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Technical Efficiency of Handline Fishers in Region 12, Philippines: Application of Data Envelopment Analysis

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Abstract

Handline fishing is a common method of catching tuna in the Philippines which is a significant tuna producer in the world. It is considered to be more environmentally sustainable than other fishing methods. Despite this, handline fishers are challenged by efficiency issues due to overcapacity resulting from open access to fish resource and counteracting declining stock. This study aimed to measure the technical efficiency of the handline industry in General Santos City, Philippines. Using Data Envelopment Analysis, the levels of production efficiency were estimated. The factors that influence the efficiency of handline fishers were identified using Tobit regression. Findings revealed that there was a large gap between the best and least performing vessels with a varied spread of scores, and there was also a huge frequency of inefficient vessels. Additionally, the factors that appeared to be significant in affecting the efficiency were the number of fishing trips per year, the number of days of stay at sea, radio cost, and costs on consumption. Berthing days and gasoline cost were also found to be approaching significance in affecting efficiency. These results indicate the diversity of input mixes among fleets. Aside from being less profitable, these handline fleets contribute to unsustainability. Thus, choosing the ideal set of inputs is critical in the industry.

Keywords: handline tuna fisheries, technical efficiency, data envelopment analysis

Introduction

Tuna is one marine fish that has received global attention due to its economic importance worldwide (Majkowski, 2007). Thus, countries with access to fishing grounds having rich tuna stocks, such as the Philippines, employ management actions geared towards industry optimisation particularly to address challenges on sustainability due to overfishing caused by overcapacity of

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vessels (World Bank, 2004). These vessels are classified according to capacity: municipal if at most of 3 gross registered tonnage (GRT) and commercial if more than 3 GRT. Based on the Bureau of Fisheries and Aquatic Resources' (BFAR) annual report, municipal fisheries and commercial fisheries, on which tuna production relies, contributed 26.3 % and 21.4 % of tuna production in 2012 respectively. Meanwhile, aquaculture shared 52.4 % of the total fish production. Despite the relatively lower contribution of the municipal and commercial landings, both earned comparatively higher per tonne value of PhP 62,089 (US$ 1,398.56) and PhP 63,218 (US$ 1,424.00) respectively (BFAR, 2014), driven by the high export value and value-adding activities.

The Philippine tuna industry functions significantly in the international trade principally for the yellowfin and bigeye tuna species (ACIAR, 2011). In 2014, tuna led fish export with 117,909 tonnes valued at USD 443,090 or PhP 19,597,882 with commodities categorised into preserved and fresh. Processed tuna reached 93,000 tonnes amounting to almost USD 310 million or PhP 13.7 billion with USA, Canada and Japan as the top destinations. Meanwhile, fresh/chilled/frozen tuna export reached 24,600 tonnes valued at USD 133 or PhP 5.9 billion, the majority delivered to Japan, USA and Indonesia (BFAR, 2014). The bulk of export-quality tuna is landed in General Santos City (GenSan) in the General Santos Fish Port Complex (GSFPC). Inherently, the almost identical trends for tuna at the regional and national levels denote that Region 12, where GenSan is situated, leads the yellowfin and bigeye production in the country. However, handliners who facilitate landings in GSFPC are not limited to those who reside in GenSan but to other provinces as well. Fishing grounds of these handliners also include several locations that are extremely distant from GenSan.

Both commercial and municipal tuna capture fisheries have a preference for handline fishing because of its sustainability (Gaia Discovery, 2011). The availability and affordability of materials and the simplicity of handline construction encourages operators to opt for hook and line. Yellowfin tuna is the most caught tuna species using handline, comprising 72–90 % of the total tuna caught. Handline fishing supports the livelihood of crews of approximately 3,000 vessels. This placed the Philippines on the second spot, after Indonesia, of producers using handline fishing. Despite the handline technique's good performance, GenSan's handline fisheries faces challenges primarily due to catch reduction. Aside from that, threats related to sustainability have also emerged due to catching of juveniles and declining stock biomass (World Wildlife Fund, 2013).

To counteract this threat, handline fishers redevise strategies and increase inputs excessively, which induce inefficiency (Wiyono & Hufiadi, 2014). As a result, input surplus leads to overcapacity and eventually magnifies the problem in declining tuna stock. Furthermore, Aranda et al. (2012) pinpointed overcapacity as a result of open access fishing. Unregulated and indefinite allowable volume of production encourages handliners to capitalise spontaneously on gadgets and equipment as long as it increases productivity. Merely focusing on productivity puts pressure on the available fish stock and increases economic waste (Aranda et al. 2012).

Traditional handline fishing for catching tuna is still widely practised in the country. Although handlining favours environmental sustainability because of its high selectivity (Gaia Discovery, 2011), the inputs utilised in each operation tend to exceed the quantity that satisfies efficiency, making the handlining operation uneconomical. Hence handlining, as a widely used and sustainable technique, needs further assessment towards efficient utilisation. Achieving the optimal capacity of the handline method requires suitable tools, efficient inputs and experienced professional hardliners. Given the fleets' features, this study attempts to verify if excess capacity and inefficiency exist in order to mitigate overcapacity and to provide a foundation for management schemes in the handline industry in GenSan. This study particularly aims to identify the factors affecting the efficiency of the handline fleets unloading in GSFPC. Literature-based methods and outcomes were presented below followed by the discussion of productivity and efficiency results. Then, recommendations pertaining to the ideal set of inputs were made.

Materials and Methods

Sampling design

The unit of analysis used for this study included the decision makers of the fishing operation of the commercial handline vessels, who were boat captains or operators. Due to the nature of their operations, they are not readily accessible. The method applied in data collection was convenience sampling, a non-probabilistic technique that was seen to be appropriate for the research. The handline boat captains/ operators who were included as a sample were only those who unloaded their catch in GSFPC at the time of data collection. Most handline vessels operate at sea for 15 days to a month. Moreover, constraints such as FAD closures, time requirement, and resource limitation limited the number of observations in this study. Therefore, due to these factors, the results could potentially be subject to sample selection bias because of the inability to achieve adequate representation and complete randomness in the sampling.

Empirical model

Gauging efficiency means construction of a frontier as a benchmark to determine firms' individual performance. Two methods are widely used in this estimation namely, stochastic frontier analysis (SFA) and data envelopment analysis (DEA). While both have common goals, the approaches that each of them uses differ. The former applies econometric solutions, whereas linear programming underlies DEA. Furthermore, DEA produces non-parametric models such as constant returns to scale (CRS) and variable returns to scale (VRS) through linear programming methods. Fig. 1 illustrates the CRS and VRS frontiers with the gap as scale efficiency. The VRS eludes the scale efficiencies existing in CRS since not all firms perform at optimal scale. With this, VRS administered the technical efficiency estimation in this study using the formula introduced by Coelli et al. 2005 (Equation 1). This paper uses DEA in the estimation of efficiency scores.

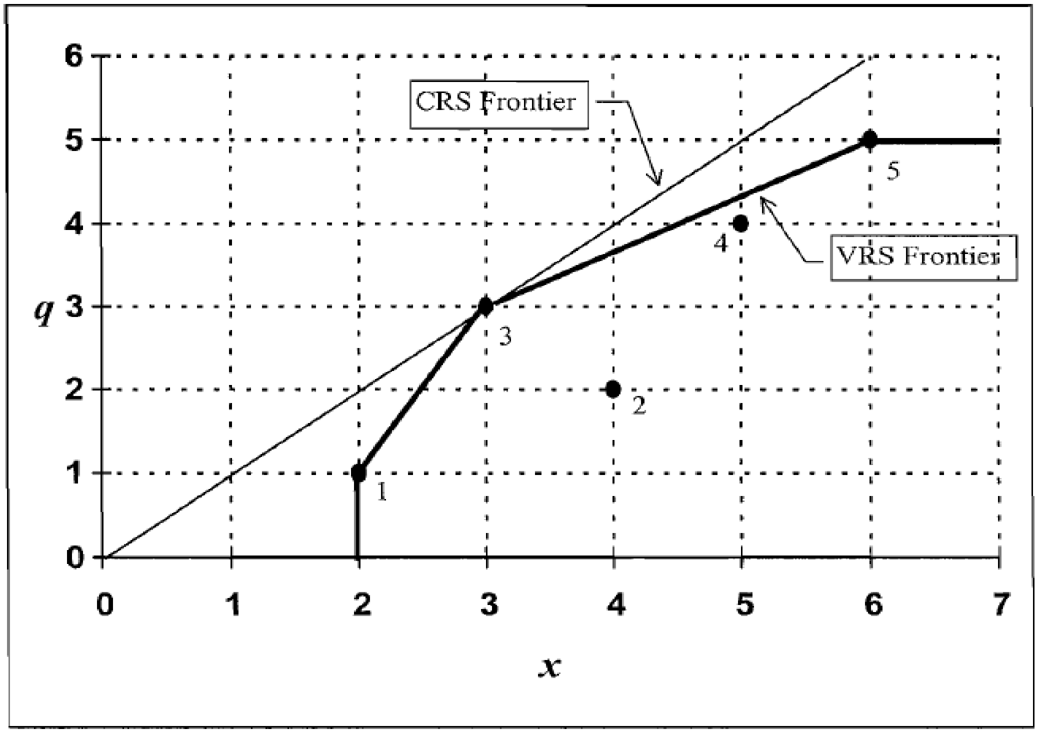

Fig. 1. CRS and VRS frontier (Coelli et al. 2005)

$$
\begin{aligned}
&\min_{\theta,\lambda}\theta,\\
&st - q_i + Q\lambda \geq 0,\\
&\theta\, x_i - X\lambda \geq 0,\\
&I1'\lambda = 1\\
&\lambda \geq 0
\end{aligned}
\qquad \textit{(Equation 1)}
$$

With N inputs, M outputs and I firms; θ is the scalar or efficiency score of the i^th^ firm that ranges from 0 to 1. This value is subject to four constraints. The first restricts the sum of two terms, $-q_i$ and $Q\lambda$, to be positive where q_i is $Mx1$ vector of outputs of i^{th} firm, Q is MxI output matrix, and λ is $Ix1$ vector of constraints with positive values. The next limitation requires θx_i where x_i is $Nx1$ vector of inputs of i^{th} firm to be greater than $X\lambda$ where X is NxI input matrix. Lastly, the convexity restriction $I1'\lambda = 1$, the distinct feature of VRS that avoids scale efficiencies intervention, appears to guarantee that firms are compared to other units with homogenous size. The DEA will compare every observation with all other samples. Upon locating the best unit or the frontier (the points lying in VRS frontier in Fig. 1), technical efficiency of the remaining units is identified relative to the frontier. Table 1 shows the factors considered in the estimation of efficiency levels using DEA.

Table 1. Variables included in the data envelopment analysis and their description

	Variable Name	Variable Description
Y	Output	Volume of tuna caught in kilograms per trip
X_1	Equipment cost	Depreciated cost of equipment used which includes GPS devices, compass and buoy/s in PHP
X_2	Effort days	Number of days while at sea per fishing trip
X_3	*Pakura* (small boats)	Number of smaller boats hosted by a mother handline boat used per fishing trip
X_4	Food cost	Cost associated with the food consumption per trip per person in PHP
X_5	Fishing years	Number of years in handline fishing
X_6	Average annual trips	Average number of fishing trips per year
X_7	Crew size	Number of people employed per fishing trip

Consequently, Tobit regression demonstrated the determination of the significant factors affecting efficiency. In order to identify the factors that may possibly affect the levels of efficiency of the handline vessels, Tobit regression presented by Tobin 1958 was used due to the inherent range of the technical efficiency scores (TE Scores) (0–1). As seen in Equation 2, the dependent variable used in the function was the derived TE score and the following independent variables (Table 2) were the inefficiency determinants for the ith respondent.

$$\text{TE score}_{\text{i}} = \beta_1 x_{i1} + \cdots + \beta_{i10} x_{i10} + \text{w}_{\text{i}} \qquad (Equation\ 2)$$

Table 2. Variables used in the Tobit model

	Variable Name	Description
Y	Technical efficiency score	TE score generated from data envelopment analysis
X_1	Crew size	Number of people employed per fishing trip
X_2	Gasoline cost	Cost spent for gasoline per fishing trip in PHP
X_3	Average trips per year	Average number of fishing trips per year
X_4	Effort days	Number of days while at sea per fishing trip
X_5	Radio cost	Depreciated cost for radio devices used in PHP
X_7	Consumption cost	Amount spent on food per fishing trip in PHP
X_8	Berthing days	Number of days
X_9	Gross Registered Tonnage	Boat Capacity =1 if GRT … =2 if GRT… =3 if GRT…
X_{10}	GPS and satellite costs	Cost of GPS and Satellite devices in PHP
X_{11}	GPS and satellite age	Number of years GPS and Satellite devices were used

Results

Cobb-Douglas production function assessed the relationship between production inputs and output of the handline fishing vessels. Meanwhile, DEA generated a non-parametric frontier and identified the efficiency of the vessels relative to the frontier. Eventually, the study presented and further explained DEA's Tobit regression results.

Descriptive analysis

Out of 71 handliners interviewed in 2015, 64 qualified with sufficient information. Men exclusively operate the fleets with 2–36 years of experience in fishing. Equipped with GPS, radio buoys, compass and variable inputs, the fleet stays in the ocean for 13 to 40 days catching an average of 3,600 kilograms of tuna, yellow fin *Thunnus albacares* Bonnaterre 1788 and bigeye *Thunnus obesus* Lowe 1839 species. Fixed inputs costs, consisting of GPS, compass and radio buoy costs, were as high as PhP 40,000, PhP 12,000, and PhP 52,000 respectively. Variable inputs comprise fuel, ice, rock, water and food supply budgeted for approximately 26 days in the ocean. On average, these fleets go on 10 trips annually (Table 3).

Table 3. Descriptive statistics of handline fishers in Region 12, Philippines

	Min	Max	Average
Number of years in fishing	2	36	18
Effort days	13	40	26
Catch per trip (kg)	351.00	20000.00	3633.00
GPS (PhP)	7000.00	40000.00	24783.00
Compass (PhP)	150.00	12000.00	1299.00
Radio buoys (PhP)	700.00	52000.00	26979.00
Number of trips per year	4	24	10

The boats used had ages of up to 20 years with mean length of 34.32 feet. Although most of the vessels harvest in the Moro Gulf (also called Centro), some extend to foreign waters, such as Malaysia and Indonesia, using vessels with capacity of 3–150 GRT.

Technical efficiency scores

One of the emerging disparities regarding DEA is the inability to separate randomness from inefficiency. This unresolved issue possibly altered the real output. However, since the majority of the units have reached perfect efficiency, the risk of miscalculation due to unobserved randomness may be relatively low. Nonetheless, the study proceeds to interpret the derived results while ignoring the issue as future studies may address this limitation. The DEA provided a mean average of 57 % technical efficiency (TE) score. Moreover, 26 vessels appeared to be perfectly technical efficient. Since the majority of the vessels lie within 0.90 to 1, this range becomes the mode of the observation. In terms of distribution, it appeared to be highly spread (Table 4).

Table 4. Technical efficiency scores generated by data envelopment analysis

	DEA			
TE Score	Freq.	%	Mean TE	Mean Catch
less than 0.10	7	10.94	0.08	1267.81
0.10 to 0.19	14	21.88	0.15	2217.14
0.20 to 0.29	1	1.56	0.26	4526.95
0.30 to 0.39	5	7.81	0.35	4394.72
0.40 to 0.49	2	3.13	0.43	5000.00
0.50 to 0.59	4	6.25	0.51	8659.29
0.60 to 0.69	3	4.69	0.64	4504.33
0.70 to 0.79	-	-	-	-
0.80 to 0.89	-	-	-	-
0.90 to 1.00	26	40.63	1.00	3594.89
Average TE Score			0.567	
Standard Deviation			0.386	

The DEA scores ranged from 0.04 to 1 gaining a huge difference of 0.96. A wide difference between the top two score ranges is evident, wherein the fully efficient vessels are followed by a vessel with a TE score of 66 %. With respect to frequency, the majority lie in the range with the highest efficiency; however, the second least-efficient group immediately followed consisting of 21.9 % of the sample scoring 0.15 on average. Driven by wide gaps and diverse distribution, the industry gained a 56.7 % mean despite having numerous efficient fleets. The results also show that 59 % have utilised their resources inappropriately and inefficiently (Fig. 2).

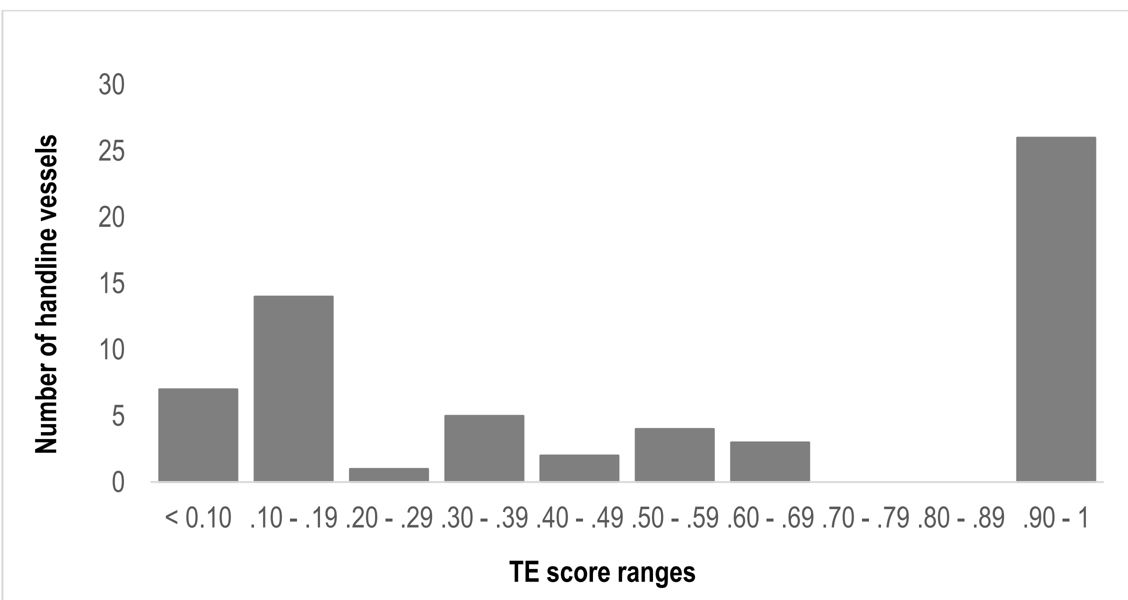

Fig. 2. Distribution of handline vessels according to technical efficiency scores.

The profound gap between the best and least performing vessels, the varied spread of scores, and huge frequency of inefficient vessels might indicate a highly diverse input mix between the vessels. Thus, there is a need to identify the economically ideal set of inputs to arrive at higher efficiency for each vessel and to the handline fisheries as well.

Tobit regression

The Tobit regression model utilised the TE scores generated from the previous modelling. The model was tested for potential issues of multi-colinearity using the variance inflation factor (VIF). The VIF values were found to be low at an average of 1.92, indicating that the multi-colinearity is not a problem for the model. The results generated were also estimated using robust standard errors in order to do away with the likelihood of heteroscedasticity (Table 5).

Table 5. Efficiency determinants and coefficients of data envelopment analysis technical efficiency scores

Variable	Coef.	Std. Err.	p>|t|	
Crew size	-0.027	0.017	0.126	
Gasoline cost	4.0E-06	2.4E-06	0.102	
Average trips per year	-0.065	0.034	0.059	*
Effort days	-0.059	0.013	0.000	***
Radio cost	-1.4E-05	6.5E-06	0.031	**
Consumption cost	-7.3E-06	2.1E-06	0.001	***
Berthing days	0.016	0.009	0.102	
Gross Registered Tonnage				
3–35 GRT	-0.421	0.290	0.152	
35–50 GRT	-0.322	0.364	0.380	
≥50 GRT	0.284	0.363	0.437	
GPS and satellite costs	-1.1E-05	8.1E-06	0.191	
GPS and satellite age	-0.010	0.016	0.529	
Constant	4.288	0.709	0.000	***
Sigma	0.396	0.051		

Pseudo R2= 0.422 Log pseudolikelihood = -32.839 Prob > F = 0.000

legend: * p<.1; ** p<.05; *** p<.01

Vessels with 0.20 to 0.69 TE scores from DEA have been catching more than those in the efficient level. This is a manifestation of overcapacity where handliners put in too much funds on labour and inputs to increase total harvest. Based on DEA scores, it is most economical to catch 3,600 kg of tuna; however, some reach up to 8,600 kg. Most of the significant variables have adverse influences, which denotes too much investment in terms of time and finance. Effort days, consumption cost, number of trips and radio buoy cost appear to decrease efficiency. Meanwhile, gasoline cost and berthing days are approaching significance in positively affecting the efficiency level.

Discussion

The significant variables affecting the productivity and efficiency determined through Cobb Douglas production modelling and Tobit regression, respectively, are expounded below. Associating these factors paved the way to more connections that enriched the justification and understanding of the regression outcomes.

On further assessment of the factors that could possibly affect the level of efficiency of the handline fishing vessels using the Tobit model, it was discovered that effort days, berthing days, crew size, consumption cost, radio cost, gasoline cost and frequency of trips significantly affect the efficiency of the handline vessels.

Effort days (-) and berthing days (+): An additional day at sea might increase total volume per trip but not the volume caught per day. Despite harvesting the second lowest total volume of 2,300 kg, the first group (shortest effort days) yields the second highest catch of 163 kg on a per day basis. Indeed, the group gained the highest efficiency score of 96 %. The remaining groups got at most 66 % efficiency since a prolonged number of effort days reduces the score by 5.9 %. The declining efficiency supports the previously discussed inverse connection between actual catch and effort days, depreciating human capacity/strength lessens the total catch as well as the efficiency. The findings complemented the idea by revealing that fleets need extra berthing days to improve efficiency by 1.6 %.

Effort days (-) and consumption cost (-): Additional auxiliary boats correspondingly raise the volume of harvest and therefore require larger crews. Nevertheless, hiring larger crews indicates higher consumption expenses. The joint inefficiency of additional crew and consumption intensifies the inefficiency of effort days by 2.7 %. The vessels employ too many crew to facilitate their operations. Moreover, extra labour results in economic waste and inefficiency (Table 6).

Table 6. Effort days according to technical efficiency and total catch

Effort days	TE scores	Frequency	%	Total catch	Catch /day
13 to 18	0.96	9	14.06	2357.28	162.57
19 to 24	0.66	13	20.31	4093.81	196.74
25 to 30	0.45	38	59.38	3918.61	132.95
31 to 36	0.29	3	4.69	2955.27	85.25
40*	1.00	1	1.56	351.30	8.78

Radio buoy cost (-): Findings indicate that additional cost on radio diminishes technical efficiency by 1.4^{-05}. This might imply that the functionality and effectiveness of an expensive and a relatively cheaper radio buoy does not differ when it comes to volume of production. Thus, it is more ideal for the fishers to buy a cheaper radio buoy for them to achieve a higher level of efficiency.

Gasoline cost (+): Larger volumes of gasoline offer vessels the ability to travel farther distances. This allows the selection of better fishing grounds with better stock availability and/ or less competing fleets. Thus, the likelihood of catching a greater volume of tuna increases. Together with productivity, the efficiency is likely to increase by 3.9^{-06} for an increase in the consumption of gasoline. Since handliners prefer to fish near FADs which are located on relatively farther high seas and also due to the declining catch in the local fishing grounds additional gasoline would allow the fishers to choose a more strategic fishing ground for them to achieve more volume and higher efficiency.

Frequency of trips (-): Findings showed that more frequent operations decrease efficiency by 6.59^{-02}. This inverse connection possibly happened due to a shorter resting period for the crew since shorter berthing (longer effort) period diminishes efficiency. Aside from human capital, overusing the equipment probably causes underperformance over time as rate of depreciation increases. High frequency of trips also denotes shorter mooring days; thus the allotted period to repair equipment is reduced which might lead to a poorer condition of the boat (Table 7).

Table 7. Frequency of trips according to technical efficiency and total catch

Trips per year	Frequency	%	TE	Total Catch (kg)
4 to 6	5	7.81	1.00	6405.20
7 to 9	21	32.81	0.54	4162.73
10 to 12	34	53.13	0.48	3071.40
13 to 15	2	3.13	0.72	2500.00
> 15	2	3.13	1.00	1844.33

Conclusion

Because of reduction in fish stock and unregulated volume of fish catch, vessels procure excessive inputs to increase productivity. The existing overcapacity of handline vessels unloading in GSFPC indicates unsustainability within the tuna industry, a sector with a huge economic contribution to the Philippine trade. Hence, this study aimed to measure the technical efficiency of the handline tuna fishing industry in General Santos City, Philippines. Using DEA's technical efficiency scores, factors affecting the production and technical efficiency were revealed, respectively. Moreover, the recognised significant factors influencing the productivity and efficiency were linked in the discussion.

The deviations and spread of TE scores from DEA indicate a highly diverse input mix or strategy among the fleets. Most of the fleets put excessive investment on labour and finance which leads to overcapacity. Apart from being less profitable, these handline fleets contribute to unsustainability. Thus, choosing the ideal level of inputs is critical in the industry in order to achieve efficiency.

Technical efficiency measurements showed that the handline tuna fishing operations of fleets unloading in GSFPC, on the average, have low technical efficiency of 56.7 %. Moreover, this study revealed that most of the factors have negative effects towards efficiency. These were effort days, consumption cost, number of trips per year, and radio buoy cost. Gasoline cost and berthing days, on the other hand, were approaching significance in increasing efficiency.

In terms of fixed input, productivity increases as the aggregate costs of GPS, compass, radio, and satellite increases; however, higher expenditure on radio buoy will lead to technical inefficiency. It is ideal to purchase relatively cheaper radio buoys since the features and functions of the cheaper and more costly ones towards productivity do not necessarily differ much. Labour wise, operators believe that prolonging of effort days eventually boosts technical efficiency as it does in productivity but returns might not compensate for the extra investments. Based on the results, 12–18 days of fishing is enough to be efficient. Overall, the mean TE score of the handline fleets was 60 %.

In spite of the handline industry's great significance in the Philippine tuna industry, more in-depth studies seem uncommon. Thus, this paper could potentially aid in bridging this gap in the literature. Further research would also enable an enhanced and apt development of management and policy initiatives in meeting economic and environmental sustainability of the tuna handlining industry.

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