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OPTIMAL INPUTS IN PANGASIUS FARMING IN THE MEKONG DELTA, VIETNAM

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Abstract. Pangasius farming has developed rapidly and significantly contributed to the Vietnamese economy. However, a decline in the profit margin of the growing-out farms due to an increase in production costs has been frequently reported. In order to give better guidance to farmers in using input efficiently and avoiding waste in production costs, this study measures cost efficiency and estimates the optimal inputs of pangasius farming in the Mekong Delta, Vietnam using meta-frontier data envelopment analysis. The results show that pangasius farms were wasting inputs. There is scope to improve the cost efficiency of pangasius farms. Technical inefficiency is found to be an important cause of cost inefficiency. Moreover, the differences in the efficiency and the optimal level of inputs are substantially large between farms and groups. Pangasius farms getting technical advice are statistically more efficient than those not. However, farms signing contracts with buyers are less statistically efficient than those not. Farms impacted by climate change are also less efficient than those not but the differences between groups are not statistically significant. These results can be useful for the farmers, local authorities as well as extension services to improve the cost efficiency of the sector. The optimal level for each input should be targeted in providing technical advice. Information on rights and obligations in trading contracts should be inserted in extension services and training courses for farmers.

Keywords: optimal inputs, efficiency, meta-frontier data envelopment analysis, pangasius farming

1 Introduction

Pangasius farming has developed rapidly and significantly contributed to the Vietnamese economy [1, 2]. More than 75% of the global pangasius production was from Vietnam [1]. Vietnamese pangasius products were exported to more than 149 countries in the world [2]. In 2019, its export value was 2.2 billion USD [2]. However, together with the rapid growth of the sector, a decline in the profit margin of the growing-out farms due to an increase in production costs has been frequently reported [3, 4]. Especially, prices of inputs have been reported to increase sharply since the emergence of the Covid-19 pandemic because of constrictions in supply [5]. This also constrains the future development of the sector [3]. Therefore, it is important to allocate and use input efficiently. A number of previous studies have measured technical efficiency [6, 7] and economic efficiency [4] of the sector and found that pangasius aquaculture in

Vietnam was technically and economically inefficient. Nevertheless, none of them have computed the optimal inputs that pangasius farms should use to be efficient.

Many determinants were also identified to improve efficiency of the sector [4, 6–8]. For example, besides some of the farmers' characteristics, Anh Ngoc et al. [6] investigated the correlation between farm location and technical inefficiency. Tho et al. [4] followed the line of many previous papers on the same sector in other countries to check the effect of farm size on the economic efficiency of pangasius farms in Vietnam. Nonetheless, no studies have considered other elements which can be directly related to the production such as source of fingerlings and which can change the farming practice such as technical advice and/or signing contracts with buyers.

At the same time, the water pollution due to nutrient emission loading from farms has been reported as one of the most common environmental concerns in the pangasius farming sector in Vietnam [9–11]. It was stressed that using inputs efficiently can also lead to possible further reductions in nutrient emissions [9]. However, the extent to which inputs can be reduced has not been mentioned.

Therefore, to fill the gap and give better guidance to farmers in using input efficiently and avoiding waste in production costs, this paper uses meta-frontier data envelopment analysis to measure cost efficiency and estimate the optimal level of inputs in pangasius farming in the Mekong Delta, Vietnam. The paper will be useful for the farmers, local authorities as well as extension services in improving the cost efficiency of the sector.

2 Research Methodology

2.1 Meta-frontier data envelopment analysis

In order to see the differences in efficiency scores and optimal inputs between groups in pangasius farming in the Mekong Delta, Vietnam, this study uses meta-frontier data envelopment analysis instead of conventional data envelopment analysis (DEA) proposed by Farrel [12]. This is because the efficiency measures defined by conventional data envelopment analysis only make sense if all farms in the sample have the same technology set [13] while the technology in pangasius farming in the Mekong Delta can be different due to the difference in production conditions.

Meta-frontier data envelopment analysis (meta-frontier DEA) is a non-parametric method introduced by O'Donnell et al. [14]. Meta-frontier data envelopment analysis is useful in comparing efficiency scores between groups when the technology or production conditions are different between farms. This method is based on the conventional data envelopment analysis which was first proposed by Farrel [12]. The production frontier is built by the most efficient input-output combinations within the observed data. The production possibilities of groups of farms having the same production conditions or using sub-technologies are group frontiers. The meta-frontier is the boundary of the unrestricted condition or technology set [14]. Consider a set of farms producing M outputs $y \in R_{+}^{M}$ by N inputs $x \in R_{+}^{N}$. The production set will be:

$$T = \{(xy) \in R_{+}^{N+M} | x\ can\ produce\ y\} \tag{1}$$

Nowadays, prices of inputs have been reported to increase continuously and sharply, using inputs efficiently is the objective of the paper. Therefore, the input-oriented DEA model for measuring efficiency is used in this paper. The input-oriented DEA model for cost minimization is as follows:

$$C(y, w) = min\{w'x(x, y) \in T\} \tag{2}$$

Where w is the prices of inputs. The input-oriented cost efficiency (CE) is the ratio of the minimum cost and the observed cost:

$$CE = w'x_{CE}/w'x \tag{3}$$

Where $w'x_{CE}$ is the minimum cost. The cost of the observed input vector is $w'x$. The optimal input (x_{CE}) is the level of input that yields the minimum cost ($w'x_{CE}$).

Cost efficiency can also be defined by the combination of technical efficiency (TE) and allocative efficiency (AE) [12]. In which, technical efficiency is the ability of a farm in producing a maximum output from a given set of inputs and available technology with output orientation or producing a given amount of output from the minimum number of inputs with input orientation. The input-oriented technical efficiency (TE) is:

$$TE(y, x) = \min_{\theta} \{\theta | (\theta x, y) \in T\} \tag{4}$$

Where θ is the technical efficiency score.

Allocative efficiency is the ability of a farm in using the inputs in optimal proportions, given their respective prices. The input-oriented allocative efficiency is the ratio between cost efficiency and technical efficiency:

$$AE = \frac{CE}{TE} \tag{5}$$

The group frontiers and meta-frontier used to estimate cost efficiency and optimal inputs are illustrated in Figure 1.

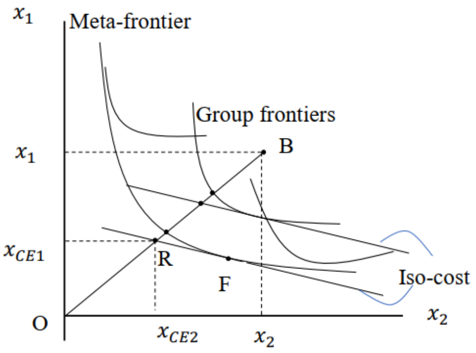

Figure 1. The group frontiers and meta-frontier in estimating cost efficiency and optimal inputs

In this figure, F is cost-efficient farm because F farm is on both meta-frontier (technically efficient) and iso-cost line (allocative efficient). The actual inputs of farm B are x_1' and x_2'. Farm B is both technically and allocative inefficient because it is neither on the meta-frontier nor on the iso-cost. Therefore, farm B is cost inefficient. The projected point for farm B to be meta cost efficient is R. The cost efficiency *(CE)* of farm B with respect to meta-frontier is:

$$CE = OR/OB \tag{6}$$

The optimal inputs for farm B to be cost efficient are x_{CE1}^* and x_{CE2}^*. These optimal inputs are calculated based on the DEA frontier and the weights (λ) which are identified by the linear combination of peers for farm B. Input changes and cost changes are then calculated as follows:

Input changes = optimal inputs (x_{CE}) - actual inputs (x)

Cost changes = optimal inputs (x_{CE}) * price of inputs (w) - actual inputs (x) * price of inputs (w) (7)

Moreover, in order to correct the bias estimators which are caused by the deterministic nature of the non-parametric method, this study uses the meta-frontier data envelopment analysis with smoothed bootstrap procedure introduced by Simar and Wilson [15].

2.2 Data and variables

In Vietnam, Mekong Delta is the main region cultivating pangasius. An Giang, Can Tho, and Dong Thap are the top provinces in pangasius farming in this area. These provinces accounted for more than 75% of the total pangasius production [16]. Pangasius farms in these provinces, therefore, were randomly visited and face-to-face interviewed in 2021. In total, data of 195 farms were collected using a structured questionnaire. The interviews include information on inputs and output of the pangasius production cycle for the period 2020–2021. In pangasius farming, feed costs account for more than 80% of the production costs [3, 6]. Labor and fingerling are the two next important expenditures in the production costs [6]. Therefore, fingerling (tons), feed

Table 1. Description of the variables used in the meta-frontier data envelopment analysis model

Variables	Description	Unit
Output	Total quantity of pangasius produced	Tons
Inputs		
Fingerling	Total quantity of pangasius fingerling cultivated	Tons
Feed	Quantity of feed	Tons
Labor	Total working hours used for cultivating pangasius	Man-hours
Prices of inputs		
Fingerling	Price per ton of pangasius fingerling cultivated	USD/Ton
Feed	Price per ton of feed	USD/Ton
Labor	Price per working hours used for cultivating pangasius	USD/Man-hour

(tons), and labor (man-days) are used as the main inputs in measuring cost efficiency in this study. The fish yield (tons) is used as the output. The description of variables used in the meta-frontier data envelopment analysis model is shown in Table 1. The descriptive statistics of these variables are shown in Table 2.

Table 2 shows a large range in inputs used and output produced between pangasius farms. This might be due to the difference in producing scale, technology, and/or producing conditions. On average, a hectare of pangasius farm produced 499.09 tons of production using 21.9 tons of fingerlings, 816.8 tons of feed, and 1,053 man-days. In order to produce one ton of output, pangasius farmers used 0.047 tons of fingerlings, 1.63 tons of feed, and 2.3 man-days.

Table 2. Descriptive statistics for inputs and output used in meta-frontier data envelopment analysis model

	Per hectare				**Per ton of output**			
	Mean	**Min**	**Max**	**Median**	**Mean**	**Min**	**Max**	**Median**
Inputs								
Fingerling	21.88	1.00	250.00	20.83	0.046	0.003	0.517	0.046
Feed	816.82	240.00	6,857.14	744.00	1.63	1.38	2.96	1.60
Labor	1,053.27	179.69	8,000.00	857.14	2.30	0.05	14.29	1.96
Prices of inputs								
Fingerling	981.27	701.75	1,535.09	1,008.77				
Feed	499.09	428.99	614.04	508.77				
Labor	8.96	7.02	12.28	8.77				
Output	499.09	150.00	4285.71	470.77	1	-	-	-

3 Results and discussion

3.1 Cost efficiency

Table 3 summarizes the cost efficiency scores of pangasius farms in the Mekong Delta, Vietnam. The results show a large range in the estimated efficiency among farms. On average, cost efficiency scores varied from 0.4930 to 0.9864. The mean cost efficiency score is 0.8651. It implies that pangasius farms in the Mekong Delta are cost inefficient. Compared to the best practice farms, they were producing 13.49% higher production costs. Information on the extent to which inputs can be saved to move to the frontier will be mentioned in the next section (Optimal inputs). The result of the Spearman test for the correlation in Table 4 shows that the cost inefficiency in pangasius farming was mainly due to technical inefficiency. The mean technical efficiency score of pangasius farms was 0.8703 (Table 3). It means that, on average, farms could reduce their current input by 12.97% without reducing output. This result is in line with the findings reported by Nguyen et al. [7]. Anh Ngoc et al. [6] showed a larger room for technical inefficiency (25%) using the Russell-type directional distance function. For this method, the 25% of technical inefficiency score was interpreted as the percentage by which output can be increased and input can be reduced [6].

In order to give better guidance to farmers in improving efficiency, this paper looks at the differences in efficiency scores between different groups. Table 5 compares efficiency scores of pangasius farms in the Mekong Delta by group based on different categories such as getting technical advice, buying fingerlings from local hatcheries, and signing contracts with buyers to sell products.

Currently, pangasius farms often buy fingerlings from local hatcheries or/and outside hatcheries. It might determine the mortality during the production process because the quality

Table 3. Cost efficiency scores with meta-frontier data envelopment analysis with bootstrap

	Mean	Min	Max	Median
TE	0.8703	0.4871	0.9805	0.8814
AE	0.9940	0.6889	1.1152	0.9970
CE	0.8651	0.4930	0.9864	0.8750

Table 4. Spearman's rank test for the correlation between efficiency measures

	TE	AE	CE
TE	1		
AE	-0.067	1	
CE	0.914***	0.258***	1

*** Indicate significance at 1 % levels

of fingerlings can also depend on the transporting distance from hatcheries to growing-out farms [17]. This impacts on the production. Therefore, pangasius farms buying fingerlings from local hatcheries were expected to be more efficient than those buying fingerlings from outside hatcheries. Table 5 shows that a group of farms buying fingerlings from local hatcheries was a bit more efficient than those not. Although the differences between the average technical efficiency and cost efficiency scores of the two groups were quite small (0.8705 and 0.866 for farms buying fingerlings from local hatcheries and 0.871 and 0.861 for farms buying fingerlings from hatcheries in other provinces), they were statistically significant.

During the production process, many pangasius farmers are frequently advised on how to conduct a good practice, how to prevent and treat disease, and sometimes being updated the market information. This is a free service given by processing enterprises, veterinary medicine and/or feed delivery companies when they do advertisement and/or promotion programs. Such service can be useful for farmers in changing their farming practices on time to solve problems and thereby improving production. Therefore, farms getting technical advice were expected to be more efficient than those not. And the results in Table 5 show that, on average, the technical, cost, and allocative efficiency for pangasius farms getting technical advice from extension officers, veterinary medicine, or food delivery companies (0.882, 0.878, and 0.995, respectively) were greater than those not (0.855, 0.848, and 0.992, respectively). Moreover, the results of Kruskal Wallis tests for the meta-frontier efficiency scores show that there were statistically significant differences in efficiency between these two groups of pangasius farms.

The link between seafood processing enterprises and pangasius farms can be reinforced by signing contracts either from the beginning of the production cycle or just before harvesting because this can help farmers ensure stable sales and price of output. Farms signing contracts, therefore, were expected to be more efficient than those not. However, the results in Table 5 show that groups signing contracts were less efficient than those not. Nevertheless, the differences in cost efficiency and technical efficiency scores were not statistically significant. Only the difference in allocative efficiency between groups was statistically significant.

Mekong Delta has been known as one of the susceptible regions to climate change in Vietnam [7]. Pangasius farming in this area, therefore, has been impacted by climate change [8, 18]. According to pangasius farmers, severe and prolonged droughts, floods, and unusual weather degrade the water environment and adversely impact the health of farmed fish. This can lower the resistance of pangasius to disease and thereby reduce the output quality and productivity. The increase in disease outbreaks in pangasius farming was claimed mainly due to climate change [8]. Many farms experienced a decrease in the quality of pangasius products and productivity due to climate change. Nguyen et al. [18] found that upstream and midstream pangasius farms experienced larger inundation areas and longer flood periods while downstream farms faced higher salinity levels for a longer period. Au et al. [8] reported

Table 5. Differences in efficiency scores between groups and Kruskal-Wallis test

	TE	**AE**	**CE**
Technical advice (n = 114)	0.882***	0.995***	0.878***
Not (n = 81)	0.855	0.992	0.848
Local hatcheries (n = 172)	0.871***	0.994	0.866***
Outside hatcheries (n = 23)	0.871	0.989	0.861
Contract (n = 31)	0.838	0.988***	0.828
Not (n = 164)	0.876	0.995	0.872
Climate change (n = 57)	0.849	0.986	0.837
Not (n = 138)	0.879	0.997	0.877

*** Indicate significance at 1 % levels

substantial differences in technical efficiency scores between farms and between different types of climate change. This study, therefore, expected that farms reporting to be impacted by climate change are less efficient than those not. Table 5 shows that the group that was not impacted by climate change had greater efficiency scores than the group impacted by climate change. However, the differences in efficiency scores between groups were not statistically significant.

3.2 Optimal inputs

Table 6 reports the optimal inputs that pangasius farms in the Mekong Delta, Vietnam should use per hectare and per ton of output, respectively, to be cost-efficient. The saving costs per hectare and per ton of output to reach a cost-efficient operation on meta-frontier are also presented in the table.

The results in Table 2, 3, 5, and 6 show that pangasius farms in the Mekong Delta, Vietnam were wasting inputs. Compared to the best practice farms, the current production costs could still be reduced by changing inputs used without a change in output. In detail, given input price information, the current amount of fingerling should be reduced by 2.43 tons, feed quantity should be reduced by 100 tons, and labor should be reduced by almost 300 man-days per hectare. Put differently, compared to the target points on the frontier, in order to produce one ton of pangasius product, farms should only use 0.04 tons of fingerling, 1.43 tons of feed, and 1.72 man-days of labor. If such reduction was to be applied, farms would move to the frontier. The estimated savings in the costs of production would be 54,744 USD per hectare or 108.83 USD per ton of output.

The results of input change and cost change by group based on different categories are shown in Table 7. On average, farms getting technical advice should reduce their current inputs per hectare by 8.45% for fingerling, 10.6% for feed, and 27.1% for labor. They, thereby, could save

Table 6. Optimal inputs to be cost efficient for pangasius farming in the Mekong Delta, Vietnam

Per hectare	**Mean**	**Min**	**Max**	**Median**
Optimal inputs				
Fingerling (tons)	19.45	2.38	48.06	19.25
Feed (tons)	717.38	217.62	6,857.14	653.03
Labor (man-days)	755.70	73.73	4,333.33	689.66
Cost changes (USD)	**-54,744.33**	**-380,965.90**	**0**	**-40,770.51**
Fingerling (USD)	-2,719.41	-228,296.60	25,500.26	-1,167.78
Feed (USD)	-49,468.16	-376,843.12	13,608.24	-37,619.38
Labor (USD)	-2,555.11	-34,502.92	3,508.77	-1,659.55
Per ton of output				
Optimal inputs				
Fingerling (tons)	0.040	0.005	0.051	0.045
Feed (tons)	1.43	1.38	1.63	1.42
Labor (man-days)	1.72	0.05	9.90	1.48
Cost changes (USD)	**-108.83**	**-771.15**	**0**	**-92.09**
Fingerling (USD)	-6.52	-472.34	39.52	-2.48
Feed (USD)	-97.31	-734.86	-24.85	-85.20
Labor (USD)	-4.99	-61.61	-7.02	-3.10

46,382 USD of production costs from such a reduction. The saving costs per ton of output would be 96.66 USD if they were to reduce the level of fingerling, feed, and labor per ton of output by 11.37%, 10.56%, and 23.24%, respectively. For those not getting technical advice, the reduction should be 14.26%, 14.2%, and 29.96% per hectare and 15.07%, 13.94%, and 27.91% per ton of output, respectively. The saving costs of farms not getting advice would be 66,685 USD per hectare or 126.17 USD per ton of output if they were to move to the cost frontier.

Farms that were impacted by climate change could reduce their current production costs up to more than 88,000 USD per hectare or 150 USD per ton of output while it was 41,076 USD per hectare or 91.58 USD per ton of output for farms that were not impacted by climate change if they were to move to the frontier. In order to reach the frontier, fingerling, feed, and labor should be reduced by 19.65%, 15.38%, 46.27% per hectare or 24.65%, 14.88%, and 36.33% per ton for farms being impacted by climate change and 5.48%, 10.4%, and 22.88% per hectare or 6.85%, 10.56%, and 20.09% per ton of output respectively for those not.

Farms buying fingerlings from local hatcheries could reduce the current production costs by 54,048 USD per hectare or 109.36 USD per ton of output if they used 11.05% less for fingerling, 12.22% less for feed, and 27.41% less for labor per hectare or 12.94% less for fingerling, 12.27%

Table 7. Input changes to be cost efficient by group for different categories and Kruskal-Wallis test

8.5	**Fingerling change**		**Feed change**		**Labor change**		**Cost change**
Per hectare	**tons**	**%**	**tons**	**%**	**Man-days**	**%**	**USD**
Technical advice (n = 114)	-1.70***	-8.45	-83.37***	-10.60	-285.96	-27.10	-46,382.33***
Not (n = 81)	-3.47	-14.26	-122.16	-14.20	-315.51	-29.96	-66,685.60
Local hatcheries (n = 172)	-2.36	-11.05	-98.16	-12.22	-287.70	-27.41	-54,048.94*
Outside hatcheries (n = 23)	-3.03	-11.67	-109.30	-11.87	-377.00	-34.61	-60,552.24
Contract (n = 31)	-3.69	-14.42	-151.20***	-16.51	-421.50	-38.89	-83,296.96***
Not (n = 164)	-2.20	-10.37	-90.26	-11.30	-278.90	-26.58	-49,749.95
Climate change (n = 57)	-5.88	-19.65	-153.41***	-15.38	-656.04***	-46.27	-88,079.79***
Not (n = 138)	-1.02	-5.48	-77.20	-10.40	-206.88	-22.88	-41,076.60
Per ton of output							
Technical advice (n = 114)	-0.005***	-11.37	-0.17*	-10.56	-0.56	-23.24	-96.66**
Not (n = 81)	-0.007	-15.07	-0.23	-13.94	-0.60	-27.91	-126.17
Local hatcheries (n = 172)	-0.006	-12.94	-0.20	-12.27	-0.57	-24.26	-109.36
Outside hatcheries (n = 23)	-0.006	-12.88	-0.19	-11.80	-0.67	-34.18	-105.59
Contract (n = 31)	-0.010	-19.59	-0.29**	-16.96	-0.80	-39.60	-161.02***
Not (n = 164)	-0.005	-0.12	-0.18	-11.11	-0.55	-23.31	-99.73
Climate change (n = 57)	-0.013	-24.65	-0.25**	-14.88	-0.89**	-36.33	-150.89***
Not (n = 138)	-0.003	-6.85	-0.17	-10.56	-0.46	-20.09	-91.58

Note: *, **, *** indicate the statistical significance at 10%, 5% and 1% levels, respectively.

less for feed, and 24.26% less for labor per ton of output. Farms buying fingerlings from hatcheries in other provinces could save 60,552 USD per hectare or 105.59 USD per ton of output for production costs if they reduced the current level of fingerling, feed, and labor by 11.67%, 11.87%, and 34.61% per hectare or 12.88%, 11.8%, and 34.18% per ton of output, respectively.

The saving production costs would be 83,296 USD per hectare or 161 USD per ton of output for farms signing contracts with buyers while it was almost 49,750 USD per hectare or 100 USD per ton of output for those not if they were to move to the frontier. To be cost efficient, fingerling, feed, and labor should be reduced by 14.42%, 16.51%, 38.89% per hectare or 19.59%, 16.96%, and 39.63% per ton for farms signing contracts with buyers and 10.37%, 11.3%, and 26.58% per hectare or 11.6%, 11.11%, and 23.31% per ton of output respectively for those not.

4 Conclusion

This is the first study using meta-frontier data envelopment analysis to measure cost efficiency performance and identify the optimal inputs of pangasius aquaculture in the Mekong Delta, Vietnam. The findings showed that pangasius farms in the study area were cost inefficient. There are substantial differences in cost efficiency scores between farms and between groups. Such cost inefficiency was primarily caused by technical inefficiency.

Pangasius farms getting technical advice and applying wastewater treatment were found to be more efficient than those not. The farms being impacted by climate change and signing contracts with buyers are less efficient than those not.

These results can be useful for the farmers, local authorities as well as extension services to improve the cost efficiency of pangasius farming. To enhance cost efficiency, pangasius farmers should focus on improving their technical inefficiency by saving inputs. Extension offices, veterinary medicine, or feed delivery companies that provide technical advice to pangasius farmers should target the optimal level for each input in each group. In this way, overusing inputs could be avoided and the costs of production could be reduced. The linkage between farmers and export traders should be strengthened to protect the rights of farmers. At the same time, information about rights and obligations in trading contracts should be provided to farmers through extension services and training courses. Moreover, a further study on climate change adaptation in pangasius farming is needed to better understand how to help farmers mitigate the negative impacts of climate changes, thereby improving economic performance.

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