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Efficiency in Chinese Large Yellow Croaker Aquaculture: Implication for Sustainable Aquaculture in China

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Abstract: Aquaculture supply from China has been a remedy to meet the growing global demand for seafood in the last decades. However, output growth has decreased dramatically in China in the 2000s. Previous literature focuses on the ecosystem problems arising in intensive farming in China. In this study, we used stochastic production analysis (SPA) to estimate the technical efficiency of Chinese large yellow croaker farming, which provides implications for impediments to the sustainable development of Chinese aquaculture. Data were collected from 430 large yellow croaker farmers in nine farming areas located along the coastline of southeastern China. The technical efficiency of large yellow croak farming is estimated to be 0.829, suggesting that farming is operated close to the production frontier with a maximal margin of 17% for improvement under the current technology. It further suggests that Chinese aquaculture growth is geared by conventional factors, expansion of fishing sites, and intensive farming, and is not sustainable under the constraint of farming areas and environmental problems in China. For the sustainable development of Chinese aquaculture, it is necessary to adopt new technology through innovation. The family-based farming model is a hinder to adopting new technology that requires systematic significant investment. Large-scale industrialized farming based on research and new technology development thus should be a modern trend in the future.

Keywords: China; sustainable aquaculture; technical efficiency; technology; global seafood supply

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1. Introduction

Seafood, which includes marine harvested and aquaculture production both in oceans and inland freshwaters, plays an important role in world food security as a protein source. Approximately 20% of worldwide dietary protein and as much as 50% for some small islands and West African countries is from seafood [1]. As the world wealth and population grow, fish consumption continues to grow [1,2]. However, there is a global challenge to meet the growing demand. The production of worldwide capture fisheries is unlikely to increase due to resource overexploitation [3,4]. Researchers have reported a general decline in fish stock worldwide and the collapse of fishery resources in many parts of the world [5–8]. To remedy the situation, aquaculture production has been believed to compensate for the shortfall in ocean harvests. Aquaculture surpassed marine fishery as the main source of seafood for human consumption in 2014 [1].

China has been the largest and most important aquaculture production country for many years [9,10], contributing 59% of the world's aquaculture production in 2019 [11]. However, the average annual growth of Chinese aquaculture production has decreased from double-digit growth rates in the 1980s and 1990s to 5.4% between 2001 and 2015 [12]. The availability and quality of water are constraint conditions to aquaculture farming in

China. Specifically, (i) growing industries other than aquaculture are competing for inshore and offshore waters with aquaculture farming, (ii) rapid urbanization and industrialization following the significant development of the Chinese economy have introduced external pollution sources such as synthetic and organic into the aquaculture ecosystem, and (iii) aquaculture itself is one of the major contributors to environmental and ecosystem degradation in China [13]. Previous literature concludes that aquaculture growth in China has been accomplished through the unsustainable exploitation of many aquatic resources. This results in ecosystem degradation and habitat and biodiversity loss [14,15]. It further means that water accessibility and quality are severe in China and increasing production by enlarging the aquaculture area is not feasible. From a long-term perspective, improving technical efficiency and technology is probably the only solution for the sustainable aquaculture supply in China and hence in the world.

Most literature on Chinese aquaculture is concerned with the problem of marine ecosystem degradation resulting from intensive farming, including pollution, diseases, and generic deterioration [14–17]. Both the Chinese government and the Chinese aquaculture industry are under great pressure to improve the problems under the United Nations' Sustainable Development Goals [18]. Sustainability and circular economy have received increasing attention from academics and policymakers over the last few decades [19–21]. Studies to measure China's aquaculture productivity are much less and mostly use aggregated official statistics at the province level. For instance, early studies include Gomiero et al. (1997) [22], who investigated the technical performance of freshwater fish aquaculture in China, and Sharma et al. (1999) [23], who measured the importance of technical efficiency in the economic efficiency of fish polyculture. Recent studies by Zhong et al. (2021) [24] measured freshwater aquaculture efficiency, and Wang and Ji (2017) [25], who measured marine culture production efficiency in general. Since Chinese aquaculture is very diverse in terms of farmed species (over 200) and farming systems/methods [12], simply aggregating the production of all fish species at a high level would lead to measurement error. Moreover, China's official fishery data are often suspected to be imprecise [26]. Yin et al. (2017) [27] used survey data to estimate the influence of industrial organization structure on the technical efficiency of large yellow croaker farming. However, they aggregated the costs of fishing boats, nets, feed, fry, and medicine into one variable called capital investment. Aggregating costs with dramatically different intrinsic economic costs and technological functions introduces unknown biases.

This study adds the literature on Chinese aquaculture productivity using farm-level survey data from 430 farmers in large yellow croaker farming regions. It first aimed to investigate the effect of the different production inputs, including feed, medicine, and technology, and the observed characteristics of producers such as pond size and farmer's education level, on the production productivity and the margin for further improvement in yellow croaker farming. Next, it sought to explore the problems in the sustainable development of Chinese aquaculture and possible solutions in the future based on the study results for large yellow croaker farming.

Large yellow croaker is one of the top three farmed finfish species in China. It is sold both to the domestic and overseas markets. As we documented in the study, a large yellow croaker farming operation is quite like that of many other species in China. Therefore, we believe the conclusion drawn from the case of large yellow croaker farming could present the situation of China aquaculture well.

Regarding the research methods, the data envelopment analysis (DEA) model and stochastic frontier analysis (SFA) are the two most extensively used methods in production efficiency literature. DEA is a non-parametric linear programming approach that is not determined by specific functional forms like SFA. These two models were compared and discussed by Porcelli (2009) [28]. Regarding studies of production efficiency in aquaculture, comprehensive reviews were provided by Sharma and Leung (2003) [29] and Iliyasu et al. (2014) [30]. Sharma and Leung (2003) [29] reviewed 13 aquaculture production efficiency studies covering species, mainly including shrimp, carp, and tilapia in Asia between 1996 and

2000, and Iliyasu et al. (2014) [30] reviewed 28 aquaculture production studies from 2001 to 2011. Both studies found SFA to be more popular than its main competitor, DEA, in estimating aquaculture productivity. Following this mainstream, SFA is also used in this study.

The rest of the paper is organized as follows: We begin with a discussion of the Chinese yellow croaker farming industry. Next, the model and data are presented, followed by the empirical results. The paper concludes with a discussion about the future of Chinese aquaculture.

2. Large Yellow Croaker Farming in China

According to the Chinese Fisheries Administrative Bureau (2016) [31] data, wild large yellow croaker used to be one of the most important species harvested along the coastline of southeastern China before the 1980s. It was also one of the most consumed species by the local people in the area. However, this fish resource was almost depleted after overfishing for many years. Farming was first introduced in the mid-1980s and quickly developed after 2003. It has now become one of the top three farmed marine finfish species, in addition to Japanese sea bass and flounder, in China. Farming is concentrated in the three provinces of Zhejiang, Fujian, and Guangdong, where wild yellow croaker is traditionally harvested (Figure 1). Among them, Fujian province had a dominant share of 91% in 2011 and 88% in 2012, and the rest was shared by Zhejiang and Guangzhou provinces.

Figure 1. Locations of large yellow croaker farming in China (source: authors).

Farming in coastal ponds dominated until the late 1970s, when cage farming was first introduced to marine fishing. After 1981, commercial cage farming began to develop on a large scale. The most used cages are small floating cages with a size of 3 × 3, and net of 3 in depth (Figure 2) [32]. Deep-sea cages were first introduced in China from Norway in 1998; however, they never became the leading fishing practice due to the high investment inherent in this advanced technology [33].

Figure 2. Illustration of a yellow croaker farming site (source: http://images.shobserver.com/news (accessed on 20 May 2019)).

The grow-out period for large yellow croakers is between 1.5 and 2 years to reach a marketable size of an average weight of 0.4 kg. Around 10,000 juveniles were reared in one cage first, then distributed to other cages during the growing process. The mortality rate varies between 10% and 30%. The average fish density of farming when the fish finally reaches harvest size is about 1500 fish/cage or, in other words, 600 kg/cage [32]. Intensive farming is suggested by the cage size used. The feed is mainly small fishes, including sardines and small hair tails, accounting for 70% of the total production costs according to Hu et al. (2010) [34] and 67% according to our calculation using the survey data in the study. Intensive farming using abundant fishmeal has caused pollution problems, as shown by Figure 2. Nutrient pollution occurs now and then due to untreated wastewater laden with uneaten feed and medicine residue floating in the ocean without any pretreatment [32].

The data used in the study was provided by the project called "Research on Industrial Chains of the Safe Quality of Yellow Croaker," funded by the China Agricultural Ministry, 2009–2013. According to our analysis based on the project survey data, more than 90% of the production was provided by individual families. Each family had an average production scale of 44 cages (Table 1). In each family, the husband usually ran the fish farm with some help from his wife. They hired a couple of people in the busy seasons. The situation was quite similar between the farming regions. Among the 430 farmers in our sample, 82% had an education below higher school, no one had a university education, and 78% had farming experience of more than 10 years.

Table 1. Producer's profile.

Education			Experience			Number of Nets	
No education	0	0%	<10 years	87	22%	Minimum	10
Primary school	64	16%	>10 years	309	78%	Mean	44
Junior high school	262	66%				Maximum	68
High school	70	18%					
Total	396	100%	Total	396	100%	Total	396

The above-described profile of large yellow croaker farming presents an overall situation of the whole China aquaculture production system. As Li et al. (2011) [13] discussed, production is operated mainly by families on a small scale depending on farmers' experience instead of their knowledge of or expertise in fish farming. Intensive farming that is heavily dependent on feed has caused pollution on the coastline. Some efforts have been taken to solve the problems. For example, the government has been encouraging farmers to develop larger floating cages or deep-sea cages. Different organizations have been established to provide farmer training courses to learn technology, control pollution, and have market-oriented production [32]. Nevertheless, the result is not very promising. In our case study, no deep-water cage farming was found. Only 23% of the farmers had joined the local yellow croaker farming associations. Among them, only 7% were closely connected to the associations. Although our data are from 2011 and 2012, no significant change has happened since 2012. As Wang et al. (2019) [35] discussed, raft cage farming is still the primary farming method used in large yellow croaker farming in Fujian Province, yielding more than 95% of the total output. According to Yang and Wang's (2020) [36] research, deep-water cage farming accounts for only 2% of the total large yellow croaker production in Zhejiang, Fujian, and Guangdong provinces. Regarding the total aquaculture production, in the 10 years between 2010 and 2019, production using deep-water cages only increased from 56,000 tons to 205,000 tons [37,38]. By 2019, deep-water cage farming still accounted for less than 1% of the total production. Therefore, the conclusions drawn by the study are still held in the current situation of Chinese aquaculture.

3. Methodology

Stochastic frontier analysis (SFA) was first developed by Aigner et al. (1977) [39] and Meeusen and Van Den Broeck (1977) [40]. They suggested a new approach to estimate parametric frontier function by introducing a new component to the error term and assuming that a part of production inefficiency is because of production and economic factors, which are under a firm's control for improvement. Since then, there has been a significant number of studies applying the model [41–43].

A theoretical stochastic production function for cross-section data following (1995) [42] can be presented as:

$$y_i = \exp(\boldsymbol{x_i}\boldsymbol{\beta} + \varepsilon_i) \qquad i = 1,\ 2,\ \ldots,\ N \tag{1}$$

$$\varepsilon_i = v_i - u_i \qquad i = 1,\ 2,\ \ldots,\ N \tag{2}$$

Equation (1) is the frontier production function of the technical efficiency of farm i operating under a given production technology [44], small floating cages in our case study. In the equation, y_i is the level of output of firm i, $\boldsymbol{x_i}$ is the corresponding $(M \times 1)$ vector of input variables, $\boldsymbol{\beta}$ is a vector of the parameters to be estimated, and ε_i is the error term. Equation (2) presents that the error term (ε_i) in the production function (1) is composed of two components, where v_i is unobserved famers' heterogeneities due to uncontrollable sources such as climate and topography. Since the frontier itself can vary randomly across firms, v_i can be positive, negative, and independent, and is identically distributed as $N\ (0,\ \sigma_v^2)$. u_i explains firm i' s deviation from optimal production due to controllable sources. u_i is independent from v_i and has a half-normal distribution truncated below zero. $u_i \geq 0$ reflects the fact that each firm's output must lie on or below its frontier $[(f(\boldsymbol{x_i};\boldsymbol{\beta}) + v_i)]$, as we discuss below. u_i is defined as the technical inefficiency effect, and is further assumed to be a function of a set of explanatory variables:

$$u_i = \boldsymbol{z_i}\delta_i + w_i \tag{3}$$

where $\boldsymbol{z_i}$ is a vector of explanatory variables for technical inefficiency, usually including the observed characteristics of firms; δ_i is a vector of unknown parameters to be estimated; and w_i is a truncated normal distribution with zero mean and variance σ_u^2, such that the point of truncation for w_i is $-\boldsymbol{z_i}\delta_i$ to be consistent with the requirement that $u_i \geq 0$.

As suggested by Equations (1) and (2), the estimated maximum possible production is

$$y_i^* = exp(\boldsymbol{x_i}\boldsymbol{\beta} + v_i) \tag{4}$$

The ratio between observed output y_i and maximum possible output y_i^* is denoted as technical efficiency (TE).

$$TE_i = \frac{y_i}{y_i^*} = \frac{\exp(\boldsymbol{x_i\beta} + v_i - u_i)}{\exp(\boldsymbol{x_i\beta} + v_i)} = \exp(-u_i) \tag{5}$$

The requirement of $u_i \geq 0$ and thus $-u_i \leq 0$ guarantees $0 \leq TE_i \leq 1$. $TE_i = 1$ means the *ith* firm has obtained the maximum feasible output.

Figure 3 gives a graphic illustration of the above formulation, where frontier 1 is the average observed output of farmers who have used similar farming technology. Frontier 1 is under the curve called metafrontier, which presents the optimal outputs under different technologies. Since Frontier 1 is not tangent to the metafrontier curve, it means production under Frontier 1 is not optimal. The optimal output is presented by Frontier 2. The distance between Frontier 1 (observed output y_i) and Frontier 2 (optimal output y_i^*) suggests technical efficiency (TE), given by Equation (5). A larger distance means a smaller ratio of observed output to optimal output. When the ratio $TE_i = 1$, production reaches its optimal level (Frontier 2).

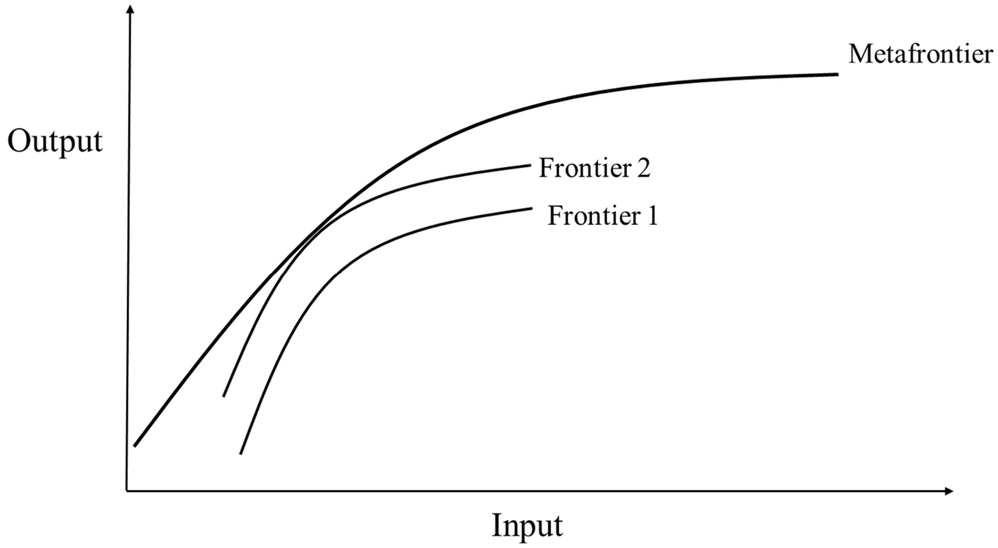

Figure 3. Graphic illustration of the SFA model (source: edited based on Figure 1 metafrontier function model (page 93) in Battese, Rao and O'Donnell (2004) [44]).

When the issue of explaining technical efficiency was raised, researchers tested whether technical efficiency depends on the observed characteristics of producers. According to reviews of studies of aquaculture production [29,30], technical efficiency is mostly explained by farm size, farming experience, farmer's education level, training program, land (farming area) ownership, fry size, pond size, culture length, culture intensity, mortality rate, water, and feed. In our case study of large yellow croaker farming, some variables were homogenous and had no variation across the farms. For instance, land ownership was the same for all the farmers since all lands in China belong to the state. Furthermore, farm-specific data for fry size and mortality rate are not available. Therefore, the final explanatory variables for technical inefficiency included in the study were farmer's education, farming experience, the ratio of family laborers among all laborers, farm scale, industrial associations, and training programs.

The corresponding empirical models for Equations (1) and (3) are therefore specified as:

$$\begin{aligned}\log(Output_i) = \beta_0 + \beta_1 \log(Labor_i) + \beta_2 \log(Juvenile_i) + \beta_3 \log(Fishmeal_i) \\ + \beta_4 \log(Medicine_i) + \beta_5 \log(Transport_i) + \beta_6 \log(Capital_i) + v_i - u_i\end{aligned} \tag{6}$$

$$u_i = \delta_1 Pschool_i + \delta_2 Jschool_i + \delta_3 Sschool_i + \delta_4 Exper_i + \delta_5 Rflabor_i + \delta_6 Scale_i \\ +\delta_7 Org_i + \delta_8 Train_i + \delta_9\ Reg_i + w_i \tag{7}$$

Production function (6) has production per floating cage (*Output)* as the dependent variable. The function includes six input variables: *Labor* includes costs of both family members who work for the fish farming and hired laborers; *Juvenile* represents the costs for fries; *Fishmeal* is the cost of fishmeal; *Medicine* is the cost of the medicines used to control fish diseases; *Transport* is the cost of the transportation boats that farmers daily use for transport of fries, feeds, harvest, and other operations; and *Capital* includes the costs of cages and other equipment for operations. All the costs were measured as the unit cost of a cage. Table 2 shows that the cost of fishmeal had a dominant share of 67%, followed by the cost of juvenile (18%) and labor (8%). Capital only accounted for 4% of the total farming costs.

Table 2. Production cost (CYR/cage).

Variable	Value	Percentage
Labor	1690	8%
Juvenile	3720	18%
Fishmeal	13,606	67%
Medicine	114	1%
Transportation	291	1%
Capital	792	4%
Total	20,213	100%

In the efficiency function (7), *Pschool*, *Jschool*, and *Sschool* are three dummies representing the primary school, junior high school, and senior high school, respectively, to identify the effect of a producer's education level on production efficiency. The base for the dummies is no school education. As discussed above, no farmer was reported to have an education higher than senior high school. *Exper* denotes years of farming experience in large yellow croaker farming, *Rflabor* is the ratio of family laborers in the total labor involved, *Scale* is the number of fishing cages operated by each farmer, *Org* represents whether farmer *i* has joined any kind of associations or organizations, and *Train* denotes whether farmer *i* has participated in any kind of training practices organized by either the government or organizations. The purposes of training programs vary from the introduction of new technology to disease control to market information to pollution control to general knowledge improvement. Training can be implemented in a classroom or on the site of farms. As we have discussed, encouraging farmers to join organizations and participate in training programs is the main measure adopted by the government to improve the problems brought on by small-scale family-based operations. Finally, *Reg* is a dummy variable of the region since our data covered operations in two different areas, where one is more industry-clustered than the other. The estimated parameter of *Reg* can also tell us whether clustering of relevant industries, including farming, processing, and marketing, can improve farmers' production efficiency.

The empirical models were estimated by R programing using the SFA package. The package was built on the Fortran source code of FRONTIER 4.1 [45], where the maximum likelihood estimation is based on the maximum likelihood function in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{\sigma^2}$, as suggested by the assumption of the property of v_i and u_i in the development of the theoretical stochastic frontier production model.

4. Data

Data were collected by the scholars and graduate students at Shanghai Ocean University via a national project. Four hundred thirty farmers from nine farming areas located in three counties of two provinces were randomly selected and asked to finish a questionnaire designed by the researchers in the project. Since the farmers' education levels were generally low, the survey was conducted face-to-face with one expert there to explain the questions asked in the questionnaire if necessary.

The two provinces were Fujian and Zhejing (Figure 1), accounting for more than 90% of yellow croaker aquaculture production. Altogether, 430 questionnaires were collected, 122 from Zhejiang province and 283 from Fujian province, with the ratio apportioned based on the actual number of farmers in the two regions. Due to incomplete information, 34 samples were excluded, and the number of the final samples used for the estimation in the study became 396.

The questionnaire included five parts: demographic data of the farmer, input and output factors for production, any organization and/or association participation by the farmer, market channels for the farmed fish, and information about farming management with a focus on safety issues such as usage of medicine and feed, and knowledge and attitude to the governments' inspections. Descriptive statistics for the main variables included in the survey are presented in Tables 1 and 2.

The survey was first designed by the researchers based on literature [46,47], then adjusted according to the practical information collected from the government departments, organizations, and associations working with large yellow croaker farming. It was further pretested by a group of target farmers in the two regions between August and October 2011 and revised accordingly afterward. The final survey was conducted between February and August 2012.

5. Estimated Results

Table 3 presents the estimated results of the stochastic frontier analysis, including the production function (Equation (6)) and efficiency equation (Equation (7)). The mean technical efficiency (TE), which was the focus of the study, for large yellow croak farming was estimated to be 0.829. This means that with the current state of technology and inputs, the production of large yellow croakers can be increased by 17.1% by optimizing technical efficiency by adopting best farming practices.

Table 3. Estimated results of production and inefficiency functions.

Production Function			Inefficiency Function			Variance Parameters and Mean Efficiency		
	Coef.	Z Value		Coef.	Z Value		Coef.	Z Value
Intercept	−1.433	−4.962	Primary school	0.236	4.096	sigmaSq	0.013	8.863
Labor	0.031	1.124	Junior high school	0.244	4.553	Gamma	0.724	4.072
Juvenile	0.158	11.191	Senior high school	0.220	3.593	Mean efficiency	0.829	
Fishmeal	0.698	29.565	Experience	0.036	2.393			
Medicine	−0.018	−1.593	Rate of family labor	0.030	1.263			
Transport	−0.039	−3.562	Scale	0.000	0.567			
Capital	0.038	3.080	Organizatin	−0.098	−3.704			
			Training	−0.043	−2.149			
			Region	−0.083	−2.510			

For the production function, the estimated coefficients of labor, juvenile, fishmeal, and capital were all positive, which means more inputs of these factors would create more production output, as expected. Among them, the coefficient of labor was statistically insignificant, and the estimated coefficient of capital was relatively small (0.038). In contrast, the estimated coefficient of fishmeal was statistically significant and had a large magnitude of 0.698, followed by the estimated coefficient of juvenile of 0.158. Since the production function was specified as log-log form, the estimated coefficients can be interpreted as elasticities directly. This therefore suggests that with 1% more fishmeal input, the output of large yellow croaker farming would grow by 0.698% on average for all the farms. This is consistent with the fact that fishmeal played a crucial role in large yellow croaker farming practice, accounting for 67% of the total costs of production inputs. The estimated juvenile coefficient suggests that when juvenile input increases by 1%, output increases by 0.158%. This is again consistent with the mortality rate of 10%–30%, according to the information provided by the farmers during the survey. The estimated coefficients of medicine and transportation were both negative. The former was statistically significant at the 5% critical level, whereas the latter was marginally significant at the 11% critical level. The negative signs of medicine and transportation indicate that when diseases happen, farmers must use more medicine to control the diseases and transport to farming sites happens more often than normal.

As discussed, the dependent variable u_i in the inefficiency functions was included in the production function with a negative sign in front of it (Equations (1)–(3)). u_i explains a firm's deviation from its optimal production due to controllable sources, which are the explanatory variables in the inefficiency equation. Therefore, a positive sign of the estimated result of any explanatory variable in the inefficiency equation suggests that the variable will reduce technology efficiency and vice versa.

For the estimated results of the inefficiency equation in Table 3, all the other estimated coefficients were statistically significant at a 5% critical level, except for the estimated coefficients of the rate of family labor and scale. Among them, the signs of the educational and experience variables were positive, and the signs of organization, training, and region were negative. As the educational variables were dummies with no education as the base, the positive signs of the three educational variables uniformly indicate that higher education decreases technical efficiency. Similarly, the positive signs of the experience variable suggest that more farming experience reduces farming efficiency. These results are contrary to expectations. However, they are consistent with the findings given by Onumah (2010) [48]. Onumah (2010) [48] argued that farmers who have experience are conservative. Thus, it is difficult for them to adjust to and adopt new technology, and farmers with less education would probably like to spend more time on farming. The signs of the estimated parameters of organization and training were negative and statistically significant. This suggests that the practical skills and technology provided by training programs and the various information distributed by associations have helped farmers utilize input resources more efficiently. This also supports the result given by Onumah (2010) [48] that technical knowledge has a more significant impact on reducing technical inefficiency than formal education. This further implies that the government policies of encouraging individual farmers to join associations and providing training programs for farmers are effective. The estimated results of the regional dummies suggest the importance of industry clustering. The regions with more farmers and the vertical linkage of processors and distributors gained much higher efficiency than their neighbor regions.

6. Discussion

The focus of this study was to investigate whether China can meet the world's expectation to continue playing a leading role in providing aquaculture output for the globally growing demand for seafood. Farming of large yellow croakers was selected as the case study since it presents a general situation of aquaculture production in China. Below we follow the standard structure in the literature [49] to discuss the study's theoretical and practical implications, as well as its limitations.

6.1. Theoretical Implications

The study adds to the literature on Chinese aquaculture productivity by using cross-sectional survey data of farmers. As discussed, the literature about Chinese aquaculture is dominated by ecosystem problems and food safety issues resulting from intensive farming [14–17]. Most of the relatively few studies on China aquaculture productivity used official statistics at an aggregated level in terms of both fish species and geographical areas [22–25]. Furthermore, this study investigated the effect of the different production inputs and the observed characteristics of producers on productivity, which helped identify factors that are hindering the sustainable development of Chinese aquaculture, such as intensive farming and the family-based farming model.

6.2. Practical Implications

Compared to the theoretical implications, the study has more significant practical implications. As we documented in the Introduction section, a large yellow croaker farming operation is quite like that of many other species in China. Therefore, we believe the practical implications drawn from the study apply to the whole Chinese aquaculture industry.

The factors gearing towards output growth can be broken down into three elements: technical efficiency improvement, input growth, and technological growth [29]. Before we analyze the potential of each element in gearing Chinese aquaculture output growth, let us first try to understand the contribution of technical efficiency and technological growth to output growth using the metafrontier function model by Battese et al. (2004) [44], illustrated in Figure 4. Under homogenous technology, improving technical efficiency can move Frontier 1 to Frontier 2 and hence increase output (as also presented in Figure 3). Adopting new technology can increase optimal output from Frontier 2 to Frontier 3. The difference between these two frontiers is called the technological gap in the literature [44,50].

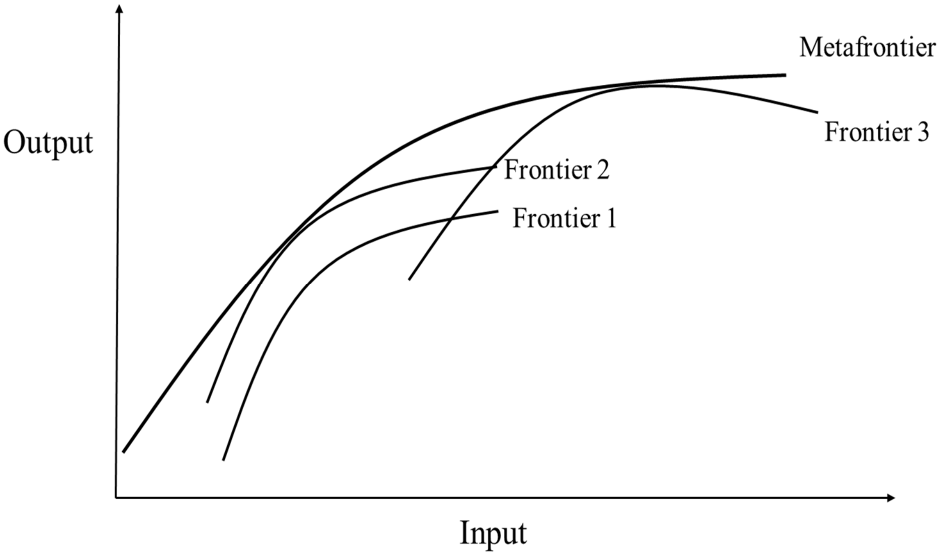

Figure 4. SFA under new technology (source: Figure 1, Metafrontier function model (page 93) in Battese et al. (2004) [44]).

Firstly, under the current homogenous technology of small floating cases, the estimated mean technical efficiency for large yellow croaker farming is 0.829 (Fronter 1), suggesting that the farming is operated close to the optimal production frontier (Fronter 2) with a small margin for improvement. Nevertheless, this margin is difficult to reduce due to the prevailing pollution problem. Nutrition loading through uneaten feed brings low productivity [13,51].

Secondly, regarding input growth, feed and fishing sites are the two most important input factors. Intensive farming heavily dependent on fishing meals has already caused water pollution and fish diseases. The fragile ecological system and food safety hazards, including fish disease agents and contamination, are considered the most severe problems in Chinese aquaculture. Furthermore, fishing meals using wild fish as a source has become a concern regarding the belief that aquaculture relieves pressure on ocean fisheries [52]. Regarding the fishing site, with only 13% of the nation's territory, the coastal region of China hosts 43.5% of the nation's population and contributes 65% of the national GDP [35]. The regions have experienced severe land scarcity caused by rapid economic growth and urbanization in recent decades and reclaiming land from the sea has become popular in managing land shortages in the regions [53]. This means expanding the production scale in the ocean is greatly constrained. We thus conclude that increasing output by increasing technical efficiency and/or input growth is infeasible. This suggests that conventional factors for Chinese aquaculture growth, including expansion of fishing sites and intensive farming, are not sustainable. A significant increase in output can only be achieved by improving overall technological inputs.

Although there is some news about the onset of fish farming using advanced technology such as factory farming in the salmon industry, technology inputs in the farming of the main species, including tilapia, catfish, and shrimp, are generally still relatively low in China. Consequently, to evaluate China's real potential in aquaculture production, future research should focus on how much can be done to improve farming technology by adopting modern equipment and facilities through innovations in China. As adopting new technology and equipment requires knowledge and considerable investment, we also conclude that family practice hinders innovation and new technology adoption. We therefore suggest involving big national or international companies capable of introducing innovations and new technologies in the Chinese aquaculture industry.

6.3. Limitations

There are two main limitations of the research. First, the study employed cross-sectional data for yellow croaker farming. Although we used the official data and the literature to document, operations in large yellow croaker farming are similar to other farming sectors. Nevertheless, the study's generalizability and reliability to other farming industries are limited. Second, large yellow croaker farming is a traditional farming industry. It cannot reflect the situation in the modern farming industry based on research and technical development (RTD), such as salmon aquaculture. Therefore, further comparative research could be conducted to identify the new trend and the effects of RTD on China's aquaculture development.

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