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APPLIED STUDIES

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A production economic analysis of different stocking density and fry size combinations of milkfish, *Chanos chanos*, farming in Taiwan

Yi-Chung Lee[1] | **Yung-Hsiang Lu**[2] | **Jie-Min Lee**[3] | **Christian Schafferer**[4] | **Chun-Yuan Yeh**[4] | **Tah-Wei Chu**[5] | **Yi-Wei Huang**[2]

[1]Institute of Aquatic Science and Technology, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan

[2]Department of BioBusiness Management, National Chiayi University, Chiayi, Taiwan

[3]Department of Shipping and Transportation Management, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan

[4]Department of International Trade, Overseas Chinese University, Taichung, Taiwan

[5]Department of Aquaculture, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan

Correspondence
Jie-Min Lee, Department of Shipping and Transportation Management, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan.
Email: jmlee866@yahoo.com.tw

Abstract

Milkfish, *Chanos chanos*, is often cultured with white shrimp, *Penaeus indicus*, to maintain ecological stability and increase profits. This study uses the outputs and cost data of 169 milkfish farmers in Taiwan for the years 2018 and 2019 and applies translog cost function modeling to analyze the production scale economy and input–input demand combinations of two stocking densities (<10,000, ≥10,000 fry/ha) and two fry stocking sizes (2–3 in. and ≥4 in.). The study found that high-density stocking (≥10,000 fry/ha) of small or large milkfish fry has economies of scale overall. Thus, the average culture cost may be reduced by expanding the scale of milkfish production. High-density stocking of small fry exhibits a comparatively higher own-price elasticity of fry. As such, farmers are sensitive to fry price variations. The study also found that labor and capital exhibit the highest substitutability. Capital inputs may thus be increased to mitigate the effects of wage increments. In terms of production, the four observed clusters do not exhibit cost complementarity. Moreover, the survival rate of white shrimp in high-density stocking milkfish polycultures is relatively low. It is thus recommended to strictly control the stocking density of white shrimp and to minimize the risk of excessively high stocking densities by stocking white shrimp in batches.

KEYWORDS

Chanos chanos, economies of scale and scope, fry size, price and cost elasticities, stocking density

1 | INTRODUCTION

The milkfish, *Chanos chanos*, is an important edible fish in the Indo-Pacific region (Chen, 1976). Milkfish cultivation was introduced to Taiwan and the Philippines 400 years ago (Ling, 1977). The milkfish culture area in Taiwan accounted for approximately 9,721 ha in 2018. With an annual output of approximately 53,954 m.t. (about 5.55 m.t./ha), milkfish production accounts for 20% of Taiwan's inland fish culture. Its total value amounted to almost NTD 4 billion, or approximately 12% of the total output value of inland culture in 2018. The milkfish is the second most popular inland-cultured fish species in Taiwan.

Depending on stocking density, feeding strategies, and water management, milkfish culture practices may be identified as extensive, modified-extensive, semi-intensive, and intensive (Baliao, de los Santos, & Franco, 1999; Castaños, 1995; Fortes, 1996; Sumagaysay-Chavoso, 2003). Tainan, Chiayi, and Yunlin have low natural productivity, and most farmers thus adopt extensive and semi-intensive farming with stocking densities below 10,000 fry per hectare. In Kaohsiung and Pingtung, water temperature and natural productivity are significantly higher. Semi-intensive and intensive culture practices are typical. However, the higher stocking density (>10,000 fry/ha) may negatively affect the water quality as well as the growth and survival rate of the fish (Lalramchhani et al., 2019; Suriya, Shanmugasundaram, & Mayavu, 2016; Tjoronge, 2005).

Stocking density and fry size generally depend on culture habits, fry prices, and culture environment. As such, most Taiwanese farmers use 2 to 3-in. fry despite the comparatively high feeding, water, and electricity costs. To shorten the breeding time, some farmers opt for larger milkfish fry (≥4 in.). Lacking a proper understanding of economic efficiency, farmers tend to use input factors excessively, leading to unnecessary additional breeding costs.

In Taiwan, milkfish is usually cultured with white shrimp to increase profitability (Helminuddin, Purnamasarib, & Abdusysyahid, 2020; Mangampa & Burhanuddin, 2014) and to remove residual feed and excrement, which is necessary for preserving water quality (Apud, 1985; Biswas et al., 2012; Eldani & Primavera, 1981; Jamerlan, Coloso, & Golez, 2014; James, 1996; Jaspe, Caipang, & Elle, 2011; Kuntiyo & Baliao, 1987; Lalramchhani et al., 2019; Pudadera Jr & Lim, 1982).

Previous research on milkfish farming has predominantly focused on the cultivation of monocultures (Chiang, Sun, & Yu, 2004; Lelono & Susilowati, 2010; Sudarmo & Fyka, 2017; Susilo, 2007) and the growth and survival rate of milkfish in polyculture with white shrimp (Eldani & Primavera, 1981; Lalramchhani et al., 2019; Pudadera Jr & Lim, 1982). This study addresses two research questions. First, it investigates the impact of stocking density and milkfish fry size on production efficiency. That is, it attempts to determine whether economies of scale can be achieved at higher rather than lower stocking densities with smaller rather than larger milkfish fry. Second, it investigates whether milkfish polycultures with white shrimp exhibit cost complementarity.

More specifically, by applying translog cost function modeling, the production scale economy and input–input demand service condition of milkfish polycultures with white shrimp at two different stocking densities (<10,000, ≥10,000 fry/ha) and with two different fry sizes (2–3 in. and ≥4 in.) are analyzed. Longitudinal and transverse culture production and input factor data of milkfish farming from 2018 to 2019 are used in the analysis. The findings of this study can provide a reference for milkfish farmers to adjust the input factors and production scale of their culture according to stocking density and size.

2 | METHODS

2.1 | Study areas and culture methods

This study covers the five primary milkfish-producing areas of Taiwan: Tainan, Kaohsiung, Chiayi, Yunlin, and Pingtung (Figure 1). Almost all of Taiwan's milkfish cultures are located within these areas. For the adult fish culture of milkfish, fishpond preparation is performed mainly during January to March, including draining and sun drying, repairing gates, screens, and dikes, as well as controlling pests, predators, diseases and disease-carrying organisms, liming, feeding and applying fertilizers, and growing benthic algae by water management. The farmers release the milkfish fry according to culture experience in the middle of or at the end of April, and white shrimp are cultured together with milkfish in the culture process. The milkfish fry size is selected according to the expected harvest time and fry price. The general size is 2 to 3 in. However, to shorten the culture cycle, larger fry (≥4 in.) are selected.

In Yunlin, Chiayi, and Tainan, the farming and harvesting of polycultures occur in the same year, with the average stocking density of milkfish fry being less than 10,000 fry/ha. The white shrimp fry used for polyculture can be released in stages. The average stocking density is approximately 500,000 fry/ha.

Kaohsiung and Pingtung are located in southern Taiwan. The more southerly latitude means that the average temperature is higher in winter and appropriate for overwinter culture. Thus, the overall culture period is relatively long. The fishpond preparation is performed in March to May, and the fry are released in June. The overwinter-harvest culture has a higher stocking density of milkfish fry and white shrimp fry. More specifically, the average stocking density of milkfish fry is ≥10,000 fry/ha and that of white shrimp fry is approximately 800,000 fry/ha.

For fishpond management, attention should be paid to the daily amount of dissolved oxygen in the fishpond. When the dissolved oxygen decreases, the waterwheel must be actuated to maintain the dissolved oxygen to prevent the fish school from dying of oxygen deficiency. In terms of feed supply, the automatic dispenser regularly supplies artificial formula feed. White shrimp in polycultures eat the leftover feed and excrement of fish, thus cleaning the water. Furthermore, fishponds need to be constantly checked for disease and insect damage.

The harvesting period is between September and November. After 3 months of white shrimp culture, the harvest lasts from July to December. In the case of overwinter culture, milkfish is harvested mainly in December, January, and February, and white shrimp from September to February.

2.2 | Model specification

This study used translog cost function modeling for the empirical analysis of the output and cost input data of milkfish and white shrimp polyculture farming households. Translog cost function modeling is often used to analyze the relationships among output, cost, and input factors (Christensen, Jorgenson, & Lau, 1971). It is also frequently applied in agricultural and fishery studies to analyze the operators' production cost structure and production input

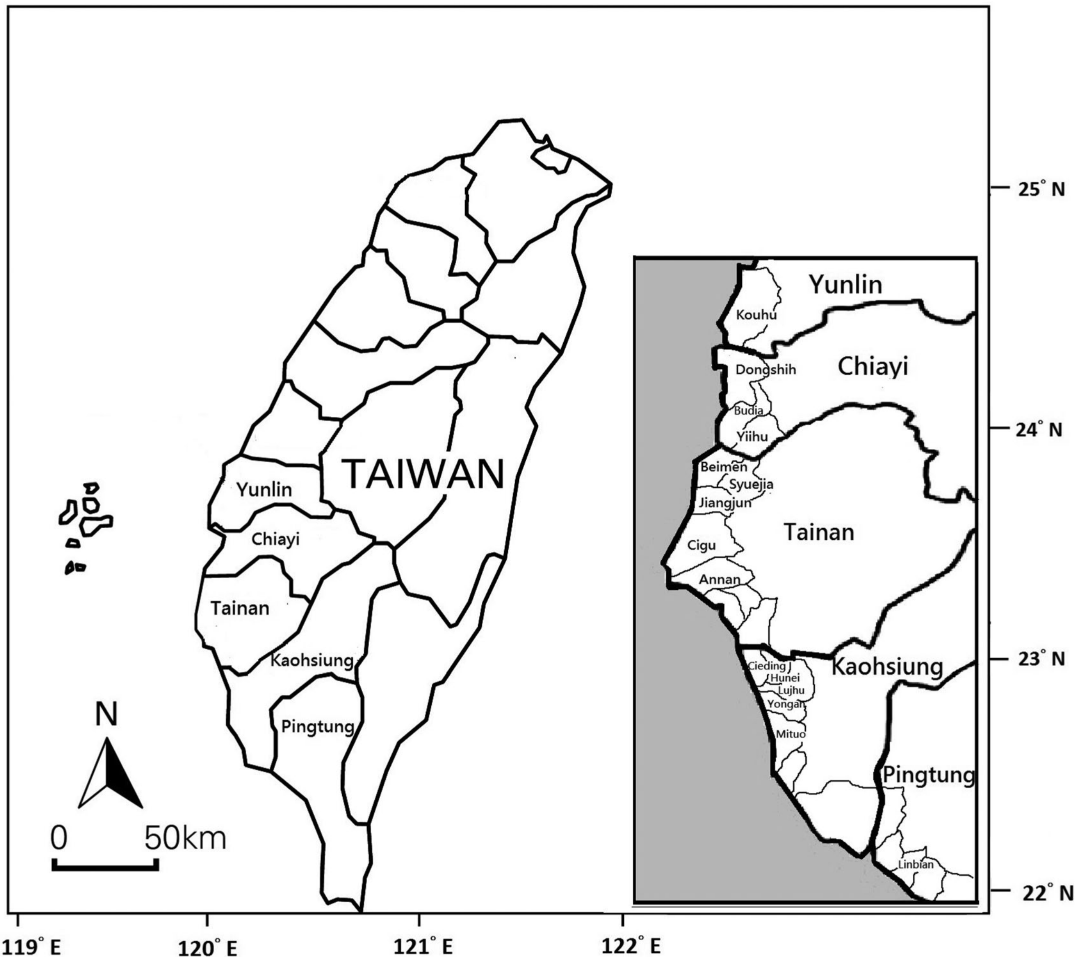

FIGURE 1 Geographic location of milkfish, *Chanos chanos*, culture in Taiwan

factors (McKay, Lawrence, & Vlastuin, 1983; Ray, 1982; Sidhu & Baanante, 1979; Sil & Buccola, 1995). This study applied a translog cost function model for parameter estimation.

In the culture cost structure of milkfish-based polycultures with white shrimps, five production inputs (labor, fry, capital, feed, and other miscellaneous production inputs), two outputs (milkfish and white shrimp), and two dummy variables (Reg and Time) are considered. The translog cost function of the milkfish-white shrimp polyculture can be defined as follows:

$$\begin{aligned}\ln C = {} & \beta_0 + \sum_k \alpha_k \ln Q_k + \frac{1}{2}\sum_k \sum_l \eta_{kl} \ln Q_k \ln Q_l + \sum_i \beta_i \ln P_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln P_i \times \ln P_j + \sum_k \sum_i \lambda_{ki} \ln Q_k \times \ln P_i \\ & + \nu_0 \times \mathrm{Reg} + \sum_k \gamma_k \mathrm{Reg} \times \ln Q_k + \lambda_0 \times \mathrm{Time} + \sum_k \omega_k \mathrm{Time} \times \ln Q_k \quad \forall i,j = L,S,K,F,O \quad k = m,s\end{aligned} \tag{1}$$

where C is the total cost of production, Q_m and Q_s are the vectors of the output of milkfish and white shrimps, respectively, and P_i is the vector of factor price. The five production factors are labor (L), fry (S), capital (K), feed (F), and other miscellaneous production inputs (O). Reg is a geographical dummy variable set to 1 in the cases of

Kaohsiung and Pingtung, and all other cases are set to 0. Time denotes the time dummy variable and equals to 1 if year is 2018 and 0 otherwise. β_0, α_k, η_{kl}, β_i, β_{ij}, λ_{ki}, ν_0, γ_k, λ_0, and ω_k are the estimated parameters.

According to Shephard's lemma, if the factor price is differentiated using Equation (1), cost-share (S_i) in Equation (2) can be obtained as follows:

$$\frac{\partial \ln C}{\partial \ln P_i} = S_i = \beta_i + \sum_j \beta_{ij} \ln P_j + \sum_k \lambda_{ki} \ln Q_k \tag{2}$$

To correspond to a well-behaved production function, the production function must meet the factor price homogeneity of degree one and symmetry requirements. The constraints include

$$\sum_i \beta_i = 1, \sum_i \beta_{ij} = \sum_j \beta_{ji} = 0, \sum_i \lambda_{ki} = 0, \beta_{ij} = \beta_{ji} \tag{3}$$

Imposing symmetry and homogeneity by using parameter constraints, the cost function (1) and cost-share Equation (2) are jointly estimated using the seemingly unrelated regression methods proposed by Zellner (1962). As mentioned, only the $n-1$ factor share equations are linearly independent.

2.3 | Input demand elasticity and scale efficiency

To further analyze the cost structure characteristics of milkfish, the input demand price elasticity and scale efficiency indices can be calculated using the estimated parameters. The input demand price elasticity is defined as the effect of the input factor price variation on the input demand variation when the other conditions are fixed. The own-price η_{ii} and cross-price elasticities η_{ij} of input demand are used to measure the demand response of input *i* with respect to changes in the price of input *i* or changes in the price of input *j*. The following formula is applied:

$$\eta_{ii} = \frac{\beta_{ii}}{s_i} + s_i - 1 \tag{4}$$

$$\eta_{ij} = \frac{\beta_{ij}}{s_i} + s_j \quad \text{for } i \neq j \tag{5}$$

The Allen partial elasticities of substitution (AES) can be calculated to further understand the substitutability and complementarity of input factors, which is a net or Hicksian elasticity. The AES between factors *i* and *j* are calculated as follows:

$$\delta_{ii} = \frac{\beta_{ii}}{s_i^2} - \frac{1}{s_i} + 1 \tag{6}$$

$$\delta_{ij} = \frac{\beta_{ij}}{s_i s_j} + 1 \quad \text{for } i \neq j \tag{7}$$

Economies of scale measure the relative changes in outputs when expenses change, but input prices are held constant. For a multiproduct firm with joint costs, the overall scale economy (OSE) is denoted as $\text{OSE} = \sum_{i=1} C(Q) / \left(\sum_{i=1} Q_i \times \frac{\partial C(Q)}{\partial Q_i} \right) = 1 / \sum_i \varepsilon_{CQ_i}$, where $C(Q)$ is the total cost, $\partial C(Q)/\partial Q_i$ is the marginal cost of producing

Q_i, and ε_{CQ_i} is the cost elasticity of the ith output. Values of OSE equal to unity, greater than unity, or less than unity imply that firms exhibit constant, increasing, or decreasing returns to scale, respectively.

Economies of scope (EOS) exist if the cost of jointly producing two or more goods is less than the total cost of producing these outputs separately. Formally, an EOS exists if $C(Q_i, Q_j) < [(C_i, 0) + C(0, Q_j)]$. Whether a multiproduct cost function exhibits EOS can be determined by analyzing the weak cost complementarities between two outputs Q_i and Q_j, which are defined as follows: $CC_{ij} = \partial^2 C / (\partial Q_i \times \partial Q_j)$. Cost complementarities between the two outputs exist if CC_{ij} is negative (Panzar, 1989).

2.4 | Data sources and variables definitions

Milkfish grow-out culture farming households are the subjects of this study. A survey was conducted to obtain data regarding the operation, biological setting, output, culture input cost, and income of the observed farming households. Local fishermen associations provided sampling data. In the first stage of the sampling process, the number of households to be interviewed in each of the five geographical regions was determined by assigning quotas to each region in proportion to their share in the total production output. In the second stage, the 228 farming households included in the study were selected by the district branches of the local fishermen's associations. The number of district branches assigned to each of the five regions was also proportional to the production output. In total, there were 20 district branches in charge of selecting the sample households through convenience sampling. Professionally trained interviewers conducted the surveys. In addition to the survey, two representatives of the fishing industry, two senior farmers, and one scholar were interviewed using semistructured questionnaires. The in-depth interviews helped control potential selection bias and determine whether the questionnaires contained unreasonable/inconsistent responses. In total, 59 out of 228 questionnaires were incomplete or inconsistent and were thus removed from the sample. The final number of farming households included in the study was 169, about 3% of the 5,597 members of the fishermen's associations.

The culture operation and biological data of the farming households for the years 2018 and 2019 are used in the analysis. The data include the farmer's age and experience, depth of culture pond, culture time, stocking density, and survival rate. The cost data are obtained by calculating the cost outlay per hectare; the unit used in the study is NTD/ha. Culture costs include labor cost, fry cost, capital cost, feed cost, and other costs. Labor costs include the costs of family workers, workers, and casual workers. Furthermore, the fry cost comprises the purchase costs of milkfish fry and white shrimp fry, while capital cost is the equipment depreciation expense. Capital investment in equipment includes the costs of fishing rafts, waterwheels, water pumps, generators, water quality, and bottom soil testing plants and farm huts. The feed cost includes the costs of the feed and fertilizer. The other costs include water and electricity expenses, fish pond and equipment maintenance costs, and drug and insurance expenses. The quantities of the inputs and input prices are listed in Table A1. The income is calculated by multiplying the production output of milkfish and white shrimp by the selling price; the unit is NTD/ha.

This study used a translog cost function model for empirical analysis. The definitions of the cost, output, input factor price, and operation variation are as follows: The total production cost (C) is the sum of labor cost, fry cost, capital cost, feed cost, and other costs; the unit is NTD/ha. The output (Q) is the output of milkfish and white shrimp (kg/ha). The production input factor price includes the price of labor (P_L), calculated by dividing the total cost of family workers, workers, and casual laborers by the culture area (NTD/ha). The fry price (P_S) is calculated by the weighted average of milkfish and white shrimp fry buying price according to the ratio of purchase outlay. The capital price (P_K) is calculated by dividing the equipment depreciation expense by the culture area (NTD/ha). The equipment includes fishing rafts, waterwheels, water pumps, generators, water quality, bottom soil testing plants, cultivation farm huts, and so on. The annual depreciation is the initial depreciation divided by the depreciation period and is calculated according to the standards set by the Directorate of Fisheries. The feed price (P_F) is calculated by dividing the total cost outlay for feed and fertilizer by the weight of feed and fertilizer (NTD/kg). The other factor price (P_O) is calculated by dividing the sum of water and electricity expenses, fish pond and equipment maintenance cost, and drug and insurance expenses by the culture area (NTD/ha).

The farming households are divided into four clusters according to two stocking densities of milkfish (low-density stocking [<10,000 fry/ha] and high-density stocking [≥10,000 fry/ha]) and two stocking fry sizes (small: 2–3 in.; large: ≥4 in.): (i) low-density stocking with small fry; (ii) low-density stocking with large fry; (iii) high-density stocking with small fry; and (iv) high-density stocking with large fry. Translog cost function modeling is used to estimate the cost function, input demand price elasticity, and scale efficiency indexes to discuss the differences in production scale economy, culture cost, and input factor use.

3 | RESULTS

Table 1 shows the descriptive statistics of the clustered farming households. Among the 338 samples collected, small milkfish fry (2–3 in.) accounts for 69.5% of all samples. Among the four clusters, low-density stocking with small fry forms the largest cluster, accounting for 35.2% of all samples. Low-density stocking with large fry (≥4 in.) is the smallest cluster, accounting for 14.8% of all samples.

In terms of production output, high-density stocking of small fry has the highest average output of milkfish per hectare (13,992 kg). Moreover, high-density stocking of large fry has the highest average output of white shrimp per hectare (1,284 kg). In terms of cost outlay structure analysis, the feed cost of high-density stocking of milkfish constitutes the largest portion of the total cost. With 51.1% of the total cost, farmers with high-density stocking of small fry have the highest relative feed costs among the four clusters. Labor costs of large fry stocking constitute a greater portion of the total cost compared with those of small fry stocking. The fry cost accounts for about 8.2 to 19.5% of total costs. The cost of large milkfish fry is 1.3 to 2.1 times higher than that of small fry. The capital cost accounts for the lowest proportion of total cost (3.0–5.4%). The observed samples with high-density stocking of small fry have the lowest average cost per kg (68.55 NTD), whereas low-density stocking of small fry, in general, incurs the highest average cost per kilogram, that is, 103.94 NTD.

In terms of profit, milkfish farming at higher stocking densities is more profitable. Households with high-density stocking of small fry have the highest average profit per hectare (529,875 NTD), followed by those with high-density stocking of large fry (356,680 NTD). Low-density stocking of milkfish is less profitable because the average cost of culture is high, while the output is relatively low.

According to the farmers' operational characteristics, the culture time extends as the stocking density increases and the stocking size decreases. As such, the high-density stocking of small fry has the longest average culture time (10.36 months) and the highest average stocking density per hectare (21,536 fry). Moreover, low-density stocking of large fry exhibits the lowest average stocking density per hectare (6,344 fry). The quantity of white shrimp increases with milkfish stocking density, but the white shrimp survival rate decreases. More specifically, households applying high-density stocking of small fry have the largest average quantity of white shrimp per hectare (831,448 fry) and the lowest white shrimp survival rate (10%).

3.1 | Parameter estimation

The cost, output, and input factor price data of the four observed clusters of farmers are used to estimate the cost function model and cost-share parameters of various clusters under the symmetry, homogeneity, and added-up constraints. The Lagrange multiplier test rejects the null hypothesis of no heteroscedasticity, which is expected because all derive from the same underlying technology (implicit in the cost minimization problem). The test of model symmetry and homogeneity is only partially established (Table 2). Nevertheless, the aforementioned constraints are still added to the model estimation based on the theoretical requirements and factors that improve the parameter estimation efficiency. Moreover, bootstrapping with 1,000 iterations is performed to evaluate the estimation errors. The standard deviation of most replicated estimates (see bootstrap standard error in Table 2) is larger than that of the non-repetitive sample (see standard error in Table 2).

The parameter estimation results are presented in Table 2. The results are broadly consistent with the theory; among the estimated parameters of the total cost and the cost share model the Chi-square test is significant, implying that all estimated parameters are not 0. That is, the model has predictive ability. The estimated cost function, R-square is 0.931 to 0.998. That is, the degree of explanation of various cost functions for the prediction result is above 93%. As such, the estimated translog cost function provides a reasonable representation of the different stocking densities and fry size production technologies. The study analyzes the possible impact of time and geographical factors on production. The parameter estimation results of the time dummy variable show that the estimated parameters are not statistically significant. That is, farmer dimensions do not create any distinction within the observations. The estimated parameters of the regional dummy variable are positive and statistically significant for all samples. As such, high production output in Kaohsiung and Pingtung generates higher total costs.

3.2 | Input demand price elasticity estimation

Table 3 shows the input demand price elasticity estimation results for the four clusters. The estimated own-price elasticity of labor, fry, capital, feed, and other input–input demands of the four clusters is lower than 1. As such, the five input–input demands of different stocking sizes and stocking densities lack price elasticity. The high and low stocking densities of small milkfish fry have higher own-price elasticity of fry than those of large fry, and the own-price elasticity of capital is lower. The high-density stocking of small fry has the highest own-price elasticity (−0.789), while the own-price elasticity of feed is the lowest at −0.141.

Table 4 shows the estimation results of the AES. Values of the partial elasticities of substitution above zero indicate substitutability, and values below zero indicate complementarity of factors. Regarding the high-density stocking of small fry, the input factors labor and fry exhibit the highest level of substitutability. That is, the partial elasticity of substitution reached 1.362. As for the high-density stocking of large fry, labor and capital show relatively strong substitutability with partial elasticities of substitution equal to 2.433. The feed and fry of low-density stocking of small fry have relatively strong substitutability, as the partial elasticities of substitution equal 1.436.

3.3 | Estimation of scale efficiency and EOS

Table 5 shows the output cost elasticity of milkfish and white shrimp, specific product scale efficiency, overall scale efficiency, and EOS. The overall scale efficiency value of milkfish-white shrimp polycultures can be estimated according to the inverse of the total cost elasticities of milkfish and white shrimp. When the overall scale efficiency value is greater than 1, the overall production presents scale efficiency. When the overall scale efficiency value is smaller than 1, the overall production presents a diseconomy of scale. The overall scale efficiency value of low-density stocking of small or large milkfish fry polyculture with white shrimp are respectively 0.957 and 1.043, which values are not significantly different from one at 5% level.

The findings of this study show that the overall scale efficiency value of high-density stocking of small or large fry is larger than 1 and is statistically significant. Indicating, that the overall production of high-density stocking of small-or large-sized milkfish fry have scale efficiency. Meanwhile, the high-density stocking of large milkfish fry has the highest overall scale efficiency at 1.536, implying that the overall high-density stocking of large milkfish fry has scale efficiency. As such, the average cost can be reduced by increasing the overall output. Regarding geographical variations, high-density stocking of small or large milkfish fry in Yunlin, Chiayi, and Tainan has higher total scale efficiency than in Kaohsiung and Pingtung. That is, increased production in Yunlin, Chiayi, and Tainan leads to

TABLE 1 Descriptive data of the observed farming household clusters

Stocking density (fry/ha)	<10,000				≥10,000					
Stocking size (in./fry)	**2–3**		**≥4**		**2–3**		**≥4**		**Total**	
No. of samples	**119**		**50**		**116**		**53**		**338**	
Variables	**Mean**	**%**	**Mean**	**%**	**Mean**	**%**	**Mean**	**%**	**Mean**	**%**
Outputs (kg/ha)										
Milkfish	5,019		4,637		13,992		11,500		9,058	
White shrimp	1,121		787		1,233		1,284		1,136	
Inputs (NTD/ha)										
Seed costs	42,643	8.2	91,896	19.5	80,853	8.4	103,415	11.4	72,572	10.0
Feed costs	168,043	32.2	122,278	25.9	490,256	51.1	369,047	40.8	303,689	41.9
Other costs	157,352	30.2	102,539	21.7	174,468	18.2	160,422	17.8	155,599	21.5
Labor costs	126,702	24.3	130,315	27.6	185,175	19.3	238,641	26.4	164,857	22.7
Capital costs	26,919	5.2	25,419	5.4	28,344	3.0	32,129	3.6	28,003	3.9
Costs, returns and profitability (NTD/ha)										
Total costs	521,659		472,447		959,096		903,654		724,720	
Gross revenue	573,550		510,671		1,488,971		1,260,334		986,053	
Net profit	51,891		38,224		529,875		356,680		261,333	
Average cost (NTD/kg)	103.94		101.89		68.55		78.58		80.01	
Technical and farmer characteristics										
Culture area (ha)	2.76		2.05		2.40		2.77		2.53	
Culture period (month)	8.50		8.32		10.36		9.90		9.34	
Water depth (cm)	3.94		3.30		3.96		3.50		3.78	
Water source (brackish water/ fresh water) (%)	12.61/87.39		38.00/62.00		31.03/68.97		10.00/90.00		20.70/79.30	
Fry stocking density (fry/ha)										
Milkfish	6,932		6,344		21,536		16,088		13,293	
White shrimp	453,072		356,020		831,448		739,696		616,453	

(Continues)

TABLE 1 (Continued)

Stocking density (fry/ha)	<10,000				≥10,000					
Stocking size (in./fry)	**2–3**		**≥4**		**2–3**		**≥4**		**Total**	
No. of samples	**119**		**50**		**116**		**53**		**338**	
Variables	**Mean**	**%**	**Mean**	**%**	**Mean**	**%**	**Mean**	**%**	**Mean**	**%**
Survival rate										
Milkfish	0.86		0.87		0.78		0.85		0.82	
White shrimp	0.17		0.15		0.10		0.11		0.12	
Experience of household head (year)	28.73		33.74		24.19		25.40		27.40	
Age of household head (year)	57.57		60.92		59.97		61.00		59.40	

Note: 1USD = 30.08NTD.

Abbreviations: ha, hectare; NTD, new Taiwan dollar; USD, United States dollar.

TABLE 2 Coefficient estimates of translog cost function and cost shares of the observed farming household clusters

Stocking density (fry/ha)		<10,000						≥10,000		
Stocking size (in./fry)		2–3			≥4			2–3		
Variables	Parameters	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*
Translog cost function (ln *C*)										
Constant	β_0	6.522*	3.870	1.708	0.518	2.623	3.299	10.963**	3.515	1.862
$\ln Q_m$	α_m	−0.097	0.896	0.394	1.230*	0.693	0.823	−0.632	0.834	0.270
$\ln Q_s$	α_s	−0.123	0.550	0.264	0.212	0.403	0.275	−0.205	0.347	0.281
$0.5 (\ln Q_m)^2$	η_{mm}	0.133	0.131	0.055	−0.050	0.109	0.110	0.146	0.108	0.036
$0.5 (\ln Q_s)^2$	η_{ss}	0.017	0.036	0.024	−0.068	0.053	0.029	0.021	0.037	0.035
$\ln Q_m \ln Q_s$	η_{ms}	0.005	0.068	0.032	0.022	0.061	0.037	0.009	0.043	0.039
$\ln P_L$	β_L	0.398**	0.159	0.090	0.403**	0.151	0.127	0.360**	0.144	0.093
$\ln P_S$	β_S	0.120*	0.069	0.073	0.277**	0.150	0.168	0.033	0.107	0.087
$\ln P_K$	β_K	0.180**	0.072	0.080	0.062	0.094	0.050	0.091**	0.017	0.033
$\ln P_F$	β_F	−0.230	0.354	0.140	0.245	0.165	0.121	0.302**	0.131	0.092
$\ln P_O$	β_O	0.533**	0.214	0.135	−0.014	0.210	0.197	0.214**	0.086	0.085
$\ln P_L \times \ln P_L$	β_{LL}	0.128**	0.012	0.007	0.152**	0.011	0.010	0.101**	0.023	0.007
$\ln P_L \times \ln P_S$	β_{LS}	−0.028**	0.008	0.005	−0.034**	0.009	0.008	0.006	0.133	0.005
$\ln P_L \times \ln P_K$	β_{LK}	−0.012	0.008	0.005	−0.005	0.007	0.004	−0.003**	0.001	0.002
$\ln P_L \times \ln P_F$	β_{LF}	−0.017	0.019	0.005	−0.052**	0.015	0.007	−0.086**	0.009	0.005
$\ln P_L \times \ln P_O$	β_{LO}	−0.071**	0.010	0.007	−0.061**	0.018	0.011	−0.019**	0.006	0.004
$\ln P_S \times \ln P_S$	β_{SS}	0.017**	0.008	0.006	0.119**	0.016	0.013	0.011	0.009	0.006
$\ln P_S \times \ln P_K$	β_{SK}	−0.002	0.006	0.005	−0.010	0.010	0.004	−0.002	0.001	0.002
$\ln P_S \times \ln P_F$	β_{SF}	0.012	0.011	0.005	−0.020	0.013	0.007	−0.015**	0.007	0.004
$\ln P_S \times \ln P_O$	β_{SO}	0.0006	0.007	0.006	−0.054**	0.014	0.013	0.0004	0.005	0.004
$\ln P_K \times \ln P_K$	β_{KK}	0.038**	0.008	0.007	0.040**	0.010	0.005	0.028**	0.004	0.003
$\ln P_K \times \ln P_F$	β_{KF}	−0.001	0.007	0.005	−0.008	0.026	0.004	−0.011**	0.001	0.002
$\ln P_K \times \ln P_O$	β_{KO}	−0.023**	0.007	0.007	−0.017	0.012	0.005	−0.012**	0.004	0.003

(Continues)

TABLE 2 (Continued)

Stocking density (fry/ha)		<10,000						≥10,000		
Stocking size (in./fry)		2–3			≥4			2–3		
Variables	Parameters	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*
$\ln P_F \times \ln P_F$	β_{FF}	0.043	0.035	0.008	0.099**	0.031	0.008	0.182**	0.010	0.007
$\ln P_F \times \ln P_O$	β_{FO}	−0.037**	0.015	0.008	−0.019	0.020	0.010	−0.070**	0.005	0.005
$\ln P_O \times \ln P_O$	β_{OO}	0.130**	0.011	0.013	0.152**	0.025	0.021	0.101**	0.008	0.006
$\ln Q_m \times \ln P_L$	λ_{mL}	−0.027	0.019	0.011	−0.030*	0.018	0.014	−0.014	0.011	0.010
$\ln Q_m \times \ln P_S$	λ_{mS}	0.004	0.010	0.009	−0.014	0.019	0.018	0.003	0.010	0.009
$\ln Q_m \times \ln P_K$	λ_{mK}	−0.006	0.007	0.010	0.003	0.012	0.006	0.002	0.002	0.004
$\ln Q_m \times \ln P_F$	λ_{mF}	0.032	0.036	0.017	0.032**	0.016	0.014	−0.004	0.013	0.009
$\ln Q_m \times \ln P_O$	λ_{mO}	−0.002	0.021	0.017	0.009	0.024	0.022	0.018**	0.008	0.009
$\ln Q_s \times \ln P_L$	λ_{sL}	0.0001	0.008	0.006	0.004	0.010	0.007	−0.006	0.008	0.006
$\ln Q_s \times \ln P_S$	λ_{sS}	−0.004	0.006	0.005	0.014	0.010	0.010	0.014**	0.005	0.005
$\ln Q_s \times \ln P_K$	λ_{sK}	−0.002	0.004	0.006	0.003	0.006	0.003	−0.003**	0.001	0.002
$\ln Q_s \times \ln P_F$	λ_{sF}	0.023**	0.011	0.009	−0.034**	0.009	0.007	0.008	0.006	0.006
$\ln Q_s \times \ln P_O$	λ_{sO}	−0.018**	0.008	0.010	0.013**	0.004	0.011	−0.013**	0.005	0.005
Reg	ν_O	0.270	0.962	0.695	−2.557**	0.043	1.816	−0.912	1.012	0.698
Reg × $\ln Q_m$	Υ_m	0.036	0.139	0.088	0.230**	<0.001	0.142	0.144	0.114	0.079
Reg × $\ln Q_s$	Υ_S	−0.010	0.083	0.058	0.170**	0.003	0.128	0.013	0.058	0.055
Time	λ_O	−0.024	0.512	0.354	−0.224**	0.054	0.323	0.082	0.467	0.289
Time × $\ln Q_m$	ω_m	0.016	0.060	0.042	0.021**	0.006	0.044	−0.023	0.046	0.029
Time × $\ln Q_s$	ω_s	−0.019	0.030	0.022	0.012**	0.002	0.019	0.021	0.021	0.020
Labor cost share (S_L)										
$\ln Q_m$	λ_{mL}	−0.028	0.019	0.011	−0.029*	0.018	0.015	−0.014	0.011	0.009
$\ln Q_s$	λ_{sL}	0.0001	0.008	0.006	0.004	0.010	0.007	−0.006	0.008	0.006
$\ln P_L$	β_{LL}	0.128**	0.012	0.006	0.152**	0.011	0.010	0.101**	0.023	0.007

TABLE 2 (Continued)

Stocking density (fry/ha)		<10,000						≥10,000		
Stocking size (in./fry)		2–3			≥4			2–3		
Variables	Parameters	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*
ln P_S	β_{LS}	−0.028**	0.008	0.005	−0.033**	0.009	0.008	0.006	0.013	0.005
ln P_K	β_{LK}	−0.012	0.008	0.005	−0.005	0.007	0.004	−0.003**	0.001	0.002
ln P_F	β_{LF}	−0.017	0.019	0.005	−0.052**	0.016	0.007	−0.086**	0.009	0.005
ln P_O	β_{LO}	−0.071**	0.010	0.007	−0.061**	0.017	0.011	−0.019**	0.006	0.004
Constant	β_L	0.398**	0.159	0.090	0.403**	0.151	0.127	0.360**	0.144	0.093
Fry cost share (S_S)										
ln Q_m	λ_{mS}	0.004	0.010	0.009	−0.014	0.019	0.019	−0.003	0.010	0.009
ln Q_s	λ_{sS}	−0.004	0.006	0.005	0.014	0.010	0.010	0.014**	0.005	0.005
ln P_L	β_{SL}	−0.028**	0.008	0.005	−0.034**	0.009	0.008	0.006	0.013	0.005
ln P_S	β_{SS}	0.017**	0.008	0.006	0.119**	0.016	0.013	0.011	0.009	0.006
ln P_K	β_{SK}	−0.002	0.006	0.005	−0.010	0.009	0.004	−0.002	0.001	0.002
ln P_F	β_{SF}	0.012	0.011	0.005	−0.020	0.013	0.007	−0.015**	0.007	0.004
ln P_O	β_{SO}	0.001	0.007	0.006	−0.055**	0.014	0.013	−0.0004	0.005	0.004
Constant	β_S	0.120*	0.069	0.073	0.277**	0.150	0.168	0.033	0.107	0.087
Capital cost share (S_K)										
ln Q_m	λ_{mK}	−0.006	0.007	0.010	0.003	0.012	0.006	0.002	0.002	0.004
ln Q_s	λ_{sK}	−0.002	0.004	0.006	0.003	0.006	0.003	−0.003**	0.001	0.002
ln P_L	β_{KL}	−0.012	0.008	0.005	−0.005	0.007	0.004	−0.003**	0.001	0.002
ln P_S	β_{KS}	−0.002	0.006	0.005	−0.010	0.009	0.004	−0.002	0.001	0.002
ln P_K	β_{KK}	0.038**	0.008	0.007	0.040**	0.010	0.005	0.028**	0.004	0.003
ln P_F	β_{KF}	−0.001	0.007	0.005	−0.008	0.026	0.003	−0.011**	0.001	0.002
ln P_O	β_{KO}	−0.023**	0.007	0.007	−0.017	0.012	0.005	−0.012**	0.004	0.003
Constant	β_K	0.180**	0.072	0.081	0.062	0.094	0.050	0.091**	0.017	0.033

(Continues)

TABLE 2 (Continued)

Stocking density (fry/ha)		<10,000						≥10,000		
Stocking size (in./fry)		2–3			≥4			2–3		
Variables	Parameters	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*
Feed cost share (S_F)										
ln Q_m	λ_{mF}	0.032	0.036	0.017	0.032**	0.016	0.014	−0.004	0.013	0.009
ln Q_s	λ_{sF}	0.023**	0.011	0.008	−0.034**	0.009	0.007	0.008	0.006	0.006
ln P_L	β_{FL}	−0.017	0.019	0.005	−0.052**	0.016	0.007	−0.086**	0.009	0.005
ln P_S	β_{FS}	0.012	0.011	0.005	−0.020	0.013	0.007	−0.015**	0.007	0.004
ln P_K	β_{FK}	−0.001	0.007	0.005	−0.008	0.026	0.003	−0.011**	0.001	0.002
ln P_F	β_{FF}	0.043	0.035	0.008	0.099**	0.031	0.008	0.182**	0.010	0.007
ln P_O	β_{FO}	−0.037**	0.015	0.008	−0.019	0.020	0.010	−0.070**	0.005	0.005
Constant	β_F	−0.057	0.310	0.137	0.243*	0.135	0.115	0.353**	0.129	0.086
Adjusted R^2		0.995			0.931			0.998		
Wald test of symmetry restrictions										
$\beta_{LS}=\beta_{SL}$		6.66**			3.77*			1.21		
$\beta_{LK}=\beta_{KL}$		6.25**			1.25			4.25**		
$\beta_{LF}=\beta_{FL}$		11.54**			4.00**			2.83*		
$\beta_{SK}=\beta_{KS}$		54.38**			4.58**			0.51		
$\beta_{SF}=\beta_{FS}$		3.30			0.03			2.71		
$\beta_{KF}=\beta_{FK}$		13.20**			0.11			0.64		
Wald test of homogeneity restrictions										
$\beta_{LL}+\beta_{LS}+\beta_{LK}+\beta_{LF}+\beta_{LO}=0$		67.24**			48.39**			11.40**		
$\beta_{SL}+\beta_{SS}+\beta_{SK}+\beta_{SF}+\beta_{SO}=0$		16.64**			11.96**			0.92		
$\beta_{KL}+\beta_{KS}+\beta_{KK}+\beta_{KF}+\beta_{KO}=0$		11.17**			18.58**			14.76**		
$\beta_{FL}+\beta_{FS}+\beta_{FK}+\beta_{FF}+\beta_{FO}=0$		40.48**			11.05**			163.06**		

TABLE 2 (Continued)

Stocking density (fry/ha)		<10,000						≥10,000		
Stocking size (in./fry)		2–3			≥4			2–3		
Variables	Parameters	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*
Joint test of symmetry and homogeneity restrictions		5,212.81**			3,237.31			5,177.36**		
Breusch–Pagan Lagrange multiplier test		140.22**			24.93**			111.30**		
Chi^2 test		645.68**			130.78**			974.22**		

Stocking density (fry/ha)		≥10,000					
Stocking size (in./fry)		≥4			All sample		
Variables	Parameters	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*
Translog cost function (ln *C*)							
Constant	β_O	1.164	7.216	15.934	4.758**	1.091	0.877
ln Q_m	α_m	−0.358	2.029	3.675	−0.203	0.355	0.196
ln Q_s	α_s	2.622	1.763	0.799	0.622**	0.203	0.139
0.5 (ln $Q_m)^2$	η_{mm}	0.168	0.330	0.428	0.174**	0.059	0.030
0.5 (ln $Q_s)^2$	η_{ss}	−0.230**	0.103	0.056	−0.026	0.018	0.018
ln Q_m ln Q_s	η_{ms}	−0.102	0.212	0.081	−0.045*	0.027	0.020
ln P_L	β_L	−0.764	0.532	0.303	0.602**	0.113	0.051
ln P_S	β_S	0.570*	0.333	0.278	0.367**	0.074	0.049
ln P_K	β_K	0.266**	0.115	0.140	0.089**	0.014	0.025
ln P_F	β_F	0.796	0.576	0.319	−0.278	0.248	0.067
ln P_O	β_O	0.131	0.331	0.319	0.221**	0.109	0.050
ln P_L × ln P_L	β_{LL}	0.053	0.050	0.013	0.090**	0.017	0.005
ln P_L × ln P_S	β_{LS}	0.003	0.019	0.011	−0.016**	0.007	0.003
ln P_L × ln P_K	β_{LK}	0.012	0.011	0.007	−0.004	0.003	0.002

(Continues)

TABLE 2 (Continued)

Stocking density (fry/ha)		≥10,000					
Stocking size (in./fry)		≥4			All sample		
Variables	Parameters	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*
$\ln P_L \times \ln P_F$	β_{LF}	−0.052**	0.027	0.012	−0.040**	0.015	0.004
$\ln P_L \times \ln P_O$	β_{LO}	−0.016	0.017	0.012	−0.030**	0.007	0.003
$\ln P_S \times \ln P_S$	β_{SS}	0.059*	0.031	0.020	0.054**	0.005	0.004
$\ln P_S \times \ln P_K$	β_{SK}	0.002	0.012	0.009	−0.003**	0.001	0.002
$\ln P_S \times \ln P_F$	β_{SF}	−0.048*	0.026	0.014	−0.010	0.007	0.003
$\ln P_S \times \ln P_O$	β_{SO}	−0.016	0.017	0.015	−0.025**	0.003	0.003
$\ln P_K \times \ln P_K$	β_{KK}	0.024*	0.013	0.009	0.041**	0.004	0.003
$\ln P_K \times \ln P_F$	β_{KF}	−0.015	0.015	0.007	−0.010**	0.002	0.002
$\ln P_K \times \ln P_O$	β_{KO}	−0.024**	0.012	0.009	−0.025**	0.004	0.002
$\ln P_F \times \ln P_F$	β_{FF}	0.153**	0.025	0.018	0.101**	0.027	0.006
$\ln P_F \times \ln P_O$	β_{FO}	−0.038	0.030	0.013	−0.042**	0.009	0.004
$\ln P_O \times \ln P_O$	β_{OO}	0.095**	0.031	0.019	0.122**	0.005	0.004
$\ln Q_m \times \ln P_L$	λ_{mL}	0.150**	0.070	0.035	−0.032**	0.011	0.006
$\ln Q_m \times \ln P_S$	λ_{mS}	−0.051	0.040	0.032	−0.030**	0.008	0.006
$\ln Q_m \times \ln P_K$	λ_{mK}	−0.027*	0.015	0.016	0.002	0.002	0.003
$\ln Q_m \times \ln P_F$	λ_{mF}	−0.078	0.065	0.035	0.044**	0.021	0.008
$\ln Q_m \times \ln P_O$	λ_{mO}	0.006	0.038	0.036	0.016**	0.007	0.006
$\ln Q_s \times \ln P_L$	λ_{sL}	−0.058**	0.026	0.012	−0.022**	0.007	0.004
$\ln Q_s \times \ln P_S$	λ_{sS}	0.014	0.016	0.012	0.012**	0.004	0.004
$\ln Q_s \times \ln P_K$	λ_{sK}	0.009	0.009	0.006	0.001	0.001	0.002
$\ln Q_s \times \ln P_F$	λ_{sF}	0.013	0.011	0.014	0.016**	0.007	0.005
$\ln Q_s \times \ln P_O$	λ_{sO}	0.021**	0.010	0.013	−0.006	0.005	0.004

TABLE 2 (Continued)

Stocking density (fry/ha)		≥10,000					
Stocking size (in./fry)		≥4			All sample		
Variables	Parameters	Coefficients	Bootstrap *SE*	*SE*	Coefficients	Bootstrap *SE*	*SE*
Reg	ν_O	−0.604**	0.056	2.140	1.561**	0.498	0.296
Reg × ln Q_m	Υ_m	0.195**	0.001	0.256	−0.114*	0.066	0.041
Reg × ln Qs	Υ_S	−0.086**	0.003	0.069	0.011	0.033	0.027
Time	λ_O	1.661**	0.453	1.090	0.147	0.194	0.182
Time × ln Q_m	ω_m	−0.120**	0.048	0.115	−0.013	−0.019	0.020
Time × ln Q_s	ω_s	−0.091**	0.010	0.050	−0.004	0.016	0.016
Labor cost share (S_L)							
ln Q_m	λ_{mL}	0.150**	0.070	0.035	−0.032**	0.011	0.006
ln Q_s	λ_{sL}	−0.058**	0.026	0.012	−0.022**	0.007	0.004
ln P_L	β_{LL}	0.053	0.050	0.013	0.090**	0.017	0.005
ln P_S	β_{LS}	0.003	0.019	0.011	−0.016**	0.007	0.003
ln P_K	β_{LK}	0.012	0.011	0.007	−0.004	0.003	0.002
ln P_F	β_{LF}	−0.052**	0.027	0.012	−0.040**	0.015	0.004
ln P_O	β_{LO}	−0.016	0.017	0.012	−0.030**	0.007	0.003
Constant	β_L	−0.764	0.532	0.303	0.602**	0.113	0.051
Fry cost share (S_S)							
ln Q_m	λ_{mS}	−0.051	0.040	0.032	−0.030**	0.008	0.006
ln Q_s	λ_{sS}	0.014	0.016	0.012	0.012**	0.004	0.004
ln P_L	β_{SL}	0.003	0.019	0.011	−0.016**	0.007	0.003
ln P_S	β_{SS}	0.059*	0.031	0.020	0.054**	0.005	0.004
ln P_K	β_{SK}	0.002	0.012	0.009	−0.003**	0.001	0.002
ln P_F	β_{SF}	−0.048*	0.026	0.014	−0.010	0.007	0.003
ln P_O	β_{SO}	−0.016	0.017	0.015	−0.025**	0.004	0.003
Constant	β_S	0.570*	0.333	0.278	0.367**	0.074	0.050

(Continues)

TABLE 2 (Continued)

Stocking density (fry/ha)		≥10,000					
Stocking size (in./fry)		**≥4**			**All sample**		
Variables	**Parameters**	**Coefficients**	**Bootstrap *SE***	***SE***	**Coefficients**	**Bootstrap *SE***	***SE***
Capital cost share (S_K)							
ln Q_m	λ_{mK}	−0.027*	0.015	0.016	0.002	0.002	0.003
ln Q_s	λ_{sK}	0.009	0.009	0.006	0.001	0.001	0.002
ln P_L	β_{KL}	0.012	0.011	0.007	−0.004	0.003	0.002
ln P_S	β_{KS}	0.002	0.012	0.009	−0.003**	0.001	0.002
ln P_K	β_{KK}	0.024*	0.013	0.010	0.041**	0.004	0.003
ln P_F	β_{KF}	−0.015	0.015	0.007	−0.010**	0.002	0.002
ln P_O	β_{KO}	−0.024**	0.012	0.008	−0.025**	0.004	0.002
Constant	β_K	0.266**	0.115	0.140	0.089**	0.014	0.025
Feed cost share (S_F)							
ln Q_m	λ_{mF}	−0.078	0.065	0.035	0.044**	0.021	0.008
ln Q_s	λ_{sF}	0.013	0.011	0.014	0.016**	0.007	0.005
ln P_L	β_{FL}	−0.052**	0.027	0.012	−0.040**	0.015	0.004
ln P_S	β_{FS}	−0.048*	0.026	0.014	−0.010	0.007	0.003
ln P_K	β_{FK}	−0.015	0.015	0.007	−0.010**	0.002	0.002
ln P_F	β_{FF}	0.152**	0.025	0.018	0.101**	0.027	0.006
ln P_O	β_{FO}	−0.038	0.030	0.013	−0.042**	0.009	0.004
Constant	β_F	0.949*	0.588	0.311	−0.131	0.203	0.064
Adjusted R^2		0.985			0.998		
Wald test of symmetry restrictions							
$\beta_{LS} = \beta_{SL}$		0.11			18.21**		
$\beta_{LK} = \beta_{KL}$		17.33**			16.41**		
$\beta_{LF} = \beta_{FL}$		1.66			0.25		

TABLE 2 (Continued)

Stocking density (fry/ha)		≥10,000					
Stocking size (in./fry)		**≥4**			**All sample**		
Variables	**Parameters**	**Coefficients**	**Bootstrap *SE***	***SE***	**Coefficients**	**Bootstrap *SE***	***SE***
$\beta_{SK} = \beta_{KS}$		1.12			42.74**		
$\beta_{SF} = \beta_{FS}$		1.89			2.00		
$\beta_{KF} = \beta_{FK}$		5.38**			2.03		
Wald test of homogeneity restrictions							
$\beta_{LL} + \beta_{LS} + \beta_{LK} + \beta_{LF} + \beta_{LO} = 0$		12.13**			97.07**		
$\beta_{SL} + \beta_{SS} + \beta_{SK} + \beta_{SF} + \beta_{SO} = 0$		2.36			69.35**		
$\beta_{KL} + \beta_{KS} + \beta_{KK} + \beta_{KF} + \beta_{KO} = 0$		26.11**			103.06**		
$\beta_{FL} + \beta_{FS} + \beta_{FK} + \beta_{FF} + \beta_{FO} = 0$		27.74**			193.47**		
Joint test of symmetry and homogeneity restrictions		2,119.14**			12,522.56**		
Breusch–Pagan Lagrange multiplier test		40.88**			350.76**		
Chi^2 test		237.07**			2,323.96**		

Note: *, ** indicates statistical significance at 10 or 5%, respectively.

TABLE 3 Estimated elasticities of inputs demand of the observed farming household clusters

	2–3 in.					≥4 in.				
	Price for					Price for				
Demand for	Labor	Seed	Capital	Feed	Others	Labor	Seed	Capital	Feed	Others
<10,000 (fry/ha)										
Labor	−0.234 (0.048)**	−0.029 (0.033)	0.002 (0.030)	0.260 (0.073)**	0.041 (0.043)	−0.177 (0.035)**	0.063 (0.029)**	0.036 (0.023)	0.077 (0.061)	0.044 (0.062)
Seed	−0.085 (0.097)	−0.712 (0.088)**	0.031 (0.071)	0.471 (0.131)**	0.334 (0.076)**	0.097 (0.045)**	−0.167 (0.092)*	−0.002 (0.047)	0.153 (0.068)**	−0.035 (0.072)
Capital	0.011 (0.144)	0.051 (0.117)	−0.211 (0.151)	0.306 (0.127)**	−0.117 (0.137)	0.189 (0.120)	−0.008 (0.161)	−0.201 (0.168)	0.121 (0.425)	−0.054 (0.218)
Feed	0.195 (0.055)**	0.122 (0.034)**	0.048 (0.020)**	−0.541 (0.106)**	0.214 (0.044)**	0.082 (0.066)	0.106 (0.047)**	0.025 (0.087)	−0.361 (0.108)**	0.191 (0.064)**
Other miscellaneous	0.031 (0.032)	0.087 (0.019)**	−0.018 (0.021)	0.214 (0.044)**	−0.274 (0.033)**	0.048 (0.066)	−0.024 (0.050)	−0.011 (0.045)	0.191 (0.064)**	−0.158 (0.094)*
≥10,000 (fry/ha)										
Labor	−0.291 (0.113)**	0.118 (0.065)*	0.021 (0.007)**	0.043 (0.043)	0.380 (0.027)**	−0.538 (0.222)**	0.140 (0.082)*	0.090 (0.052)*	0.183 (0.118)	0.343 (0.075)**
Seed	0.271 (0.149)*	−0.789 (0.104)**	0.013 (0.016)	0.306 (0.079)**	0.471 (0.056)**	0.249 (0.146)*	−0.410 (0.255)	0.056 (0.101)	0.037 (0.208)	0.288 (0.134)**
Capital	0.122 (0.042)**	0.033 (0.042)	−0.146 (0.114)	0.143 (0.033)**	0.120 (0.116)	0.548 (0.316)*	0.190 (0.345)	−0.307 (0.378)	0.026 (0.479)	−0.236 (0.327)
Feed	0.018 (0.018)	0.055 (0.014)**	0.010 (0.002)**	−0.141 (0.020)**	0.329 (0.009)**	0.099 (0.064)	0.011 (0.063)	0.002 (0.043)	−0.217 (0.065)**	0.324 (0.074)**
Other miscellaneous	0.159 (0.011)**	0.086 (0.010)**	0.008 (0.008)	0.329 (0.009)**	−0.311 (0.016)**	0.186 (0.041)**	0.088 (0.041)**	−0.021 (0.029)	0.324 (0.074)**	−0.356 (0.079)**

Notes: *, ** indicates statistical significance at 10 or 5%, respectively. Standard errors, calculated using the delta method, are in parentheses.

TABLE 4 Estimated Allen partial elasticities of substitution of the observed farming household clusters

	2–3 in.					≥4 in.				
	Price for					Price for				
Demand for	Labor	Seed	Capital	Feed	Others	Labor	Seed	Capital	Feed	Others
Stocking density <10,000 (fry/ha)										
Labor	−0.951 (0.194)**	−0.345 (0.398)	0.046 (0.619)	0.793 (0.230)**	0.126 (0.129)**	−0.629 (0.140)**	0.347 (0.169)**	0.672 (0.436)	0.293 (0.221)	0.171 (0.237)
Seed		−8.339 (1.045)**	0.602 (1.391)	1.436 (0.403)**	1.021 (0.232)**		−0.912 (0.474)*	−0.048 (0.952)	0.582 (0.270)**	−0.135 (0.285)
Capital			−4.089 (2.911)	0.934 (0.387)**	−0.359 (0.411)			−3.721 (3.428)	0.462 (1.803)	−0.208 (0.809)
Feed				−1.652 (0.329)**	0.654 (0.139)**				−1.375 (0.454) (0.517)**	0.729 (0.294)**
Other miscellaneous					−0.837 (0.105)**					−0.602 (0.367)
Stocking density ≥10,000 (fry/ha)										
Labor	−1.463 (0.574)**	1.362 (0.741)*	0.614 (0.208)**	0.092 (0.091)	0.800 (0.061)**	−2.338 (0.986)**	1.106 (0.655)*	2.433 (1.378)*	0.442 (0.288)	0.827 (0.178)**
Seed		−9.073 (1.203)**	0.386 (0.489)	0.643 (0.161)**	0.989 (0.123)**		−3.234 (2.058)	1.499 (2.620)	0.090 (0.556)	0.693 (0.339)**
Capital			−4.311 (3.283)	0.300 (0.073)**	0.252 (0.241)			−8.245 (9.864)	0.062 (1.080)	−0.567 (0.769)
Feed				−0.292 (0.041)**	0.692 (0.021)**				−0.552 (0.155)**	0.780 (0.175)**
Other miscellaneous					−0.653 (0.034)**					−0.858 (0.188)**

Notes: *, ** indicates statistical significance at 10 or 5%, respectively. Standard errors, calculated using the delta method, are in parentheses.

TABLE 5 Product-specific cost elasticities, marginal costs, economies of scale, and scope of the observed farming household clusters

Stocking density (fry/ha)	Stocking size (inch/fry)	Cost elasticities: Milkfish	Cost elasticities: White shrimp	Milkfish: Marginal cost	Milkfish: Average cost	Milkfish: Scale economies (SE)	Milkfish: Chi^2 test (H_0: SE = 1)	Overall scale economies (OSE)	Chi^2 test (H_0: OSE = 1)	Overall scale economies of producing areas: Kaohsiung and Pingtung	Overall scale economies of producing areas: Tainan, Chiayi, and Yunlin	Economies of scope
<10,000	2–3	1.033 (0.118)**	0.011 (0.029)	110.49 (12.618)**	106.95 (12.265)**	0.968 (0.110)**	0.52 [0.460]	0.957 (0.094)**	1.29 [0.257]	0.933 (0.105)**	0.957 (0.092)**	0.019 (0.067)
	≥4	0.966 (0.081)**	−0.008 (0.027)	98.59 (8.273)**	102.04 (8.511)**	1.035 (0.084)**	0.51 [0.473]	1.043 (0.070)**	0.66 [0.417]	0.762 (0.040)**	1.096 (0.078)**	0.014 (0.081)
≥10,000	2–3	0.897 (0.045)**	0.033 (0.019)*	61.65 (3.155)**	68.67 (3.246)**	1.114 (0.057)**	6.53 [0.011]**	1.075 (0.054)**	3.24 [0.071]*	1.024 (0.057)**	1.221 (0.157)**	0.039 (0.048)
	≥4	0.731 (0.125)**	−0.080 (0.047)*	57.30 (9.824)*	78.32 (10.107)**	1.367 (0.234)**	4.22 [0.039]**	1.536 (0.355)**	5.71 [0.016]**	1.451 (0.307)**	1.723 (0.448)**	−0.160 (0.194)
Total		1.019 (0.042)**	0.024 (0.013)*	83.86 (3.535)**	82.26 (3.436)**	0.981 (0.041)**	0.68 [0.408]	0.958 (0.037)**	4.58 [0.032]**	1.017 (0.044)**	0.921 (0.042)**	−0.020 (0.031)

Notes: Estimates based on the coefficients in Table 2. Standard errors, calculated using the delta method, are in parentheses and *p*-values in brackets. ** and * significant at 5 and 10%, respectively.

TABLE 6 Estimation result of robust linear regression between milkfish production outputs and specific scale efficiency for scale efficiency milkfish farmer

Variables	Coefficients	*SE*	*t*	*p* > |t|
High-density stocking of high-sized fry				
Q_i	−0.752	0.207	−3.63	0.001
Constant	2.813	0.263	10.67	0.000
High-density stocking of low-sized fry				
Q_i	−0.246	0.020	−12.06	0.000
Constant	1.448	0.024	57.94	0.000

significantly higher reductions in average costs than in Kaohsiung and Pingtung. The specific product scale efficiency value of milkfish can be derived from the common values of the cost elasticity estimation of individual milkfish and white shrimp. The scale efficiency value of the high-density stocking of small or large fry is larger than 1 and is significantly different from one. Thus, milkfish production has scale efficiency. Therefore, in the high-density stocking of small and large milkfish fry, the average production cost can be reduced by increasing the milkfish output. As the scale efficiency value of white shrimp is less than 1, the production has scale efficiency.

Multiple output cost functions offer the opportunity to determine cost complementarity among different outputs, and estimates for scale efficiency by cluster are statistically insignificant, ruling out cost complementarity in milkfish polycultures with white shrimp. When the specific scale efficiency (SE) value of milkfish is 1, the farmer's output reaches the minimum efficient scale (MES), and the average cost of the farmer reaches the lowest level. To assess the MES, the linear relationship between milkfish production outputs and specific scale efficiency should be estimated, as shown in Equation (8):

$$\mathrm{SE}_i = \rho_0 + \rho_1 Q_i + \varepsilon_i \tag{8}$$

where SE_i is the specific scale efficiency, Q_i is the production quantity in farmer *i*, and ε_i is an error term. To minimize the effect of outliers, we performed an estimation using a robust linear regression model rather than an ordinary least squares model. The estimation results are shown in Table 6, and all the estimated coefficients are statistically significant at a significance level of 5% or less. To estimate the MES, we substituted the estimated coefficients in Table 6 into Equation (8) and calculated Q_i when SE_i became 1. For scale-efficient milkfish farmers, the MES production output for high-density stocking of large fry amounts to 24,109 kg/ha. For high-density stocking of small fry, the MES production output amounts to 18,211 kg/ha.

4 | DISCUSSION

The findings of this study show that the specific product scale efficiency value of high-density stocking of small or large milkfish fry is larger than 1 and statistically significant, implying that the production of the high-density stocking with small or large milkfish has scale efficiency. As such, farmers can reduce the average cost of culture by expanding the milkfish production scale (Dey, Paraguas, Bimbao, & Regaspi, 2000; Golez, 1995; Nunoo, Asamoah, & Osei-Asare, 2014; Reddy, Reddy, Sontakki, & Prakash, 2008; Tho, Vromant, Hung, & Hens, 2008; Yeh, Huang, Lee, & Schafferer, 2017). This result coincides with prior findings that show that scale efficiency can be achieved by expanding the production scale. In addition, the study found that the production of low-density stocking of small or large milkfish fry does not exhibit scale efficiency. Thus, farmers are not advised to expand the scale of production to reduce costs.

The own-price elasticity of input factors such as labor, fry, capital, and feed of the four observed clusters is lower than 1, implying that the farmers' input factor use is rigid when the factor price changes. The fry input factor of high-density stocking of small milkfish fry has the highest own-price elasticity at −0.789. That is, farmers are sensitive to variations in fry prices. Thus, governments are advised to provide market information on fry stockings that could help farming households adjust their stocking quantity.

The feed factor of high-density stocking of small fry has a relatively low own-price elasticity. As such, the feed factor use has the highest rigidity when the milkfish feed price rises, and farmers cannot reduce the feed input expenditure when the feed price rises. Feed costs account for up to 51.1% of the total costs, and farmers are thus confronted with very high feed expenditures. As to reduce breeding costs, the government can assist in the development of high-protein substitutes for fish meal, such as plant-based proteins, and the use of probiotics to ferment agricultural by-products.

The findings of this study show that for any additional milkfish output of 1 kg, the feed input must be increased by 2.33 kg, which is significantly more than the average feed conversion ratio of aquatic livestock of 1.6 (Fry, Mailloux, Love, Milli, & Cao, 2018). Farmers can adopt small-quantity multiple-time feeding and judge the satiety of fish according to the water splashing and the swimming behavior when the fish are rushing for food after the feed spray. Simultaneously, attention must be given to weather conditions, fish growth, and water quality to allow effective and efficient feeding. More specifically, feed should be increased under the following conditions: clear weather, extensive growth, absence of disease, clean water, and sufficient dissolved oxygen. Meanwhile, the amount of feed should be reduced, or feeding should be avoided in case of bad weather conditions, disease, poor water quality, and insufficient dissolved oxygen.

Many studies have found substitutability among culture input factors (Guttormsen, 2002; Huang, Lee, & Sun, 2013; Salvanes, 1993). The findings of this study show that fry and labor of high-density stocking of small fry exhibit comparatively higher substitutability because of rising labor costs. That is, farmers confronted with wage increases may not be able to reduce their labor input. However, increasing stocking density may result in higher profits and subsequently mitigate the losses incurred by higher wages. This approach illustrates the scope of labor input management and explains the practice of excessive fry use. This finding coincides with prior research concluding that labor and fry of high-density stockings have relatively higher substitutability (Yeh et al., 2017).

The labor and capital of high-density stockings of large fry exhibit relatively high substitutability. As such, farmers opting for larger fry will utilize more capital and equipment, such as waterwheels, water quality monitoring equipment, and automatic feeders, and are likely to increase the capital equipment input as a substitute for wage increases. The fry and feed of low-density stocking of small fry have relatively high substitutability. This result is consistent with prior research, which concluded that a decrease in stocking density could be compensated by an increase in feed input to provide better management for smaller ponds (Chiang et al., 2004).

Polycultures of milkfish and shrimp species have ecological and economic benefits (Lalramchhani et al., 2019). The findings of this study show that polycultures of milkfish and white shrimps with low- and high-density stocking of small and large milkfish fry do not exhibit cost complementarity, which would help reduce the culture cost. However, to minimize the risk of losses due to low fish prices and high breeding costs, farmers prefer milkfish polycultures with highly profitable white shrimp.

Milkfish farmers in Taiwan often release 60 to 80 times more milkfish than white shrimp fry into their polycultures and maintain a constant ratio throughout the culture period. When the milkfish-stocking amount is too high, the feed will be excessive, and there will be residual feed, excrement, and organic matter impacting the water quality, adversely affecting the growth of shrimp species. The findings of this study also show that in the observed polycultures of high-density stocking of small or large milkfish fry, the stocking density of white shrimp per hectare is rather high (about 730,000–840,000 fry per hectare), but the survival rate of white shrimp is relatively low (10–11%). Although white shrimp help improve the water quality of milkfish polycultures, shrimp species are also reported to have negative ecological impact on the aquaculture activity itself

(Jamerlan et al., 2014; Jaspe et al., 2011; Lalramchhani et al., 2019). However, several other studies conclude that increases in the stocking density of white shrimp do not significantly affect the survival rate (Eldani & Primavera, 1981; Junior, da Azevodo, Pontes, & Henry-Silva, 2012). Therefore, farmers stock small or large-sized milkfish fry at high density. In order to avoid reductions in the water quality and the survival rate of white shrimp, farmers practicing high-density stocking of small or large milkfish fry are advised to strictly control the stocking density of white shrimp and to minimize the risk of excessively high stocking densities by stocking white shrimp in batches.

5 | CONCLUSIONS

This study applies a translog cost function model to analyze the production scale economy, cost complementarity, and input–input demand of Taiwanese milkfish farmers. The sampled households were divided into four clusters according to the milkfish stocking density and fry stocking size. This study found that high-density stocking (≥10,000 fry/ha) of small or large milkfish fry have economies of scale overall. More specifically, the largest OSE value (1.536) is found in cultures with high-density stockings of large fry. Therefore, farmers can reduce the average culture cost by expanding the milkfish production scale. Governmental agencies may assist the farming industry in obtaining low-interest loans, developing processed food products, and in diversifying sales channels so as to provide incentives to farming households to increase stocking density and achieve economies of scale in breeding. High-density stocking households of small fry have a higher own-price elasticity of fry in terms of input factor use. Thus, farmers are sensitive to fry price variations. Moreover, labor and capital exhibit the highest substitutability. As such, farmers tend to increase capital inputs to mitigate the effects of wage increments. Low-density stocking households of small fry, fry, and feed are substitutes. Thus, the feed input may be increased to deal with increases in fry prices. In terms of production, the four observed clusters do not exhibit cost complementarity. Moreover, the survival rate of white shrimp in high-density stocking milkfish polycultures is relatively low. It is thus recommended to strictly control the stocking density of white shrimp and to minimize the risk of excessively high stocking densities by stocking white shrimp in batches.

ORCID

Jie-Min Lee https://orcid.org/0000-0003-3350-3176

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APPENDIX A.

TABLE A1 Price and quantity of input factors

Item	Price	Quantity/remarks
Fry cost		
Milkfish Fry	2-in. fry: NT$ 3 per individual 3-in. fry: NT$ 4 4-in. fry: NT$ 5 5-in. fry: NT$ 7 6-in. fry: NT$ 8 7-in. fry: NT$ 11 8-in. fry: NT$ 15	Actual quantity depends on the market price and expected harvesting time. 2-in. fry: 16,000 individuals/ha 3/4-in. fry: 12,000 individuals/ha 5/6-in. fry: 10,000 individuals/ha 7/8-in. fry: 8,000 individuals/ha
White shrimp fry	NT$ 0.0033 per individual	800,000 individuals/ha
Feed/fertilizer cost		
Fish feed	NT$ 450–500 per bag (30 kg)	Fish feed per hectare and culture period (9 months): 20,000 kg
Fertilizer	NT$ 3,000 per bag (10 kg)	Fertilizers mainly nutrients, such as probiotics: 10–20 kg Apply once or twice per month
Plowing/tilling of bottom soil	Rent an excavator to plow the bottom soil: 1–2 working days/ha; NT$ 10,000 – 20,000	After each harvest season, the fishpond must be disinfected and maintained. The pond floor must be exposed to sunlight and disinfected/maintained by using tea seed meal (300–600 kg/ha) and lime (400–800 kg/ha). Total pond cost: approximately NT$ 20,000–30,000 per hectare
Pond disinfection and maintenance	1. Tea seed meal: NT$ 380–460 per bag (30 kg) 2. Lime: NT$ 75–100 per bag (40 kg)	
Water and electricity	NT$ 5,000–22,000 per month and hectare (culture period 9 months)	The water quality of the fishpond and the climate may change daily, it is thus necessary to use paddle wheel aerators and water pumps to adjust for changes in water quality and salinity
Labor Cost (harvesting, pond cleaning)	NT$ 1,000–1,200 per casual worker and day	1. Milkfish harvesting and pond cleaning: 22 workers 2. White shrimp harvesting: 11 workers
Maintenance and administration	NT$ 20,000–50,000 per hectare and culture period (9 months)	
Equipment and depreciation charges	NT$ 15,000 per hectare and culture period (9 month)	Equipment needed per hectare: 1 bamboo raft 7 paddle wheel aerator 2 water pumps 1 workshop

Note: NT$ = New Taiwan Dollar, 1US$ = 30.08NT$.