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Technological progress bias and its impact on resource efficiency in China's mariculture industry

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Technological progress (TC) is an important driving force of resource efficiency, and its bias has an important impact on resource efficiency. Based on the data of China's mariculture industry from 2008 to 2020, this paper constructs a double-layer nested CES production function, and uses the seemingly unrelated regression method to estimate the elasticity of substitution between resource elements and non-resource elements of mariculture industry, and measures the level of resource biased technological progress (RBTC). On this basis, the vector autoregressive model is used to explore the relationship between RBTC, resource price and resource efficiency. The results show that: Firstly, there is complementarity between the resource elements of China's mariculture industry and the non-resource elements aggregated by labor and capital. Secondly, there is a long-term equilibrium relationship between resource biased technological progress, resource price and resource efficiency. resource biased technological progress has a short-term negative and long-term positive impact on resource efficiency, and resource price has a short-term negative and long-term positive impact on resource efficiency. Based on this, this paper puts forward relevant policy recommendations to promote the improvement of resource efficiency of mariculture.

KEYWORDS

resource biased technological progress, resource efficiency, elasticity of substitution, mariculture, CES

1 Introduction

Resources are an indispensable factor in human production and life, and play an important role in economic development. In the development of mariculture, marine resources play an important role. As an important material carrier for the development of mariculture, marine resources provide a suitable space environment for the growth of mariculture organisms. However, under the background of the rapid development of mariculture, the utilization of marine resources has been close to saturation. According to the data of China Fishery Statistical Yearbook, the increase rate of mariculture area decreased from 17.759% in 2009 to 0.169% in 2020, and the room for mariculture area expansion is limited. With the marine resources that can be exploited and utilized being gradually reduced, the production activities of mariculture will be limited, and the development scale of mariculture will also be hindered. In addition, the increasingly scarce marine resources will cause mariculture practitioners to compete for the marine area, making the marine resources competition intensified, which will lead to resources over-use and environmental deterioration, posing challenges to the sustainability of mariculture industry. Therefore, how to improve the utilization efficiency of marine resources is one of the urgent problems that need to be solved in the development of the current mariculture industry. For this, this research adopts a double nested CES production function to conduct an in-depth study on the RBTC of mariculture, which is of great significance for coastal areas to improve the efficiency of the utilization of marine resources and promote the development of mariculture.

This paper mainly reviews the existing research from the perspective of biased technological progress (BTC) and resource efficiency. Regarding the technological progress bias, scholars have confirmed that technological progress helps to improve the efficiency of factor utilization and reduce resource consumption, which is the main driving force for industrial development (Chen et al., 2019; Li et al., 2020). Moreover, more and more scholars have noticed the important impact of the technological progress bias on the sustainable development of the industry (Li and Sun, 2020; Liang et al., 2020; Wei et al., 2019). In the field of mariculture, the research on the BTC is still in the exploratory stage. Ren (2021) constructed a transcendental logarithmic production function model to measure the BTC, and found that in mariculture industry the degree of bias in the use of labor factors for technological progress gradually decreased. Sun and Ji (2021) applied data envelopment analysis model to discern the bias of the mariculture industry between capital, labor and sea area factors, and developed factor endowment indicators to explore the desirability of the input bias. Ji et al. (2022) studied the bias of mariculture between desired and undesired outputs from the output perspective and analyzed the time-series characteristics and regional differences in output bias. There are abundant studies on the efficiency of mariculture, which can be divided into two categories based on different research methods. One is the efficiency study based on the stochastic frontier method. Kularatne et al. (2019) estimated the breeding efficiency based on the data of fish breeding in Sri Lanka, and found that the average efficiency was only 0.33. Rahman et al. (2020) took Bangladesh as the research object to measure the total factor productivity (TFP) of shrimp-carp-rice joint breeding, and found that the TFP increased at an annual rate of 0.86%. Thriveni et al. (2022) measured the efficiency of shrimp farming in India and found that the average efficiency was 0.93, which was at a high level. The other is the efficiency research based on DEA method. Long et al. (2020) calculated the efficiency of intensive white leg shrimp farming in Vietnam. The results showed that the cost and technical efficiency after deviation correction were 0.533 and 0.723, respectively. There is a large room for improvement in farming efficiency. Aung et al. (2021) measured the efficiency of small-scale aquaculture in Myanmar, and the efficiency of most households was 45-60% below the production boundary. Yu et al. (2020) measured the efficiency of China ‘s mariculture industry based on the super-efficiency SBM model and GML index, and found that from 2004 to 2016, China's mariculture efficiency increased by 6.45%. Wang et al. (2024) further studied the spatial imbalance of mariculture efficiency and found that compared with high mariculture efficiency areas and low mariculture efficiency areas, the spatial imbalance of medium efficiency areas is greater. Dong et al. (2023) used the SBM model to measure the efficiency and found that the average eco-economic efficiency of mariculture in China is above 0.8, and the convergence analysis results verify that the difference in eco-economic efficiency of mariculture is significantly narrowing. Ren and Xu (2024) also used the SBM model to measure the efficiency and found that the average ecological efficiency of the mariculture industry was 0.586, and the efficiency improvement space was 41.4%. At present, there are relatively few studies on the impact of technological progress bias on resource efficiency. According to the theory of technological progress bias, technological progress bias will affect the marginal output of unit input factors, so that the production efficiency will change when the input factors remain unchanged, that is, technological progress bias can affect resource efficiency (Hicks, 1932). Fan et al. (2020) studied the impact of different forms of technological progress on production efficiency based on data envelopment analysis. The results show that capital-embodied technological progress can promote production efficiency more than neutral technological progress.

Currently, there is little literature measuring the level of resource biased technological progress and its growth rate in the mariculture industry, and there is also a lack of quantitative studies on the relationship between RBTC and resource efficiency. This paper expands on the basis of existing research, and the main contributions can be summarized into two aspects. Firstly, the introduction of sea area resources into the research framework of mariculture enriches the research on the bias of technological progress in mariculture. Most of the existing literature on technological progress bias only includes capital and labor, and few literature considers resource factors. This paper introduces the production factor of resources into the production function, transforms the measurement of biased technological progress from two-factor conditions to three-factor conditions, and analyzes the elasticity of substitution between factors and resource biased technological progress from the time dimension and regional dimension. Secondly, based on the discussion of the elasticity of substitution among various elements in the traditional theory of technological progress bias, this paper combines resource biased technological progress with the improvement of resource efficiency. Based on the measurement of resource biased technological progress, this paper attempts to conduct a detailed study on the equilibrium relationship between this technological progress bias and resource efficiency, so as to provide a basis for improving the resource efficiency of mariculture.

The structure of this paper is as follows. The second part is the research methodology. The third part is the empirical results. The fourth part is the analysis of the impact of resource biased technological progress on resource efficiency. The fifth part is the conclusions and policy recommendations.

Abbreviations: TC, Technological progress; RBTC, Resource biased technological progress; BTC, Biased technological progress; TFP, Total factor productivity.

2 Research methodology

2.1 Production function

The research on the BTC in mariculture mainly involves three factors: labor, capital and resources. This paper fits labor and resource factors into non-resource factors and uses Cobb-Douglas production function to represent them. The CES production function is used between the non-resource elements represented by ' labor-capital ' and the resource elements.

Referring to the research of Liao and Ren (2020) and Hassler et al. (2021), the double nested CES production function is represented as follows.

$$Y_t = \left\{(1-\gamma)[A_t K_t^{\alpha} L_t^{1-\alpha}]^{\frac{\varepsilon-1}{\varepsilon}} + \gamma [A_t^R R_t]^{\frac{\varepsilon-1}{\varepsilon}}\right\}^{\frac{\varepsilon}{\varepsilon-1}} \tag{1}$$

In the expression, Y_t is total output, K_t is capital inputs, L_t is labor inputs, $A_t$is capital-labor-enhancing technological progress, R_t is resource inputs, A_t^R is resource biased technological progress, ε denotes the elasticity of substitution of capital-labor for resources, and α is the share of capital income as a proportion of the joint share of labor and capital.

The following can be obtained by assuming that factor markets are perfectly competitive, that is, the marginal output of a factor is equal to its real price.

$$L_t^{share} = \frac{\partial Y_t}{\partial L_t}\frac{L_t}{Y_t} = (1-\alpha)(1-\gamma)\left[\frac{A_t K_t^{\alpha} L_t^{1-\alpha}}{Y_t}\right]^{\frac{\varepsilon-1}{\varepsilon}} \tag{2}$$

$$R_t^{share} = \frac{\partial Y_t}{\partial R_t}\frac{R_t}{Y_t} = \gamma\left[\frac{A_t^R R_t}{Y_t}\right]^{\frac{\varepsilon-1}{\varepsilon}} \tag{3}$$

From Equations 2, 3, the level of technological progress for the two categories is as follows.

$$A_t^L = \frac{Y_t}{K_t^{\alpha} L_t^{1-\alpha}}\left[\frac{L_t^{share}}{(1-\alpha)(1-\gamma)}\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{4}$$

$$A_t^R = \frac{Y_t}{R_t}\left[\frac{R_t^{share}}{\gamma}\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{5}$$

As can be seen from the above equations, the level of TC in the two categories can be found by setting the values of α、 ε、 γ and utilizing the data Y_t、 K_t、 L_t、 R_t、 L_t^{share} and R_t^{share}. For the value of γ, this research refers to Hassler et al. (2012), assuming γ = 0.05.

2.2 Estimation of elasticity of substitution

From Equations 4, 5, it can be observed that the prerequisite for studying the level of technological progress of factors is to estimate the elasticity of substitution between them.

Given the level of TC satisfies the following conditions.

$$a_t - a_{t-1} = \theta^A + \varpi_t^A \tag{6}$$

$$a_t^R - a_{t-1}^R = \theta^R + \varpi_t^R \tag{7}$$

If $a_t = log(A_t)$, $a_t^R = log(A_t^R)$, $\varpi_t^A \sim N(0,\Sigma)$, $\varpi_t^R \sim N(0,\Sigma)$

Then from Equations 4, 5, the following can be deduced.

$$\frac{A_t}{A_{t-1}} = \frac{Y_t}{K_t^{\alpha} L_t^{1-\alpha}}\frac{K_{t-1}^{\alpha} L_{t-1}^{1-\alpha}}{Y_{t-1}}\left[\frac{L_t^{share}}{L_{t-1}^{share}}\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{8}$$

$$\frac{A_t^R}{A_{t-1}^R} = \frac{Y_t}{R_t}\frac{R_{t-1}}{Y_{t-1}}\left[\frac{R_t^{share}}{R_{t-1}^{share}}\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{9}$$

The logarithm of Equations 8, 9 is taken and substituted into Equations 6, 7. The following equations are obtained.

$$\log\left(\frac{Y_t}{K_t^{\alpha} L_t^{1-\alpha}}\right) - \log\left(\frac{Y_{t-1}}{K_{t-1}^{\alpha} L_{t-1}^{1-\alpha}}\right) = \theta^A - \frac{\varepsilon}{\varepsilon-1}[\log L_t^{share} - \log L_{t-1}^{share}] + \varpi_t^A \tag{10}$$

$$\log\left(\frac{Y_t}{R_t}\right) - \log\left(\frac{Y_{t-1}}{R_{t-1}}\right) = \theta^R - \frac{\varepsilon}{\varepsilon-1}\left[\log R_t^{share} - \log R_{t-1}^{share}\right] + \varpi_t^R \tag{11}$$

Let $s_t^A = \log\left(\frac{Y_t}{K_t^{\alpha} L_t^{1-\alpha}}\right) - \log\left(\frac{Y_{t-1}}{K_{t-1}^{\alpha} L_{t-1}^{1-\alpha}}\right)$, $s_t^R = \log\left(\frac{Y_t}{R_t}\right) - \log\left(\frac{Y_{t-1}}{R_{t-1}}\right)$, $z_t^A = \log L_t^{share} - \log L_{t-1}^{share}$, $z_t^R = \log R_t^{share} - \log R_{t-1}^{share}$

So Equations 10, 11 can be abbreviated as follows.

$$s_t^A = \theta^A - \frac{\varepsilon}{\varepsilon-1} z_t^A + \varpi_t^A \tag{12}$$

$$s_t^R = \theta^R - \frac{\varepsilon}{\varepsilon-1} z_t^R + \varpi_t^R \tag{13}$$

For Equations 12, 13, the value of the elasticity ε can be estimated by seemingly uncorrelated regression.

The value of α can be obtained by the following equations.

$$L_t^{share} = \frac{\partial Y_t}{\partial L_t}\frac{L_t}{Y_t} = (1-\alpha)(1-\gamma)\left[\frac{A_t K_t^{\alpha} L_t^{1-\alpha}}{Y_t}\right]^{\frac{\varepsilon-1}{\varepsilon}} \tag{14}$$

$$K_t^{share} = \frac{\partial Y_t}{\partial K_t}\frac{K_t}{Y_t} = \alpha(1-\gamma)\left[\frac{A_t K_t^{\alpha} L_t^{1-\alpha}}{Y_t}\right]^{\frac{\varepsilon-1}{\varepsilon}} \tag{15}$$

Then $\frac{L_t^{share}}{K_t^{share}} = \frac{1-\alpha}{\alpha}$ can be obtained.

2.3 Description of data and variables

This paper takes the data of mariculture industry in ten coastal areas from 2008 to 2020 as the research sample. Based on the availability of data, it does not consider Shanghai, Hong Kong, Macao and Taiwan. The relevant data mainly come from China Fishery Statistical Yearbook, China Statistical Yearbook, China Rural Statistical Yearbook and China Fixed Asset Investment Statistical Yearbook. The specific indicators are as follows.

Output (Y): This paper uses the output value of mariculture in coastal areas to measure output, and uses the regional GDP index to deflate to obtain the actual output value of mariculture.

Labor (L): This paper selects the number of employees in the marine aquaculture industry to measure the labor input of the marine aquaculture industry. Regarding labor prices, the per capita net income of fishermen is approximately used as the wage level of mariculture practitioners. For the labor income share, this paper uses the product of the number of workers and the labor price to calculate.

Capital (K): the capital stock of mariculture industry is estimated by perpetual inventory method (Ji et al., 2022). On the capital price, using the method of Doraszelski and Jaumandreu (2014), capital price = investment price index * (loan interest rate + depreciation rate-inflation rate), in which the investment price index, loan interest rate, depreciation rate and inflation rate are replaced by the price index of agricultural means of production, the loan interest rate of 3-5 years, the depreciation rate of fixed assets and the change rate of consumer price index respectively. For the capital income share, this paper uses the product of capital stock and capital price to calculate.

Resources (R): This paper selects the area of marine aquaculture to measure the input of marine resources. Regarding the price of resources, considering that the sea area use fee levied on the sea for aquaculture in various regions has policy preferences and exemptions, it is difficult to accurately measure. Therefore, this paper uses the residual value of mariculture output value after deducting labor income share and capital income share to approximate the resource income share. The resource price is the ratio of sea area resource income share to mariculture area.

3 Empirical results

3.1 Full sample factor elasticity of substitution and resource biased technological progress

Regression analysis was first performed on the data of the full sample from 2008 to 2020, and seemingly uncorrelated regression estimation was carried out on Equations 12, 13. The estimation results of parameter coefficients are shown in Table 1.

As can be seen from the table, $-\frac{\varepsilon}{\varepsilon-1} = 0.6539$, the elasticity of substitution between the non-resource factors aggregated by "capital-labor" and the marine resource factors can be calculated as 0.3954. This result is in line with the meaning of economics, indicating that there is a certain substitutability between resource factors and non-resource factors, that is, the increase in the input of non-resource factors such as labor and capital or marine resource factors will promote each other 's marginal output, but the degree of substitution is weak, showing a complementary relationship as a whole. From the perspective of a completely free market, the ratio of the marginal output of factors is the ratio of the price of factors. Therefore, this complementarity between resource factors and non-resource factors indicates that as the price of resources increases, the production cost of mariculture activities also increases. In order to cope with the cost pressure caused by the increase in the price of resource factors, producers can only moderately adjust the proportion of input of resources and non-resource factors, such as appropriately reducing the input of resources and reducing the marginal output of capital-labor, resulting in a decline in total output. Therefore, in order to maintain the total output of the mariculture industry will not decrease with the decrease of resource input, it is necessary to increase the marginal output by improving technological progress.

The level and growth rate of RBTC in mariculture industry from 2009 to 2020 can be calculated by bringing the obtained substitution rate into Equation 5. The results are shown in Table 2.

From the table, it can be found that the RBTC of mariculture industry generally shows a trend of decreasing first and then increasing. The growth rate of resource biased technological progress has experienced a trend of "sharp rise-sharp decline-slow rise". Since 2015, the level of technological progress of marine resources has gradually increased, and the growth rate of resource biased technological progress has fluctuated around 5%, which is basically consistent with the actual situation of mariculture. From 2015 to 2020, the Ministry of Agriculture and Rural Affairs has announced six batches of national marine ranching demonstration areas, a total of 136, marine ranching construction and management standard system basically established, to a certain extent, promote the development of mariculture. During this period, the development of mariculture industry attaches great

TABLE 1 Results of SUR estimation.

Parameter	Estimate	P value
θ^A	-0.0314	0.007
$-\frac{\varepsilon}{\varepsilon-1}$	0.6539	0.000
θ^E	-0.0034	0.759

TABLE 2 The resource biased technological progress of mariculture industry from 2009 to 2020.

Year	Resource biased technological progress	The growth rate of resource-biased technological progress
2009	0.0107	-15.2451%
2010	0.0089	-16.7267%
2011	0.0085	-4.3061%
2012	0.0096	12.6831%
2013	0.0090	-6.1360%
2014	0.0092	1.6405%
2015	0.0091	-0.8331%
2016	0.0097	6.9128%
2017	0.0105	8.0398%
2018	0.0108	2.4898%
2019	0.0110	2.3723%
2020	0.0115	4.3275%

importance to the protection of fishery resources, mariculture industry pays more and more attention to green aquaculture in production practice, and the technological progress level of marine resource elements has been steadily improved. As far as the level of BTC is concerned, because the TC of non-resource factors such as "resources-labor" is greater than the technological progress level of marine resource factors, and the substitutability between the two types of factors is weak, there is a certain complementarity. It can be concluded that in the production process of mariculture, the marginal production of non-resource factors is greater than the marginal production of marine resource factors. Increasing one unit of non-resource factor input requires more than one unit of marine resource factor input, and the overall TC is RBTC. This result also reflects that the TC of mariculture industry tends to increase the use of sea area resources as a whole.

3.2 Factor elasticity of substitution and level of technological progress across regions

On the basis of estimating the elasticity of substitution and resource biased technological progress for the full sample, this research divided the regions into the Bohai rim region, the East China Sea and Yellow Sea region and the South China Sea region, and performed seemingly uncorrelated regression estimation of the time-series data for each region respectively. The parameters obtained are shown as Table 3.

Thus, the elasticity of substitution of each region was further calculated as Table 4.

It can be seen from the table that the factor elasticity of substitution is less than 1 in all three regions and has relatively small values. This result suggests that there is a complementarity between marine resource factors and non-resource factors, i.e., that an increase in either marine resource factors or non-resource factors can lead to marginal outputs of the other type of factor in each of the three coastal regions. Comparing the elasticity of substitution of the three major coastal regions, it can be found that the South China Sea region has the smallest elasticity of substitution, the Bohai rim region has the second highest, and the East China Sea and Yellow Sea region has the highest elasticity of substitution. This result evinces the very weak substitutability between resource and non-resource factors in the South China Sea and Bohai rim regions. Therefore, when the price of marine resources fluctuates relative to the price of non-resource factors, producers cannot effectively achieve the goal of reducing costs and ensuring output simply by adjusting the ratio of inputs between resource and non-resource factors. For the East China Sea and Yellow Sea region, on the other hand, the elasticity of substitution is 0.4492, and although the two types of factors also show a complementary relationship, the degree of substitutability between resource and capital-labor factors is significantly higher than in other regions. This result suggests that when there is a relative change in the price of marine resources to the price of non-resources, there will be a relatively larger change in the ratio of marine resources to the inputs of capital and labor.

Table 5 shows resource biased technological progress and its growth rates for the three regions. Significant differences can be found between the three regions in terms of resource biased technological progress. TC in the South China Sea region is much higher than that in the East China Sea and Yellow Sea region and the Bohai rim region, with RBTC in the South China Sea region averaging about 0.317 over the sample period, which is 7 times higher than that in the Bohai rim region and 40 times higher than that in the East China Sea and Yellow Sea region. This is mainly due to the fact that the South China Sea region is more richly endowed with marine resources, and technological progress communicates itself in a resource biased manner, while the level of TC in the resource factors in the Bohai rim and the East China Sea and Yellow Sea regions need to be further improved. In terms of growth rates, RBTC in the South China Sea region achieves steady growth at an average rate of 3.272%, while resource biased technological progress in the East China Sea and Yellow Sea region grows at a slightly slower rate than that of the South China Sea region, at 1.303%, and in the Bohai rim region, at -1.912%. In addition, the figure depicted that the growth rate of resource biased technological progress in the three major coastal regions peaked in 2012, with both the South China Sea region and the Bohai rim region growing at more than 20%. The reason may be that in 2012, the country proposed to build a strong marine nation and strengthen the development and utilization of marine resources, which to a certain extent promoted the growth rate of RBTC.

4 Analysis of the impact of resource biased technological progress on resource efficiency

4.1 Empirical model

As indicated by the definition of share of resources (Chen et al., 2015), the resource share is expressed as follows.

TABLE 3 SUR estimation results of three regions.

Bohai rim region			East China Sea and Yellow Sea region			South China Sea region		
Parameter	Estimate	P value	Parameter	Estimate	P value	Parameter	Estimate	P value
θ^A	-0.0182	0.023	θ^A	-0.0458	0.000	θ^A	-0.0333	0.147
$-\frac{\varepsilon}{\varepsilon-1}$	0.5074	0.000	$-\frac{\varepsilon}{\varepsilon-1}$	0.8156	0.000	$-\frac{\varepsilon}{\varepsilon-1}$	0.4343	0.000
θ^E	-0.0112	0.439	θ^E	0.0049	0.522	θ^E	0.0121	0.300

$$R_t^{share} = \frac{R_t P_t^R}{Y_t} \quad (16)$$

Then unite Equations 3, 16, 17 is yielded.

$$\ln\frac{Y_t}{R_t} = (1-\epsilon)\ln A_t^R + \epsilon(\ln P_t^R - \ln\gamma) \quad (17)$$

In this research, resource efficiency is defined as the ratio of output to resource consumption. From Equation 17, it can be assumed that resource efficiency is closely linked to resource biased technological progress and resource prices. Therefore, drawing on the study of the relationship between resource biased technological progress and resource efficiency and accommodating the variable of marine resource price, the research establishes an econometric model to study the influence of the two on resource efficiency.

4.2 The results of resource efficiency

As evident by Figure 1, the resource efficiency of mariculture increased from 6.81 in 2009 to 7.50 in 2020, with an overall increase of 10.18%, a result which indicates that the resource efficiency of mariculture has shown an upward trend, and the output of marine resources per unit has been increasing during the study period. Further detailed analysis shows that from 2009 to 2011, the resource efficiency of mariculture showed a sharp decline, followed by a sharp increase from 2011 to 2012, and a fluctuating upward trend from 2012 to 2020. The reason is mainly due to the extensive aquaculture in the early stage of mariculture, and the increase of economic benefits at the expense of a large amount of resources. Moreover, due to the decrease of aquaculture density and the backwardness of technology, the output efficiency per unit sea area is relatively low. In 2011, the resource efficiency reached its lowest point, mainly due to natural disasters, such as typhoons, resulting in a decrease in aquaculture area and social resource, which directly led to a decline in the efficiency of mariculture resources. While in other years, the resource efficiency of mariculture industry is higher than 6.5, and reaches its peak of 7.50 in 2020.

4.3 Analysis of the dynamic impact of resource biased technological progress, resource prices on resource efficiency

To reduce the possible heteroskedasticity in the data, this research takes the natural logarithm of the sequence $\frac{Y_t}{R_t}$、 A_t^R、 P_t^R, to obtain lny, lna and lnp. The stationarity of the data needs to be tested before constructing the vector autoregressive model. The ADF unit root test is performed to determine its stationarity, and the results are shown in Table 6.

TABLE 4 Elasticity of substitution for the three regions.

Bohai rim region	East China Sea and Yellow Sea region	South China Sea region
Elasticity of substitution	Elasticity of substitution	Elasticity of substitution
0.3366	0.4492	0.3028

To construct a vector autoregressive model, it is first and foremost to determine the optimal lag order. If the optimal lag order is too small, it will cause the error to have strong autocorrelation, which will affect the reliability of the parameter being estimated. And if the optimal lag order is too large, it will lead to the reduction of the degree of freedom and the validity of the parameter estimation will be significantly affected. The LR test is implemented to determine that the lag order is 1. Further, this research constructs the VAR (1) model and results grabbed as shown below:

$$\text{lny} = 3.1921*\text{lny}(-1) - 1.2172*\text{lna}(-1) - 3.0604*\text{lnp}(-1) - 4.7667 \quad (18)$$

It can be noted that the elasticity coefficient of resource efficiency with respect to resource biased technological progress is -1.2172 at lag 1, which indicates that in the short run, the level of resource biased technological progress in mariculture has a significant dampening effect on resource efficiency. When the level of technological progress rises by 1%, there is a corresponding decline in resource efficiency of -1.2172%. In terms of the impact of resource prices on resource efficiency, the lag 1 elasticity coefficient is -3.0604, which suggests that there is a negative impact of the price of marine resources on resource efficiency. When the price of marine resources rises by 1%, it will result in a decrease in resource efficiency of -3.0604%. The reason may be that resource biased technological progress, resource prices and resource efficiency have not yet been in a synergistic growth situation. In the short term, due to the pressure of rising costs, farmers may not be able to immediately adjust their production methods and improve resource utilization efficiency, resulting in a decline in resource efficiency.

4.4 Analysis of the long-run impact of resource biased technological progress and resource prices on resource efficiency

In order to further investigate the long-run equilibrium relationship between resource biased technological progress, resource price and resource efficiency, the three variables lny, lna, lnp are first tested for cointegration. The results of the cointegration trace test indicate that there is only one linearly independent cointegration variable. The results of the maximum eigenvalue test demonstrated that the null hypothesis of "cointegration is 0" can be rejected at the level of 5%, but the null hypothesis of "cointegration is 1" cannot be rejected. It can be concluded from the test results that there is a cointegration relationship among the three variables, which implies that there is a long-run equilibrium relationship among the three.

Using Johansen's MLE approach to estimate the cointegration equation.

TABLE 5 The resource biased technological progress in the three regions.

Year	Resource biased technological progress			The growth rate of resource-biased technological progress		
	Bohai Rim	East China Sea & Yellow Sea	South China Sea	Bohai Rim	East China Sea & Yellow Sea	South China Sea
2009	0.0505	0.0077	0.2682	-20.8765%	-7.0099%	-3.3992%
2010	0.0404	0.0069	0.2742	-20.0198%	-10.8795%	2.2646%
2011	0.0369	0.0069	0.2327	-8.6439%	-0.1162%	-15.1314%
2012	0.0445	0.0073	0.2946	20.4520%	6.8157%	26.5804%
2013	0.0405	0.0073	0.2971	-9.0381%	-0.4808%	0.8316%
2014	0.0413	0.0074	0.3078	2.0461%	1.3347%	3.6189%
2015	0.0400	0.0076	0.3061	-3.1857%	2.6938%	-0.5407%
2016	0.0439	0.0075	0.3084	9.7330%	-1.9220%	0.7265%
2017	0.0448	0.0084	0.3598	2.0240%	12.7382%	16.6889%
2018	0.0447	0.0086	0.3850	-0.0671%	1.7694%	7.0003%
2019	0.0455	0.0090	0.3817	1.7377%	4.9929%	-0.8692%
2020	0.0468	0.0095	0.3874	2.8919%	5.7027%	1.4892%

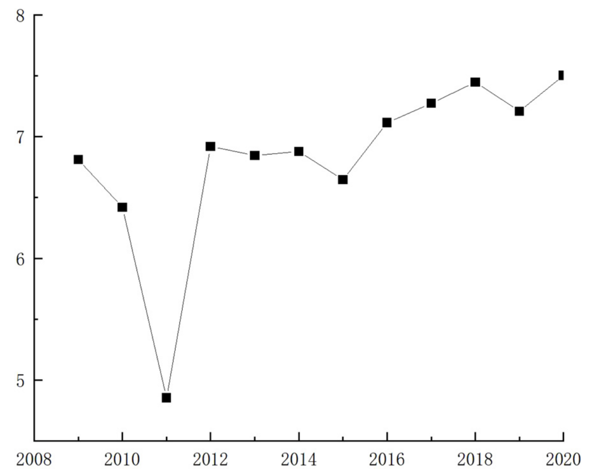

FIGURE 1
Resource efficiency in mariculture.

$$\ln y_t = 2.1598 + 0.5733*\ln a_t + 1.4570*\ln p_t \quad (19)$$

As a comparison, the EG-ADF two-step method is used to estimate the long-run equilibrium relationship of the three variables, and the co-integration equation is obtained.

$$\ln y_t = 3.6162 + 0.6533*\ln a_t + 0.8006*\ln p_t \quad (20)$$

The two estimates are similar, but the MLE estimate is theoretically more efficient. According to the MLE estimation results, the coefficient of elasticity of technical progress for resource efficiency is 0.5733, suggesting that when the level of resource biased technical progress increases by 1%, it will contribute to an increase in resource efficiency by 0.5733%. The price elasticity coefficient of resource efficiency is 0.8006, importing that when prices increase by 1%, it will contribute to an increase in resource efficiency by 0.8006%. This result reveals that both resource biased technological progress and marine resource prices promote resource efficiency in mariculture in the long-run, with marine resource prices contributing slightly more than resource biased technological progress.

TABLE 6 Unit root test results of variable.

Variable	ADF statistic	5% statistic	P value	Result
lny	-2.254	-3.000	0.1872	Non-stationary
D (lny)	-4.465	-3.000	0.0002	Stationary
lna	-1.049	-3.000	0.7348	Non-stationary
D (lna)	-4.279	-3.000	0.0005	Stationary
lnp	-3.908	-3.000	0.0020	Stationary
D (lnp)	-5.517	-3.000	0.0000	Stationary

5 Conclusions and policy recommendations

5.1 Conclusion

Taking the data of China's mariculture industry from 2008 to 2020 as research samples, this research introduced marine resource factors into the input-output system of mariculture industry to study the technological progress level of marine resource factors. On this basis, an econometric model was built to study the impact of resource biased technological progress and resource price on resource efficiency. The main research results are summarized as follows.

Firstly, a double-nested CES production function was constructed to estimate the elasticity of substitution between non-resource factors represented by labor and capital factors and resource factors, so as to measure the level of resource biased technological progress in the mariculture industry, which yielded that there was a complementary relationship between resource and non-resource factors in marine areas, and that the level of technological progress of non-resource factors was higher than that of resource factors. resource biased technological progress among the three major coastal regions presents heterogeneous characteristics, with the level of resource biased technological progress in the Bohai rim region showing a small downward trend, the level of resource biased technological progress in the South China Sea region basically remaining stable, and the level of resource biased technological progress in the South China Sea region being the highest among the three major regions and showing a steady growth.

Secondly, the research analyzed the relationship between resource biased technological progress, resource prices and resource efficiency and fount that, in the short term, resource biased technological progress and resource prices had a negative impact on resource efficiency; in the long term, there was a long-term equilibrium relationship between the three, and resource biased technological progress and resource prices had a positive impact on resource efficiency. Moreover, the improvement of resource price on resource efficiency could reflect greater utility. When the level of resource biased technological progress increased by 1%, the resource efficiency would increase by 0.5733%, whereas 1% increase in the price of marine resources would lead to a 0.8006% increase in resource efficiency.

5.2 Policy recommendations

The first is to improve the technological progress level of marine resource elements. R & D and promotion of resource-saving mariculture technology, coastal areas can increase efforts to R & D and promotion of resource-saving mariculture technology, improve the ability of independent innovation, strengthen the development and utilization of green aquaculture technology. This includes optimizing the aquaculture structure, developing multi-level comprehensive aquaculture, making full use of the three-dimensional space of seawater, and improving the utilization efficiency of marine resources. In addition, in the field of key technology research, technical research on fish industrial ships and deep-water cage culture was carried out, and technical specifications for ship-borne cabin culture and deep-water giant cage fish culture were established. This helps to improve breeding efficiency and resource utilization efficiency. At the same time, the integration and demonstration of aquaculture platform should be carried out, the industrialization platform should be established, and the technical mode of large-scale aquaculture in deep sea should be constructed.

The second is to build a perfect marine resource price evaluation system. Coastal areas need to improve the management system of marine resource price assessment, establish and improve the procedures and methods of marine resource price assessment, and establish a database of transaction information including the price of marine resources sold by various places and types, so as to fully and truly reflect the market price of marine resources. Moreover, coastal areas can consider introducing differentiated sea area resource price policies to make full use of regional differences to improve the utilization of sea area resources in various regions. This means that according to the resource situation, economic development level and ecological environment requirements of different regions, different sea area resource prices are formulated to promote the rational allocation and efficient utilization of resources.

Data availability statement

The datasets presented in this article are not readily available because access to the data is limited to our research group. Requests to access the datasets should be directed to 15853037813@163.com.

Author contributions

JK: Data curation, Funding acquisition, Writing – original draft. YS: Conceptualization, Formal analysis, Software, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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