to 2017 was 0.348. The inputs and outputs of marine scientific and technological resources in 11 coastal areas are in a state of inefficiency. There are five regions where the efficiency of the first stage is above the average, namely, Hebei, Shanghai, Jiangsu, Shandong, and Guangdong, accounting for 45% of the coastal areas. There are six regions where the efficiency is below the average value, among which Guangxi and Hainan have the lowest marine scientific and technological efficiencies, which are 0.074 and 0.169, respectively, which means that there is still much room to improve the marine scientific and technological efficiency.

The average efficiency of the second stage in coastal areas from 2006 to 2017 was 0.837, which was significantly higher than that of the first stage. Among them, Shanghai, Guangdong, and Hainan have achieved DEA effectiveness, accounting for 27% of the coastal areas. There are six areas where the efficiency is above the average, namely, Tianjin, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan, accounting for 55% of the coastal areas. Hainan’s marine
4.2. Results of Influencing Factor Analysis. Since the efficiency is between 0 and 1, the panel tobit regression model was selected. In addition, to eliminate the dimensional problem of different variables and avoid heteroscedasticity, the data of all variables are in logarithmic form, as shown in Table 3.

The influencing factors are tested by the Stata 15.0 software. The regression results are shown in Table 4.

Table 3: Descriptive statistics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean value</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Observed quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln TET</td>
<td>-0.5874</td>
<td>0.3090</td>
<td>-1.7012</td>
<td>0</td>
<td>132</td>
</tr>
<tr>
<td>ln TEF</td>
<td>-1.3433</td>
<td>0.8544</td>
<td>-4.0788</td>
<td>0</td>
<td>132</td>
</tr>
<tr>
<td>ln TES</td>
<td>-0.2146</td>
<td>0.2852</td>
<td>-1.0722</td>
<td>0</td>
<td>132</td>
</tr>
<tr>
<td>ln ois</td>
<td>0.1551</td>
<td>0.4072</td>
<td>-0.7829</td>
<td>1.1915</td>
<td>132</td>
</tr>
<tr>
<td>ln edu</td>
<td>-4.6811</td>
<td>0.7187</td>
<td>-7.5346</td>
<td>-3.5957</td>
<td>132</td>
</tr>
<tr>
<td>ln fe</td>
<td>-3.8330</td>
<td>0.6644</td>
<td>-5.6931</td>
<td>-2.6308</td>
<td>132</td>
</tr>
<tr>
<td>ln gap</td>
<td>-1.8413</td>
<td>0.6099</td>
<td>-2.9495</td>
<td>0.5420</td>
<td>132</td>
</tr>
<tr>
<td>ln open</td>
<td>-0.7407</td>
<td>0.7278</td>
<td>-2.1246</td>
<td>1.6038</td>
<td>132</td>
</tr>
<tr>
<td>ln hc</td>
<td>-7.7281</td>
<td>0.7359</td>
<td>-9.7054</td>
<td>-6.4250</td>
<td>132</td>
</tr>
</tbody>
</table>

Table 4: Regression results of influencing factors.

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>The first-stage efficiency</th>
<th>The second-stage efficiency</th>
<th>Comprehensive efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Standard error</td>
<td>Coefficient</td>
</tr>
<tr>
<td>ln ois</td>
<td>-0.321</td>
<td>0.2385</td>
<td>-0.512***</td>
</tr>
<tr>
<td>ln edu</td>
<td>-0.0566</td>
<td>0.1323</td>
<td>-0.0682</td>
</tr>
<tr>
<td>ln fe</td>
<td>-0.185*</td>
<td>0.1097</td>
<td>0.120*</td>
</tr>
<tr>
<td>ln gap</td>
<td>0.119</td>
<td>0.2205</td>
<td>0.891***</td>
</tr>
<tr>
<td>ln open</td>
<td>0.0441</td>
<td>0.1938</td>
<td>-0.251*</td>
</tr>
<tr>
<td>ln hc</td>
<td>0.453**</td>
<td>0.1806</td>
<td>-0.316***</td>
</tr>
<tr>
<td>_cons</td>
<td>1.500</td>
<td>1.2266</td>
<td>-0.688</td>
</tr>
</tbody>
</table>

Wald chi2(6) = 61.11***

4.2. Results of Influencing Factor Analysis. Since the efficiency is between 0 and 1, the panel tobit regression model was selected. In addition, to eliminate the dimensional problem of different variables and avoid heteroscedasticity, the data of all variables are in logarithmic form, as shown in Table 3.

The influencing factors are tested by the Stata 15.0 software. The regression results are shown in Table 4.

Table 4 shows that the Wald chi2(6) values of the three regression equations passed the 10% significance level test, indicating that the overall goodness of fit for the three models was good.

In the first stage, marine human capital is significantly positive under the confidence of 95%, indicating that the greater the proportion of marine professionals and technical personnel in the number of sea-related employees, the higher the efficiency of the first stage. The intensity of fiscal expenditure is significantly positive under the confidence of 90%, indicating that the greater the proportion of science and technology in fiscal expenditure is, the higher the efficiency of the second stage is. The development level of the marine economy is significantly positive under the confidence of 99%, indicating that the greater the proportion of gross ocean product in regional gross product is, the more developed the marine economy is and the more conducive it is to the efficiency of the second stage. The degree of openness to the outside world has a negative effect on the efficiency of the second stage. The development level of marine education, upgrading the marine industrial structure and the marine economy, and the degree of openness to the outside world have no significant impact on the efficiency of the first stage.

In the second stage, the upgrading of the marine industrial structure has a negative effect on the efficiency of the second stage at the significance level of 1%, indicating that the service-oriented marine industrial structure does not lead to the improvement of the efficiency of the second stage. The intensity of fiscal expenditure is significantly positive under the confidence of 90%, indicating that the greater the proportion of science and technology in fiscal expenditure is, the higher the efficiency of the second stage is. The development level of the marine economy is significantly positive under the confidence of 99%, indicating that the greater the proportion of gross ocean product in regional gross product is, the more developed the marine economy is and the more conducive it is to the efficiency of the second stage. The degree of openness to the outside world has a negative effect on the efficiency of the second stage at the significance level of 10%, indicating that the spillover effect of new technologies introduced by openness to the outside world has not been brought into play effectively and has not promoted the improvement of green efficiency of the second stage. Marine human capital is significantly negative under the confidence of 99%. A possible reason is that the proportion of marine professionals and technical personnel is too small to promote the green efficiency of the second stage. The development level of marine education has no significant effect on the green efficiency of the second stage.
In terms of comprehensive efficiency, the development level of marine education and the intensity of fiscal expenditure have no significant impact on comprehensive efficiency. The upgrading of marine industrial structure and the degree of opening to the outside world have a negative effect on the comprehensive efficiency at the significance level of 1%, indicating that they do not promote the improvement of comprehensive efficiency. The development level of the marine economy is significantly positive under the confidence of 99%, indicating that the more developed the marine economy is, the more conducive it is to the improvement of comprehensive efficiency. Marine human capital has a negative effect on the comprehensive efficiency at the significance level of 5%, indicating that the proportion of marine professionals and technical personnel does not promote comprehensive efficiency.

5. Discussion

Taking the average efficiency of each stage as the dividing point, this paper divides the efficiency in coastal areas into four types, as shown in Figure 3.

The first type is "high science and technology-high efficiency," which includes Shanghai and Guangdong. The efficiency of the two regions in the two stages is above the average value, indicating that the more developed the marine economy is, the more conducive it is to the improvement of comprehensive efficiency. The development level of the marine economy is significantly positive under the confidence of 99%, indicating that the more developed the marine economy is, the more conducive it is to the improvement of the comprehensive efficiency value. Marine human capital has a negative effect on the comprehensive efficiency at the significance level of 5%, indicating that the proportion of marine professionals and technical personnel does not promote comprehensive efficiency.

The second type is "low science and technology-high efficiency," which includes Tianjin, Zhejiang, Fujian, and Hainan. The common point of these regions is that the efficiency of the first stage is low, but the efficiency of the second stage is high. The possible reason is that the utilization rate of marine scientific and technological outputs and the conversion rate of marine scientific and technological achievements in these areas are high, which can be quickly transformed into productivity and drive the higher quality development of the marine economy. In addition, marine economic development in these areas pays attention to the constraints of resources and the environment. The environmental cost of marine economic development is low, which is in line with the concept of high-quality development. Therefore, the efficiency of the second stage is high.

The third type of marine economic development is "low science and technology-low efficiency," which includes Liaoning and Guangxi. Guangxi is mainly due to its low education level and scientific research ability, insufficient investment in marine scientific and technological resources, and the ability of marine science and technology to be improved. In addition, Guangxi’s marine economy is not sufficiently developed, so the efficiency values of the two stages are low. Liaoning’s marine economy is not sufficiently developed, the efficiency values of the two stages are low. Liaoning is an old industrial base in China. The input-output efficiency of marine scientific and technological resources of Liaoning is not high, resulting in low efficiency of the first stage. In addition, the application of marine emerging technologies in Liaoning is insufficient, and marine scientific and technological achievements cannot play a role in promoting the marine economy.

The fourth type of marine economic development is "high science and technology-low efficiency," which includes Hebei, Jiangsu, and Shandong. The efficiency of the
first stage in these three regions is high, but the green efficiency of the second stage is low. Shandong and Jiangsu have a higher level in education and marine scientific research abilities, and the resource allocation level of marine science and technology is also relatively high, so the efficiency of the first stage is high. The low green efficiency of the marine economy may be due to the high environmental cost in the process of marine economic development.

6. Conclusion

Based on the unexpected output network SBM-DEA model, this paper calculates the two-stage efficiency and comprehensive efficiency. According to the calculation results, 11 coastal provinces and cities are divided into four types, and the characteristics of each type are analyzed. The influencing factors of two-stage and comprehensive efficiency were tested by the panel tobit model.

(1) The comprehensive efficiency of the marine economy from 2006 to 2017 was low, with an average of 0.581. The comprehensive efficiency value of 11 coastal provinces and cities has not achieved DEA effectiveness. The reason is that the efficiency of the first stage is less than 1. There is a large regional gap in the comprehensive efficiency value, of which the efficiency of 5 regions is above the national average, accounting for 45% of the coastal areas. The areas with high total efficiency evaluation value are mostly marine economically developed areas with strong marine scientific and technological ability.

(2) From the efficiency value of the two stages, the efficiency of the second stage is significantly higher than that of the first stage. In the efficiency of the second stage, Shanghai, Guangdong, and Hainan have achieved DEA effectiveness.

(3) Among the influencing factors, marine human capital has a significant positive effect on the efficiency of the first stage, and the development level of the marine economy has a significant positive effect on the second-stage efficiency and comprehensive efficiency. The intensity of fiscal expenditure has a significant positive effect on the efficiency of the second stage.

This study provides the following implications that can improve the green efficiency of the marine economy:

(1) The input-output efficiency of marine scientific and technological resources should be optimized. The above research shows that the comprehensive efficiency of the marine economy is low, mainly due to the low efficiency of the first stage. The efficiency of the first stage in 11 coastal provinces and cities has not achieved DEA effectiveness, so there is room for improvement. Therefore, it is necessary to allocate marine scientific and technological resources reasonably. The allocation method of marine scientific and technological resources should be designed with the goal of output to avoid waste caused by the unreasonable structure.

(2) The transformation of marine scientific and technological achievements should be accelerated. From the two-stage efficiency value, it can be seen that the efficiency of the first stage in some areas is low, but the efficiency of the second stage is high. The possible reason is that the achievement conversion rate of marine science and technology in these areas is high, and the ability to convert marine scientific and technological achievements into real productivity is strong, which promotes the efficiency of the second stage. Therefore, it is necessary to actively promote the transformation of marine scientific and technological achievements. Enterprises with a high degree of science and technology can be selected for pilot studies to promote the timely application of marine scientific and technological achievements to the marine industry and form realistic productivity.

(3) The development of the marine economy should be accelerated, and material guarantees should be provided for marine science and technology. As demonstrated by the analysis of influencing factors, the level of marine economic development has a significant positive effect on second-stage efficiency and total efficiency. The marine scientific and technological ability provides power for higher quality development of the marine economy and also provides material guarantees for marine science and technology. Therefore, it is necessary to continue promoting the development of the marine economy and improving the proportion of the marine economy.

This study has the following limitations: when measuring the green efficiency of the marine economy, this paper does not consider the indicators of marine resources and energy in the input variables. In the future research, these factors in marine economic input will be fully considered to measure the green efficiency of the marine economy more accurately. Under the constraints of resources and environment, we should explore the way of green development of the marine economy.

Data Availability

The data used to support the findings of this study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References


