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Assessment of the Technical Efficiency of the Eel Aquaculture Industry in Taiwan

Abstract

The purpose of this research was to evaluate the production frontier and the technical efficiency of the eel aquaculture industry in Taiwan. Following the lead of Battese and Coelli (1995), the stochastic production frontier model was used in this study. The production frontier of the eel aquaculture industry in Taiwan was estimated first, then the efficiency for each individual eel farm was generated. Through the specification of the technical inefficiency model, the factors that may affect the productive performance are discussed. The original data for the research came from the survey of 48 eel farms in 1998 and were collected from Changhwa, Yunlin, Chiayi, Tainan and Kaohsiung. The estimated results imply that seed, labor, land and capital are relatively important in eel production in Taiwan. At the 5 percent significance level, the owner's culture experiences, the pond age and degree of automation showed significant inflüences on the farmers' technical efficiencies. The results also show that farmers' efficiencies was between 0.8 and 0.9. The average technical efficiency for the sample farms was 0.87.

Key words: Eel aquaculture industry, Technical efficiency, Stochastic production frontier

Eel aquaculture is one of the most important aquaculture industries in Taiwan. In 1989, eel production ranked first in quantity among all Taiwanese aquaculture industries[1]. According to the statistics from the fisheries yearbook of Taiwan area, the eel production in 1981 amounted to 27,624 metric tons, which increased to 55,837 metric tons in 1990. The production value of the eel aquaculture industry increased from 5.2 billion NT dollars in 1981 to 12.4 billion NT dollars in 1990. During the same period, the annual eel production value occupied 35 percent of total aquacultural production value in Taiwan. In 1988, its percentage even increased to a record high of 43 percent. Although the annual eel production in the 1990s is not as much as that in the 1980s, the eel aquaculture industry still plays a vital role in Taiwan's finfish culture. It is very interesting to examine the eel farmers' production performance and provide some thoughts for further development of the industry.

In the past, most of the studies on production economics of aquaculture have applied traditional production function approaches. Panayotou et al.[2] and Nerrie et al.[3] employed Cobb-Douglas production function to catfish pond farming in Thailand and United States, respectively. Jackson[4] and Chong et al.[5] use similar approaches to analyze

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the brackishwater aquaculture in Indonesia and the milkfish farming in the Philippines, respectively. The average Cobb-Douglas form was also applied to the analyses of tilapia, milkfish and eel farming in Taiwan[6]. The traditional approach is not only unable to evaluate individual farmer's productive performance, it is also ineffective in investigating the factors that may influence production efficiency.

The production frontier and technical inefficiency models have been widely used in evaluating productive performance in agriculture. Until recently, their application to aquaculture has been very limited. Moreover, these approaches are seldom adopted in the assessment of the productivity of the Taiwanese aquaculture industry.

Based upon the point of view mentioned above, the purpose of this research was to evaluate the production frontier and the technical efficiency of the eel aquaculture industry in Taiwan using the stochastic frontier approach. Through the estimated results, some implications are provided and suggested for the eel aquaculture industry in Taiwan.

Materials and Methods

I. The theoretical model of stochastic production frontier

According to Battese and Corra[7], the stochastic frontier production function for the cross-sectional data can be specified as follows:

$$\ln Y_i = f(x_i, \beta) + \varepsilon_i = f(x_i, \beta) + v_i - u_i,$$

$$i = 1, 2, \ldots, n \qquad (1)$$

where Y_i denotes the output level of *i*th eel farm; x_i represents a $1 \times k$ input vector of *i*th eel farm used in eel production; β is a $k \times 1$ vector of unknown parameters; ε_i is an error term which can be expressed as the summation of two independent variables, that is $\varepsilon_i = v_i - u_i$. The random variable, v_i, is following the normal distribution $N(0, \sigma_v^2)$. All the unexpected risk in eel production is incorporated into v_i. The random variable, u_i, is nonnegative and follows a half normal distribution $|N(0, \sigma_u^2)|$ (or truncated normal distribution at zero); it can be used to represent the technical inefficiency of eel farm.

Before getting into the estimation of production frontier, the probability density functions of v_i, u_i, and their joint probability density function should be realized first. The probability density function of v_i can be expressed as:

$$g_{V_i}(v_i) = \frac{1}{\sqrt{2\pi} \cdot \sigma_v} \exp\left[-\frac{1}{2}\left(\frac{v_i}{\sigma_v}\right)^2\right] \qquad (2)$$

The probability density function of u_i can be written as:

$$h_{U_i}(u_i) = \frac{1}{\sqrt{2\pi} \cdot \sigma_u} \exp\left[-\frac{1}{2}\left(\frac{u_i}{\sigma_u}\right)^2\right], \quad u_i > 0 \qquad (3)$$

Then the joint probability density function of v_i and u_i can be written as follows:

$$\begin{aligned} f_{E_i}(\varepsilon_i) &= \int h_{U_i}(u_i)\, g_{V_i}(v_i)\, dv_i \\ &= \int h_{U_i}(v_i - \varepsilon_i)\, g_{V_i}(v_i)\, dv_i \end{aligned} \qquad (4)$$

From equation (1) and (4), the probability density function of Y_i can be written as :

$$f_{Y_i}(y_i) = 2\left[1 - \Phi(z_i)\right]\left(2\pi\sigma^2\right)^{-\frac{1}{2}} \exp\left[-\frac{(y_i - x_i\beta)^2}{2\sigma^2}\right] \qquad (5)$$

where $z_i = \left[\frac{(y_i - x_i\beta)}{\sigma}\right]\left(\frac{\gamma}{1-\gamma}\right)^{\frac{1}{2}}$, and $\Phi(\cdot)$ is the distribution function of the standard normal random variable; and $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\gamma = \sigma_u^2/\sigma^2$. From equation (5), the log likelihood function that can be used directly in the estimation is expressed as:

$$\begin{aligned} \ln L(y_i \mid \beta, \sigma^2, \gamma) &= -\frac{n}{2}\ln\left(\frac{\pi}{2}\right) - \frac{n}{2}\log\left(\sigma_v^2\right) \\ &+ \sum_{i=1}^{n} \ln[1 - \Phi(z_i)] - \frac{1}{2\sigma_v^2}\sum_{i=1}^{n}(y_i - x_i\beta)^2 \end{aligned} \qquad (6)$$

To investigate the impacts of factors on the technical inefficiency, Battese and Coelli[8] further relax the assumption that u_i is truncated at zero. Let u_i follow a truncated-normal distribution at μ_i, i. e. $|N(\mu_i, \sigma_u^2)|$. And let $\mu_i = z_i\delta$, z_i is the vector of factors that may affect the *i*th eel farm's technical efficiency. δ is the vector of parameters to be estimated. The Davidon-Fletcher-Powell Quasi-Newton nonlinear iteration method was used in the estimation. The parameters representing the production frontier can be estimated and the value of γ can also be generated. The value of γ can provide some evidence that whether there are some differences of the technical efficiency among eel farmers.

According to the concept of the production frontier, technical efficiency is a relative efficiency. In other words, under a fixed combination of inputs, the *i*th farmer's technical efficiency can be expressed as the ratio of its output level (Y_i) to the most efficient output level(Y_i^*), that is:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{exp(ln\ Y_i)}{exp(ln\ Y_i^*)} \frac{exp(x\beta + v_i - u_i)}{exp(x\beta + v_i)} = exp(-u_i) \quad ,$$
$$0 \leq TE_i \leq 1 \qquad (7)$$

Due to the value of the random error, v_i, is unknown, it is impossible to find the potential maximum output. The concept of conditional expectation proposed by Jondrow et al.[9] was adopted to evaluate the individual farm's conditional technical inefficiency:

$$E(u_i \mid \varepsilon_i) = \sigma_A \left[\frac{\phi(\gamma\varepsilon_i/\sigma_A)}{\Phi(-\gamma\varepsilon_i/\sigma_A)} - \frac{\gamma\varepsilon_i}{\sigma_A} + \frac{\sigma_u\sigma}{\sigma_v} \right] \qquad (8)$$

where $\sigma_A = \frac{\sigma_u\sigma_v}{\sigma}$; $\phi(\cdot)$ is the probability density function of the standard normal random variable. $E(u_i \mid \varepsilon_i)$ is used to replace u_i to estimate the *i*th eel farm's technical efficiency.

II. Data and variables

(I) Data source

Changhwa, Yunlin, Chiayi, Tainan and Kaohsiung are the major eel production areas in Taiwan. Since the eel production in these areas accounted for 90 percent of the Taiwanese eel production in 1998, the data used in this research were collected from these areas. A preliminary survey was conducted first to revise the questionnaire. The original data for this research came from the survey of 48 eel farms in 1998. The data which were used in the production frontier analysis include each farmer's eel production and the expenditures on seed, feed, labor, rent and capital (included utility, depreciation, maintenance, chemicals, interest and miscellaneous). The data used in the technical inefficiency model were each farmer's area, education and experience of each owner; the age of the pond, the type of pond (concrete or earthen), the degree of automation and signing a contract. All variables and their definitions are organized and listed in Table 1.

(II) Output and input variables

Since the pond area of the sample eel farm varies, it was necessary to eliminate its effect on the input and output variables. All output and input variables used in this research were based on a per hectare basis. The descriptive statistics of the variables associated with the stochastic production frontier for the sample eel farms are described and summarized in Table 2.

Of the 48 farms analyzed, the average grow-out pond is 1.66 hectare and the average eel production is 14,708 kg/ha. The types of ponds used in eel production are concrete (40 %) and earthen (60 %). From the sample, we also found that 70 percent of owners have devoted themselves in eel farming for more than 10 years. The phenomena may suggest the high barrier of entering the industry. The entrance barrier perhaps is due to the following reasons:

1. High capital investment and high risk at the early stage of eel farming is involved.
2. Since the prices of elvers are extremely unstable, eel farmers have to be very sensitive to the price change and pick up the right time to buy elvers to get higher profits. It takes time, however, for farmers to learn when is the right time to buy the elvers.
3. Due to the high price and the excess demand for the Japanese eel elvers, some businessmen use other species and sell them as Japanese eel into the market to get high profit. Although the knowledge of distinguishing the elvers among different species has been taught to the industry, it is difficult for the new entrants to distinguish the differences. This situation causes a high risk for the new entrants of the industry.

4.The expertise, which includes feeding, water quality management, disease prevention and maximizing the market size and so on, are necessary for eel aquaculture.

Table 1. Description of the variables used in the model.

Variables	***Definition (Unit)***	***Remarks***
	Production Frontier Model	
Y	Eel production (kg/ha, year)	
QSEED	Seed use (piece/ha, year)	Seed expenditure / seed price
QFEED	Feed use (kg/ha, year)	Feed expenditure/ feed price
QTLAB	Total labor used (person/ha, year)	Full-time labor input+temporary labor input
QLAND	Total land use (ha/ year)	Rent expenditure / 100,000
CAPT	Total capital use (NT $/ ha, year)	Include utilities, depreciation, maintenance chemicals, interest and miscellance
	Technical Inefficiency Model	
A1	Farm area (ha)	A1=0 for area lower or equals to 1 hectare; A1=1 otherwise.
E1, E2	Owner's education	E1=0 and E2=0 for elementary school graduates; E1=1 and E2=0 for junior high school graduates; E1=0 and E=1 for college graduates.
EXP	Farming experience (year)	
PAGE	The age of pond (year)	
TYPE	Type of pond	TYPE=1 for concrete pond; TYPE=0 for earthen pond.
REC	The degree of automation (water re-circulating system)	REC =1 with automation; REC =0 otherwise.
SIGN	Sign a contract before eel harvest to agree with the eel price	SIGN=1 with contract; SIGN=0 otherwise.

(III) Empirical model

Following the lead of Battese and Coelli[8], the stochastic production frontier model was used in this study. The production frontier of the Taiwanese eel aquaculture industry was estimated first, then the efficiency for each individual eel farm was generated. Through the specification of the technical inefficiency model, the reasons that causes the differences of efficiencies among eel farmers are discussed.

In eel aquaculture, seed, feed, labor, land and capital are the most important factors, affecting its production significantly. The double nature log of the Cobb-Douglas stochastic production frontier model was applied in estimation. The model is specified as follows:

$$\ln Y_i = \alpha_0 + \alpha_1 \ln QSEED_i + \alpha_2 \ln QFEED_i + \alpha_3 \ln QTLAB_i + \alpha_4 \ln QLAND_i + \alpha_5 \ln CAPT_i + \varepsilon_i \quad (9)$$

where Y_i, $QSEED_i$, $QFEED_i$, $QTLAB_i$, $QLAND_i$ and $CAPT_i$ are ith eel farm's output, seed, feed, labor, land and capital inputs, respectively.

Table 2. The descriptive statistics of the data used in the analysis.

Variables	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
	Output variable			
Eel output level (kg/ha)	14,708.33	1,832.08	10,700	18,900
	Input variables			
Seed expenditure (NT$/ha)	4,521,981	585,809	3,404,160	5,589,675
Feed expenditure (NT$/ha)	920,091	89,380	765,600	1,104,705
Full-time labor expenditure (NT$/ha, year)	365,827	35,357	266,396	442,428
Part-time labor expenditure (NT$/ha, year)	94,931	16,771	60,713	123,331
Rent (NT$/ha, year)	113,612	18,134	73,466	148,347
Utilities (NT$/ha, year)	204,721	36,495	142,096	307,164
Depreciation (NT$/ha, year)	84,276	13,817	57,276	111,470
Maintenance (NT$/ha, year)	59,560	11,040	39,520	89,646
Chemicals expenditure (NT$/ha, year)	29,029	4,733	22,792	47,476
Interest (NT$/ha, year)	571,178	62,469	451,005	710,730
Miscellance (NT$/ha, year)	28,239	3,353	20,502	35,280
Total expenditure (NT$/ha, year)	6,991,870	726,160	5,544,396	8,215,420
	Management variables			
Experience (year)	12.48	5.5	3	25
Pond age (year)	10.35	2.47	6	15
	Other variables			
Eel price (NT$/kg)	529.64	16.26	501.64	570.18
Total revenue (NT$/ha)	7,776,798	890,468	5,692,464	9,786,042
Profit (NT$/ha)	784,929	625,241	-833,375	2,280,076
Stocking density (piece/ha)	98,211	8,693	81,750	119,250
Feed conversion rate	2.0	0.2	1.6	2.3
Survival rate (%)	74.9	7.7	58.1	90.9
Fry price (NT$/piece)	46.0	3.8	37.4	52.2

In general, it is expected that the more is the seed input, the higher is the harvest level. In other words, it is anticipated that the sign of the coefficient of seed use is positive; i.e. $\alpha_1 > 0$. In the same manner, the more feeds is used, the higher is production level; so we expected to have a positive coefficient of feed use ($\alpha_2 > 0$). The quantity of labor input is expected to affect the production level also. It is anticipated that the more labor input , the higher is the output level. Therefore, the sign of the coefficient of the labor input is positive ($\alpha_3 > 0$). The scale of land use can be treated as a proxy of the scale of eel farming. It is expected that the larger is the farming scale, the higher is the production. Therefore, the anticipated sign of the land coefficient is positive, i.e. $\alpha_4 > 0$. Since eel farming belongs to a capital-intensive industry, the capital investment and the output level are expected to move in the same direction, i.e. $\alpha_5 > 0$.

Using the estimated production frontier model, each farmer's technical inefficiency can be generated followed by the evaluation of the technical efficiency model. Because the individual farmer's inefficiency may be influenced by the scale of culture, the education and experience of owner, the age and type of pond, the degree of automation and signing a contract, the technical inefficiency model can be specified as follows:

$$\mu_i = \beta_0 + \beta_1 A_1 + \beta_2 E_1 + \beta_3 E_{21} + \beta_4 EXP + \beta_5 PAGE + \beta_6 TYPE + \beta_7 REC + \beta_8 SIGN \tag{10}$$

According to the approach proposed by Jondrow et al.[9], u_i can be used to represent the ith eel farm's technical inefficiency. μ_i is the expected value of u_i. According to the theoretical model, equation (10) can be used to examine the impact the each input influences the technical efficiency. In the above specification, A_1 represents the dummy variable for eel aquaculture scales. In Taiwanese case, the eel farm scale, which is smaller than 1 hectare, belongs to small size farming. Generally speaking, large eel farms can enjoy the economies of scale. It is anticipated that the larger the scale, the higher is the technical efficiency. In other words, the coefficients of farm scale that is greater than 1 hectare is expected to be negative, i. e., $\beta_1 < 0$. The variables E_1 and E_2 denote the education level of farm owners. Let E_1 be equal to one, representing the owners whose the highest education level is high school; while E_2 be equal to one representing owners college level higher. In general, our expectation is that the higher education, the higher acceptance for new technologies and development. We also assume that the higher the acceptance for new technologies or innovation, the higher is the production efficiency. Based upon this point of view, the signs of the coefficients of higher education levels are expected to have positive influence on technical efficiency ($\beta_2 < 0$, $\beta_3 < 0$). The variable, EXP, is used to denote farm owner's farming experiences. It is anticipated that the more experienced the owners are, the better is their ability in management and monitoring the culture environment. Therefore, it is expected that we will have a negative sign on its corresponding coefficient, i.e. $\beta_4 < 0$. PAGE represents the age of ponds used in eel production. Although the ponds used in production will be cleaned every three years, it is inevitable for the precipitate to accumulate on the pond bottom. Older pond would have the higher possibility of contamination. It is expected that $\beta_5 > 0$. The variable, TYPE, denotes the type of ponds. Let TYPE equal to one representing the concrete pond; while TYPE equal to zero denote the earthen pond. According to the past experiences, the earthen pond has better productivity in eel farming; therefore, it is expected that the coefficient of TYPE has a positive sign ($\beta_6 > 0$). Besides, the automation system can be used to monitor and improve water quality, which will have positive influence on eel production efficiency so it is expected $\beta_7 < 0$. In eel production, seed supply is one of the most important inputs. Signing a contract to guarantee future seed supply can reduce the production uncertainty. The eel farmers, however, have to bear the price fluctuation. Therefore, the impacts of signing a future contract for seed supply on production efficiency is uncertain.

Results and Discussion

The cross-sectional data of 48 eel farms' production in 1998 and the maximum likelihood estimation method were employed to estimate the stochastic production frontier of the Taiwanese eel aquaculture industry. The individual farm's efficiency was also generated based on the estimated production frontier. The estimated results of production frontier are listed in Table 3.

Table 3. Parameter estimates in the models.

Variable	*Coefficient*	*t-ratio*
	Production Frontier Model	
CONSTANT	-1.5297	-1.3405
QSEED	0.1988	2.5674*
QFEED	0.1044	1.5274
QTLAB	0.1420	2.0714*
QLAND	0.1572	3.5746*
QCAPT	0.5651	5.6410*
	Technical Inefficiency Model	
CONSTANT	0.1314	1.9258
A1	-0.0113	-0.6376
E1	-0.0048	-0.6986
E2	-0.0173	-1.4896
EXP	-0.0060	-11.1324*
PAGE	0.0083	2.8307*
TYPE	0.0076	1.0512
REC	-0.0336	-2.9574*
SIGN	0.0235	1.6166
Gamma(γ)	0.99	3.1057*
LR test of the one-sided error	= 48.3246	
The critical value of the LR test	= 17.67	

*: Significant difference from zero at the 5% significance level.

The t-ratios of all coefficients have positive signs. All of them, except that of feed use, are also significant at 5 % level. These results imply that seed, labor, land and capital are relatively important in Taiwanese eel aquaculture production. The summation of α_1 through α_5 is 1.17, which is close to one, indicating that eel production technology exhibits increasing returns to scale. The production elasticities for seed, feed, labor, land, and capital are 0.2, 0.1, 0.14, 0.16, 0.57, respectively. All of them are inelastic.

The above results also suggest the following: 1. The Taiwanese eel aquaculture industry is a capital-intensive industry, which needs enough capital and land in its production. 2. The average stocking density ranges from 80,000 to 120,000 pieces/ha. The estimated results show that at the range of 80,000 to 120,000 pieces/ha, the higher the stocking density, the higher the production level. Since the seed supply and its prices are the major factors influencing the stock density, successful development of the technology for larval rearing to stabilize the elver supply will maintain a consistent growth in eel production in Taiwan. 3. The eel aquaculture industry is highly dependent on land, labor, and capital. Due to the limitation of land and other resources, the eel aquaculture industry needs to do something different from its traditional management style and promote itself from the primary industry to the secondary industry for continuous development in the future. A further development in automation, processing, marketing, strategies, and training may be the right directions to achieve the goals of the industry.

Using the estimated efficiencies, the technical inefficiency model can be estimated to analyze the factors that may affect the individual farmer's productive performance. The estimated results are also presented in Table 3. At 5% significance level, owner's culture experiences, the age of the pond used in eel production and the degree of automation have significant influences on farmers' technical efficiencies. The results suggest that there is no significant difference among eel farms in terms of culture scale. Considering the relationship between the education and the technical efficiency, the estimated coefficients have a positive sign. These findings suggest, however, that there is not enough evidence to support the assumption that education will improve production efficiency. This may be due to the fact that most of the graduates from fishery colleges in Taiwan have devoted themselves in the feed plants, chemical companies, hatcheries, or administrative bureaus of the government and few of them are really devoted in aquaculture production. Because this phenomenon prevails in the industry, therefore, experience in eel aquaculture is relatively more important than education in aquaculture production. It may be anticipated that education will have significant impact on the culture technical efficiency when the structure of aquaculture changes to super-intensive and automatic production. Results of the present study show that the farmers with more experiences in eel aquaculture production have higher technical efficiency than those with less experiences.

Concrete ponds and earthen ponds are the most popular types for eel farming in Taiwan. According to Chou and Lee[11], the expenses on feed, labor, and utilities in concrete pond are higher than those in earthen pond, which make the production cost of concrete ponds to be 10 to 20 % more than that of earthen ponds. Furthermore, earthen ponds possess the ability of stabilizing water quality, decreasing the use of water, and lowering the occurrences of diseases, which make the earthen ponds the more popular type, in the counties of Chiayi, Yunlin and Tainan. On the other hand, concrete ponds are popular in Changhwa and Pingtung areas. From the estimated outcomes, however, there is no significant difference in the technical efficiencies between these two types of ponds. According to the estimated results, the older the pond, the lower the efficiency of the eel production.

It is believed that the water re-circulating system may not only stabilize the water quality but also prevent the occurrences of diseases. Therefore, the Taiwanese government has encouraged the farmers to install the system. It is expected that the system will improve the production efficiency in eel production. The estimated results also support the viewpoint that automation will improve the technical efficiency of eel production. Signing a contract for the future supply of seed, on the other hand, has no significant impact on farm's technical efficiency.

The estimated results show the existing differences of efficiencies among eel farmers. The average technical efficiency of eel farms is 0.87; moreover, a third of them has efficiency higher than 0.9. These results suggest that a long term investment in the research and development of eel aquaculture technology has made the Taiwanese eel auqaculture industry to mature. The results can be verified by the need of more sophisticated techniques in the current intensive eel farming.

Conclusion

Our results imply that after 70-80 year's culture experiences, the Taiwanese eel aquaculture industry has very fruitful achievements in the fields of feed combination, disease prevention, water quality management and processing. The technology spill over in the eel aquaculture industry also resulted in a stable growth in eel production. The evidences of low feed conversion ratio (1.5 to 2.0), high survival rate (80% to 90%) and low occurrences of diseases support the findings. The major factors influencing eel farmer's technical efficiency are culture experiences, the age of ponds and water re-circulation system.

Those who have longer culture experiences have higher efficiency. Older ponds have lower production efficiency. The eel farms with water re-circulation system will have better technical efficiency than those without the system. There is no evidence to show that the owner's education has significant influence on farmer's efficiency.

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