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ANALYSING THE PERFORMANCE OF FISHING TECHNOLOGIES AMONG MARINE ARTISANAL FISHERS IN THE CENTRAL REGION OF GHANA

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Abstract

The meta-frontier stochastic model is used to estimate and compare the productivity, efficiency levels, and determining factors of 150 entrepreneurs (owners of fishing gear) employing the drift gillnet and purse seine technologies along the coast of the central region of Ghana. The results revealed that premix fuel, labour and the cost of other inputs were highly productive under both technologies, but the variable 'fishing duration' (hours per round of fishing) was not productive under the purse seine technology. Owners of the drift gillnet were operating under an increasing return to scale, while those with the purse seine showed a decreasing return to scale. The mean meta-efficiency values were 0.61 and 0.63, with Technology Gap Ratio scores of 0.74 and 0.78 for the drift gillnet and purse seine operators, respectively. The inefficiency test revealed that 81% and 93% of the variation in total outputs of drift gillnet and purse seine owners were due to inefficiencies in input use *and other human-related characteristics in managing the fishing business, whereas the remaining percentage (19% and 7%) were attributed to stochastic factors (moon light effects, unfavourable weather at sea, high tidal shocks, foreign vessels interferences and other natural factors). Following the meta-efficiency analysis, the frontier of the purse seiners was higher and closer to the metafrontier than the drift gillnetters. In this regard, owners of the drift gillnet must capitalise on the merits of economies of scale to intensify operations to raise their frontier. Fisheries stakeholders (designated ministries, departments, and development affiliates) must provide fishermen with subsidised fishing inputs, particularly premix fuel and high-horsepower outboard motors, to make aspiring entrepreneurs' dreams a reality.*

Keywords: Inefficiency, Meta frontier, Productivity, Return to Scale, Technical Efficiency

INTRODUCTION

Fish is one of the most traded and consumed commodities in the world because billions of people worldwide trace their livelihoods and life satisfaction to fishing and related activities (Loring et al., 2019). The marine fisheries sector has been the backbone of the global economy, serving as the source of food and livelihood for both urban and rural coastal communities. According to Kolding, over 90% of the world’s full-time or part-time individuals earn their living mainly on fishing and associated ventures, spanning from marine or aquaculture fishing, processing and trading. FAO (2015) recorded that in the North American Arctic, like many underdeveloped regions, the fish diet contributes nearly 80% of the individual’s protein source. The paper continues to report that 21%, 23%, and 14% of the total protein consumed in China, Japan, and Norway, respectively, is derived from fish.

In light of the immense contribution of the fisheries industry to the worldwide economy, small-scale fisheries are the most employed sub-sector, employing about 90% of the total workforce in the fisheries industry, of which the majority are located in developing countries, particularly Asia (FAO 2014). In terms of volumes of world fish landings, Pauly and Zeller (2016) postulate that small-scale fishing contributes 25%, provides food to the world population, income for most economies, and a livelihood for many coastal duelers; more than 4.5 billion people depend on the small-scale fishermen for their protein. In terms of employment, FAO (2016) holds that the artisanal fishing sector employs 85% of the total workforce in the fishing industry and contributes 47% of the total value of fish landings in Africa.

The contribution of Africa's artisanal fisherfolk to the overall commercial species landed by all sectors is greater than the global average contribution of small-scale fisheries to the world's total catch (Belhabib, 2015). The artisanal sub-sector of the marine fisheries (fishing conducted mainly from shore using small fishing boats and employing less sophisticated technologies and less capital investment by coastal duelers) is a keen livelihood sector, contributing to the income and food security for people living in coastal communities (Belhabib et al., 2015). (FAO, 2012). West Africa was among the first areas where the industrialised European and Asian tuna fishing fleets were exploited, way back in the seventies. Again, Okyere et al. (2020) reported that the fisheries sectors of West Africa have been a sustainable revenue source for defraying national debt through the exportation of fish and licencing of local and foreign fishing fleets.

The marine, coastal lagoons, and inland freshwaters are the main resources of Ghana's fisheries industry, with patches of aquaculture units (Nunoo et al., 2014). These resources (marine and inland waters) provide a livelihood for many Ghanaian coastal communities and serve as a crucial source of nutrients in most diets. The Ghana Statistical Service (2021) declared that the fisheries sector alone contributes 1.4% of the total GDP value of the country and provides jobs for at least 2 million people, with 135,000 fishers belonging to the marine sector. Empirical reports (Republic of Ghana Plan, 2014; Belhabib et al., 2015; Owusu and Andriesse, 2020) indicate that about 10% of the Ghanaian population are into artisanal fishing, contributing 75–80 percent of the total marine fish landed and generating 341 million dollars annually. In terms of consumption, Akuffo and Quagrainie (2019) revealed 22kg of fish consumption per capita (60% share of protein food), putting Ghana in the bracket of the top ten fish-consuming countries in Africa.

Besides the monumental contribution of the fishery industry to the world's economy, a general declaration by FAO (2016) indicated a falling trend in marine fish landings from 1999 (420,000 tonnes) to 2014 (202,000 tonnes). In Europe, Froese et al. (2010) signalled that most stocks are overfished and many are below safe biological limits. As a global canker, Lazar et al. (2018) also revealed that annual marine fish landings in Ghana are currently below 20% of the record-breaking fish landed (140,000 mt) in 1998. Following these revelations, a variety of factors have been attributed to the declining trend of global fish landings; the work of Fleming et al. (2014) on the effect of climate change on the Australian seafood supply chain discovered a negative impact of climate change on the biology of the oceans; and, once again, from the perspective of fishing gear, Kuczenski et al. (2012) blame derelict fishing gear as a visible source of marine plastic pollution causing mortality and ecosystem destruction. In a way to address this menace, the Fisheries Management Plan for Ghana (2015–2019) enacted species protectionary measures around Ghana's oil fields as well as precautionary laws to curb illegal fishing practices. Currently, the Ministry of Fisheries and Aquaculture

Development (MoFAD), in collaboration with the Fisheries Commission, has enacted a "closed season" policy (July to August) for artisanal and industrial fishing fleets in Ghana to stay away from the sea.

Nonetheless, all the policies and numerous research works (Maulu et al., 2021; Asamoah et al., 2012; Onumah et al., 2010) implemented and conducted by the government and individuals in addressing the annual fish shortage and efficient production approaches have barely focused on a meta-analysis of artisanal fishing technologies. Owing to this, the government and all fisheries-supporting partners and investors are in a dilemma as to which efficient and sustainable technology will enhance higher productivity with the least adverse ocean-ecosystem impact. Abetted by the low investment in research relating to marine fishing technology and input productivity, several governments and private investments in the fisheries industry are unable to meet expectations. Not idiosyncratically, the world is looking for efficient artisanal marine technology, productive marine fishing inputs, and answers to whether the persistent annual output variations in the marine fish landing are due to inefficiencies or random errors.

In a way to address this gap, two predominant locally employed fishing technologies (drift gillnet and purse seine) empirically identified by Dankwa et al. (2014) are considered in this study. Following the meta-frontier approach used by Battese et al. (2004), the productivity levels and efficiency levels are estimated. Technology gap ratios (differences between respective technologies' frontiers and the meta-frontier) as well as some assumed determinants of Fisher’s efficiency are modelled, estimated, and compared.

MATERIALS AND METHODS

Conceptual Framework

Likening fishing to other production enterprises that combine more than one input in a production process under different technologies, the meta-frontier model proposed by Battese & Rao (2002) and Battese et al. (2004) in their study is also adopted here. Comparing the drift gillnet (passive fishing gear that catches fish by gilling, entangling, or enmeshing them in the netting) and purse seine technologies (an active fishing gear that surrounds schools of fish and sweeps an area of the seabed), this model is adopted to estimate the technology gap ratio, the parameters of the frontiers, and the technical efficiencies. The illustration in Figure 1 (the conceptual framework), displays the individual stochastic frontiers for the two technologies (drift gillnet and purse seine) a benchmark efficiency levels of the individual fishers. Also, above these two frontiers is the meta-frontier that envelops the two technology frontiers. According to O’Donnell (2008), the meta-frontier will enable the comparison of industry-potential performance levels against the individual technology frontiers.

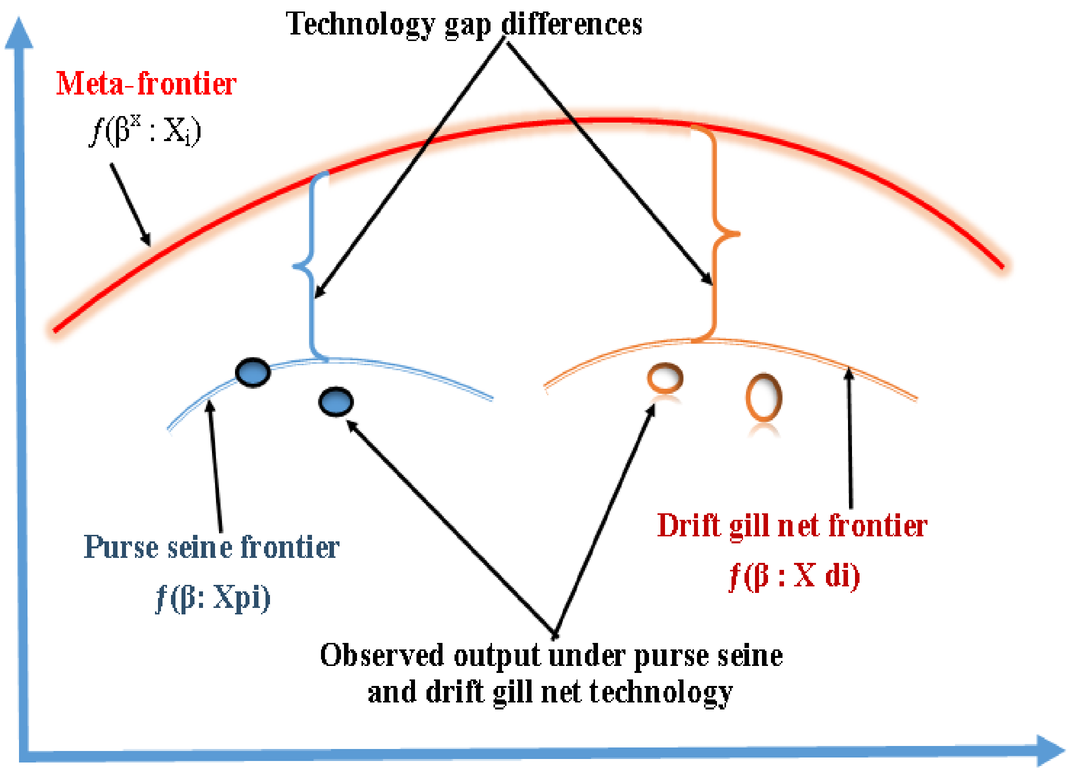

Figure 1: Meta-frontier model for the two fishing technologies

Source: Adopted from Battese et al. (2004)

Theoretical Framework

To compare the efficiency of different groups of artisanal fishers operating different technologies with different productive frontiers, the stochastic meta-frontier model employed by Battese et al. (2004) was chosen over other frontier estimating tools like the switching regression model, latent class models, and random parameter model. The stochastic production frontier procedure propounded by Coelli et al. (2005) is used to estimate group frontiers. This aided in the estimation of the efficiencies of the individual respondents (herein also referred to as "fishers") relative to their respective group frontier.

Referencing the works of Onumah et al. (2013) and Onumah and Essilfie (2020), the conventional stochastic approach for the technologies (r) of the artisanal fisheries subsector is specified as equation one (1):

$$Y_i^r = f(X_i; \beta^{(r)}). \exp^{v_i^{(r)} - u_i^{(r)}} = \exp^{x_i \beta^{(r)} + v_i^{(r)} - u_i^{(r)}} \qquad 1$$

Where:

Yi = total normalized output per annum for the ith owner of rth fishing technology in Ghana Cedi.

Xi = normalized vector of variable input quantities used by the ith owner in the rth fishing technology per annum. $\beta^{(r)}$ = parameter vector for the input factors in the frontier model for the rth fishing technology. $\mathrm{v}_\mathrm{i}^{(\mathrm{r})}$ = is the symmetric random term which is assumed as identically and independently distributed with a zero mean and a constant variance $N(0, \sigma^2_{V^{(r)}})$. $\mathrm{u}_\mathrm{i}^{(\mathrm{r})}$ = autonomous inefficiency term that is also assumed as a truncation of the $N(\mu^{(r)},\ \sigma^2_{u^{(r)}})$ dispersions such that the mean ($\mu_i^{(r)}$) is specified as equation two (2):

$$\mu_\mathrm{i}^{(\mathrm{r})} = \delta_\mathrm{m}^{(\mathrm{r})} \mathrm{Z}_\mathrm{mi} \qquad 2$$

Battese and Coelli (1992 and 1995) employed equation two (2) to analyze the determinants of technical efficiency. Finding the differential characteristics among the two fishing technologies, this work uses the likelihood ratio test (LR) to compute the difference in the log-likelihood value for the pooled technologies and the sum of the log-likelihood values from the individual technologies. The result justifies whether the metafrontier is the best technique for comparing the technical efficiencies of the two fishing technologies. Following this assertion, the metafrontier production model is expressed as equation three (3):

$$\mathrm{Y}_\mathrm{i}^* = f(X_i; \beta^*) = \mathrm{e}^{\mathrm{x}_\mathrm{i}\beta^*}.\ i = 1, 2, 3, \dots\dots\dots, N_r \qquad 3$$

Where:

$\boldsymbol{\beta}^*$ = the parameter of the metafrontier such that $(X_i\beta^*) > (X_i\beta^r)$. This expression demonstrates the dominance of the metafrontier model over the individual technology frontier models. The actual output for the ith owner characterized by the stochastic frontier of the rth fishing technology in equation one (1) is expressed in terms of the metafrontier model in equation four (4):

$$\mathrm{Y}_\mathrm{i} = \exp^{u_i^r}\ .\ \frac{\exp^{x_i\beta^r}}{\exp^{\mathrm{X}_\mathrm{i}\beta^*}}\ .\exp^{\mathrm{X}_\mathrm{i}\beta^* + v_i^r} \qquad 4$$

The expression ($\exp^{\mathrm{u}_\mathrm{i}^\mathrm{r}}$) in model four (4) denotes the technical efficiency relative to the stochastic frontier for the rth fishing technology and is also represented in equation five:

$$\mathrm{TE} = \frac{\mathrm{Y}_\mathrm{I}}{\exp^{\mathrm{X}_\mathrm{i}\beta^* + \mathrm{v}_\mathrm{i}^\mathrm{r}}} = e^{-u_i^r} \qquad 5$$

From model four (4), the second term stands for the technology gap ratio (TGR) and is expressed as equation six (6):

$$\mathrm{TGR} = \frac{\exp^{x_i\beta^r}}{\exp^{\mathrm{X}_\mathrm{i}\beta^*}} \qquad 6$$

Equation six (6) (technology gap ratio) measures the ratio of output for the two technology frontiers relative to the possible output marked by metafrontier. TGR value ranges from zero to one where a value closer to one implies that the owner is producing close to maximum potential output (meta-frontier) in the light of the technologies available for the marine artisanal fishing industry as a whole.

Estimating Meta-Technical Efficiency

The technical efficiency of the i^{th} owner operating under r^{th} technology relative to the metafrontier is recalled from equation five (5) as $\mathrm{TE}^* = \frac{\mathrm{Y_i}}{\exp^{\mathrm{x_i}\beta^* + \mathrm{v_i^r}}}$. The mathematical relationship of TE^* to the metafrontier model from equation five (5) is also represented as equation seven (7):

$$\mathrm{TE_i^*} = \mathrm{TE_i} \ \mathrm{X} \ \mathrm{TGR_i} \qquad 7$$

Recalling O'Donnell et al. (2008), the coefficients of the metafrontier were obtained by reducing the sum of deviation squares of the metafrontier from the technology-wise frontiers in the optimization problem as specified in equation eight (8):

$$\mathrm{M_{in}L} = \sum_{\mathrm{i=0}}^{\mathrm{N}} (\mathrm{x_i}\beta^* - \mathrm{x_i}\beta^{\mathrm{r}})^2 \text{ , where: } \mathrm{s.t} \quad \mathrm{x_i}\beta^* > \mathrm{x_i}\beta^{\mathrm{r}} \qquad 8$$

This procedure agrees with the least-squares criterion mechanism (Battese et al., 2004). Equation eight (8) is a quadratic programming method that employs simulation (applied for this work) or bootstrapping procedures to estimate the metafrontier parameters' standard errors.

Operationalizing the Frontier Models

This paper considers the translog functional form as adopted in several works in different fields of study (Rahman and Anik, 2020; Rocha and Tveterås, 2019; Onumah and Acquah, 2010; Baten et al., 2009). The translog functional form is flexible to estimate the cross effects of inputs on output at different levels of production. Equations 9 represent the translog stochastic frontier function assuming the production technology for the two fisher groups.

$$\mathrm{lnY_i} = \mathrm{ln}\beta_0 + \sum_{\mathrm{r=1}}^{4} \beta_{\mathrm{r}} \mathrm{lnX_{ri}} + \frac{1}{2} \sum_{\mathrm{r=1}}^{4} \sum_{\mathrm{k=1}}^{4} \beta_{rk} \mathrm{lnX_{ri}} \mathrm{ln} X_{ki} + (\mathrm{V_i} - \mathrm{U_i}) \qquad 9$$

Where:

$\ln = \text{natural log}$, i = i^{th} fisher under a particular r^{th} fishing technology, β = vector of the unknown parameter to be estimated; Note: $\beta_{rk} = \beta_{kr}$ for all k and r, Y_i = total normalized output value of fish catch per annum (GH₵), Xi_1, Xi_2…..Xi_4 = annual normalized vector of variable input quantities such that; X_1=Labour, X_2=Premix fuel, X_3=Duration per fishing trip, X_4=Cost of other inputs apart from those described by X_1, X_2, and X_3. Referencing related works (Onumah et al., 2013; Onumah and Essilfie, 2020), the output and input variables are normalized per canoe size to neutralize the effect of the differences in canoe size. Restricting the squared and crossed product terms of equations 9 and 10 to zero changes them to the Cobb-Douglas production function.

The metafrontier model parameters were estimated by minimizing the sum squares of the deviations of the values on the metafrontier from the individual stochastic frontier production systems at the observed input levels (Battese et al., 2004). The estimated maximum likelihood values were obtained with the Ox program developed by Brummer (2015).

The Elasticity of Output with respect to Input

According to the works of Onumah et al. (2013) and Onumah and Acquah (2010), the first and second-order coefficients in addition to the levels of input variables constitute the output elasticities with respect to the inputs. Based on this, the coefficients in the translog production functional form cannot be interpreted straight away. Resolving this, the variables were rescaled to have unit means making the coefficient of the square term (β_{rk}) and the cross-terms (β_{kr}) zero. The first term (β_r) expressed in equation 11 now become direct elasticities.

$$\mathcal{E}_{\mathrm{y}} = \frac{\partial \mathrm{InE(Y_i)}}{\partial \mathrm{Inx_{ri}}} = \left\{\beta_{\mathrm{r}} + \beta_{\mathrm{rr}}\mathrm{Inx_{ri}} + \sum_{\mathrm{i=1}}^{4} \beta_{\mathrm{rk}}\mathrm{Inx_{ki}}\right\} = \beta_{\mathrm{r}} \qquad 11$$

Where:

The letters (r and k) represent inputs r and k, $\mathcal{E}$y denotes output elasticity, Xs denote variables of input and $\boldsymbol{\beta}$s represent the coefficients to be estimated. Summing up the elasticities ($\mathcal{E}$y) gives the total elasticity ($\mathcal{E}$) that represents the return-to-scale (RTS). Where: ($\mathcal{E}$) > 1 is increasing return-to-scale, ($\mathcal{E}$) < 1 is decreasing return-to-scale and ($\mathcal{E}$) = 1 is constant return-to-scale.

Determinants of Metafrontier Inefficiency

Explaining the variations in the technical and metafrontier efficiency levels, respondents" demographic, management and operational characteristics assumed to influence their efficiency are modelled in equation 12:

$$\mu_{\mathrm{i}} = \delta_0^r + \sum_{\mathrm{m=1}}^{10} \delta_m^r Z_{mi} \qquad 12$$

Where:

Z = vector of variables explaining the inefficiency effects, δ = parameters to be estimated, δ_0 = constant r = definition in model one and $\boldsymbol{\mu}_i$ =non-negative error assumed to cause the inefficiency effects in the fishing business.

Demographic Factors

Z_1 = Age (number of years), Z_2 = Marital status (married =1, other status = 0), Z_3 = Household size (number of dependents).

Business Managerial Factors

Z_4 = Ownership of fishing resources (solely owned = 1, otherwise = 0), Z_5 = Experience (number of years in fishing business), Z_6 = Education (formal education = 1, no formal education = 0), Z_7 = Engage in other occupation (yes =1, no =0).

Fishing Operational Factors

Z_8 = Alternative finance sources (market queens = 1, other source = 0), Z_9 = Capacity of outboard motor (40hp = 1, others lower capacities = 0), Z_{10} = Depth of Fishing ground (length in metres from surface to the seabed).

From the inefficiency model, the variance parameters are specified as; $\sigma = \sigma_u^2 + \sigma_v^2$. Referencing the work of Addison et al. (2016), $\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2}$ estimates the variance ratio where γ lies between zero (0) and positive one ($0 \leq \gamma \leq 1$). The value of γ close to one implies that the observed output deviation from the frontier is caused by the assumed inefficiency determinants.

Hypotheses Test

The hypotheses underlying the assumptions and significance of the specified models are stated in Table 1; verifying the validity of the specified model, the existence of inefficiency in artisanal fishing, the effects of the assumed determinants of inefficiency included in the model, whether inefficiency effects are stochastic or non-stochastic and the need to adopt the metafrontier model over other estimation tools.

To validate the hypotheses, the generalized likelihood-ratio test (LR) is used and specified in equation 13.

$$LR = 2[In\{L(H\boldsymbol{o})\} - \mathrm{In}\{\mathrm{L}(\mathrm{H}_1)\}] \qquad 13$$

Where:

$L(H_O)$ = null and (H_1) = alternative values of the likelihood function. LR has approximately a Chi-square (or mixed Chi-square) distribution if the given null hypothesis is true with a degree of freedom equal to the number of parameters assumed to be zero (0) in (H_0). As proposed by Coelli (1995), all critical values are obtained from the appropriate Chi-square distribution. But, if the tested hypothesis involves $\Upsilon = 0$, it implies the asymptotic distribution demands the mixed Chi-square distribution (Kodde and Palm, 1986; Table 1).

Table 1: Statement of Hypotheses for the Technological and Metafrontier Model Assumptions

Hypothesis	Description
1. H_0: $\beta rv = 0$	Coefficients of the second-order variables in the translog model are zero
H_1: $= \beta rv \neq 0$	Coefficients of the second-order variables in the translog model are not zero
Purse seine	
Drift gill net	
Pooled	
2. H_0: $\Upsilon = \delta_0 = \delta_1$-----$\delta_{11} = 0$	There are no inefficiency effects
H_1: $\Upsilon = \delta_0 = \delta_1$-----$\delta_{11} \neq 0$	There are inefficiency effects
Purse seine	
Drift gill net	
Pooled	
3. H_0: $\delta_1 = \delta_2$-,-,-,= $\delta_{11} = 0$	Inefficiency variables included in the model are not relevant and have no effect on efficiency/inefficiency
H_1: $\delta_1 \neq \delta_2$--,--,--,≠ $\delta_{11} \neq 0$	Inefficiency variables included in the model have a relevant effect on efficiency/inefficiency
Purse seine	
Drift gill net	
Pooled	
4. H_0: $\Upsilon = 0$	Inefficiency effects are non-stochastic
H_1: $\Upsilon \neq 0$	Inefficiency effects are stochastic
Purse seine	
Drift gill net	
Pooled	
5.H_0:$fp(X{:}\beta p) = fd(X{:}\beta d)$	Both technologies (purse seine and drift gill net) are the same and the specification of the meta-frontier model is unnecessary.
H_1:$fp(X{:}\beta p) \neq fd(X{:}\beta d)$	Both technologies (purse seine and drift gillnet) are never the same and deemed appropriate to specify the meta-frontier model.

Data Description

Studies (Ameyaw et al., 2021; Amador et al., 2006) have identified Greater Accra and Central regions with the highest number of canoes (64.49%) and fishermen (63.98%) along the coast of Ghana. Upon these statistics, the Central region was considered as the study area for this work.

Employing the multistage sampling approach, one hundred and fifty (150) entrepreneurs who are owners of canoe and fishing nets were selected from two coastal municipalities (Effutu and Komenda Edina Eguafo Abirem) and two districts (Gomoa West and Abura Asebu Kwamankese). Purposefully, one community was chosen from Gomoa West, Effutu and Abura Asebu Kwamankese (Apam, Weneba and Moree respectively). By the same approach, two towns were chosen from Komenda Edina Eguafo Abirem (Elmina and Komenda) as a result of the activeness of fishing activities in these towns. With the notion of reaching out to two different frames of the population employing different technologies (purse seine and drift gillnet), a stratified sampling method was adopted to put the respondents into two in each of the selected communities. Subsequently, the different stratum was subjected to a simple random sampling approach where fifteen respondents were selected from every stratum in each community.

The method of collecting data was personal interviews with structured questionnaires, observations and contact with the key informant. An initial test of the survey instrument was organised to descriptively check the reliability, suitability and validity of the questions. Following the response from the pilot survey, all concerns detected from the questionnaire were duly addressed and mastered for smooth data collection at the main stage. Analysis was done using the Ox program, and SFAMB package employed by Tweneboah-Kodua (2022) and adopted the maximum likelihood estimator for the parameter estimates.

RESULTS

Results of Validated Hypotheses

Presented in Table 2 are the results obtained from the hypothesized analogies underpinning the fitness and correctness of the conceptual and theoretical bases of this research. Hypothesis one was strongly rejected due to the fact that the Cobb-Douglas model is not an adequate representation for the purse seine and drift gillnet technologies as well as the pulled data, hence the need for a translog Frontier model. This was proven by the non-zero coefficients of the second-order variables in the translog model. Again, all three specified models showed greater LR test statistics against the critical values, indicating acceptance of the results from the translog model as accurate and consistent. This indicates the suitability of the specified translog stochastic frontier model for drawing a valid conclusion from the data. Hypothesis two (2) verifies whether inefficiency effects are present in all three specified models. In line with the work of Onumah et al. (2010), the result from the test proved a high level of inefficiency effects in all three models, hence rejecting the decision to exclude them.

Attributing the inefficiency effects to being non-stochastic, the null hypothesis puts the average production response function (OLS) against the stochastic model in the third hypothesis. This decision was rejected in favour of the stochastic model, implying that the stochastic frontier model is the most appropriate to be used for all the analyses.

From the fourth hypothesis, the null hypothesis states that all the coefficients except their respective constant terms in the three specified models are zero. This null hypothesis was rejected in favour of the alternative, as the test proved that the combined effects of the determinants of inefficiency were pertinent factors leading to the variability in fishers' total output.

The null hypothesis in point five explains that the two technologies are the same, but the log-likelihood ratio test estimation (163.46) was significantly greater than the critical value (17.67). This outcome led to the rejection of the null hypothesis, affirming that the two technologies under study are completely different, hence the need to specify the metafrontier model for this work. This finding confirms similar works like Battesse et al. (2004) and Onumah et al. (2013).

Table 2: Validated Hypotheses for the Technological and Metafrontier Model Assumptions

Null Hypothesis	LR Statistics (λ)	Critical Values	Decision
H_0: $\beta rv = 0$			
Purse seine	47.41	23.21	H0 Rejected
Drift gill net	44.67	23.21	H0 Rejected
Pooled	164.29	23.21	H0 Rejected
H_0: $\Upsilon=\delta_0=\delta_1=\delta_2$--,--,=$\delta_{11}$=0			
Purse seine	58.48a	27.03b	H0 Rejected
Drift gill net	62.59a	27.03b	H0 Rejected
Pooled	83.26a	27.03b	H0 Rejected
H_0: $\Upsilon = 0$			
Purse seine	63a	5.41b	H0 Rejected
Drift gill net	23a	5.41b	H0 Rejected
Pooled	75a	5.41b	H0 Rejected
H_0: $\delta_1=\delta_2$--,--,=δ_{11}=0			
Purse seine	41.35	26.3	H0 Rejected
Drift gill net	47.83	26.3	H0 Rejected
Pooled	54.26	26.3	H0 Rejected
H_0:$f p(X:\beta p) = f d(X:\beta d)$			
Only pooled	163.46	10.5	H0 Rejected

Note: a= Values of test for one-sided error obtained from the Ox output of the ML estimates. b = critical values at 0.001 for the test of the hypothesis involving γ obtained from Kodde and Palm (1986: Pp. 1246).

Statistics of the Output and Input Variables

From table 3, the statistical representation of the observed annual values of output (GH₵) given their respective inputs is expressed in terms of mean, maximum, minimum, and standard deviation. The estimated means and standard deviations of the output and input levels indicate some levels of disparity among respondents even under the same technology.

Table 3: Summary of Output and Input Variables

Fishing Technology	Output (GH₵/yr)	Labour (Man/year)	Premix Fuel (Litres/yr)	Duration (Hours/yr)	Other Cost (GH₵/yr)
Purse Seine					
Mean	195711	534	26553	5150	9946
Minimum	145000	423	19603	3025	6895
Maximum	235000	624	37819	6340	11440
St. Dev.	12384	66	4527	864	1175
Drift Gill Net					
Mean	189437	442	21325	5842	10788
Minimum	136250	294	14020	3425	7982
Maximum	211250	541	36091	7852	12765
St. Dev.	15939	68	5687	1227	1203
Pooled					
Mean	192574	488	23939	5496	10367
Minimum	136250	294	14020	3025	6895
Maximum	235000	624	37819	7852	12765
St. Dev.	14569	81	5755	1113	1258

Note: Values of output and inputs were derived from the costs and quantities per round of fishing operation.

The estimated mean, maximum, and minimum output values for the pooled system were GH₵192574.00, GH₵235000.00 and GH₵136250.00 respectively. This outcome provides evidence of variation in the output values among the respondents. Given the two technologies, the output records of respondents employing the drift gillnet range from GH₵136250.00 to GH₵211250.00 per annum while their counterpart purse seiners range from GH₵145000.00 to GH₵235000.00. These statistics indicate a considerable difference in output values among artisanal marine fishermen. According to the mean analyses, respondents using drift gillnet and purse seine technologies will bring home GH₵189437.00 and GH₵195711 respectively in a critical year. This shows that the output level of respondents using the purse seine technology is to some extent higher than that of their counterpart drift gillnetters.

The mean annual labour quantity recorded under the pooled system in man/year is 488man/year. On average, year-on-year labour requirements for drift gillnet and purse seine were estimated to be 442 and 534man/year, respectively. The respective minimum and maximum ranges of labour employed under the drift gillnet and purse seine technologies were 294 to 541and 423 to 624man/year.

Premix fuel was a significant input in the operations of artisanal fishers, and this research found that purse seines consumed more of it than drift gillnets. The average recorded premix fuel consumption for the drift gillnet and purse seine technologies were 21325 and 26553litre/year respectively. In terms of consumption ranges, the minimum and maximum recorded under the drift gillnet are 14020 and 36091litre/year with those employing the purse seine recording 19603 and 37819litre/year minimum and maximum respectively. Recorded statistics under the pooled system suggest that in a critical year, no artisanal marine fisher operating any of the under-studied technologies will consume below and above 14020 and 37819litre/year respectively.

The duration per round of fishing operations was quantified as one of the input variables in the fishing business. The following activities cumulated into the computation of an effective round of fishing time: sailing from the beach to a fishing ground; casting and hauling the net; and sailing from a fishing ground back to the beach. The statistics presented in Table 3 indicate that in a critical year, the number of hours used by drift gillnetters, purse seiners and the pooled system is 5842, 5150, and 5496hours/year respectively. This record put the drift gillnetters ahead of their counterparts in terms of time consumption per fishing trip, with a range of 3425 to 7852hours/year compared to 3025 to 6340hours/year for the purse seiners. Any artisanal fisher who uses either of the two understudied technologies must work 5496 hours per year on average. In a related study, Lucakovic and Uphoff (2002) generalized that fishing duration per trip could range from 12 to 18 hours without mentioning any specific fishing technology.

Apart from labour, premix fuel, and duration per round of fishing, all other items used in the course of the fishing operation are quantified in monetary terms (in Ghanaian cedis) and referred to as the "cost of other inputs." All the identified cost elements (food, tax, ice block, and royalty) were common to both technologies except signal light and dry cell, which were peculiar to drift gillnet technology. According to the fishermen, signal lights can be used for a period of one month, and based on this proposition, the per-trip cost for signal lights was estimated using the straight-line depreciation approach. Against this backdrop, the estimated annual cost of other inputs under the pooled system ranged from GH₵6895.00 to GH₵12765.00 with a mean of GH₵10367.00. In terms of averages, GH₵10788.00 and GH₵9946.00 were the year records for fishers employing the drift gillnet and purse seine technologies respectively. Within a critical year, no fisherman incurred an amount less than GH₵6895.00 or more than GH₵12765.00 on the cost of other inputs in the course of their fishing operations.

Parameter Estimates of the Stochastic Frontier and Meta-frontier Models

The estimated maximum-likelihood statistics for the two frontiers (drift gillnet and purse seine technologies) as well as the meta-frontier are summarized in Table 4. The fitness of the model and the need for the specified distributional assumptions are justified by the significance (1%) of the estimated sigma-square values for the pooled system and the two technologies (drift gillnet and purse seine).

Considering the gamma (γ) values, which explain whether the variation in total outputs is due to stochastic factors or inefficiencies on the part of the fishermen, The gamma estimates of 88%, 81%, and 93% for the pooled system and the two technologies (drift gillnet and purse seine), respectively, explain why the total output of artisanal marine fishing fluctuates due to inefficient input use and demographic factors. It is therefore agreed that 12%, 19%, and 7% of the deviation are due to stochastic factors (moonlight effects, high tidal shocks, weather shocks, the impact of foreign vessels, etc.).

The estimated output elasticities in Table 4 show the implied effectiveness of the specified model. The input variables (premix fuel, labour and the cost of other inputs) were found to be positively significant under the pooled system and that of the purse seine technology, adding more to output except for duration per fishing trip, which showed otherwise though not significant. This revelation implies that these resources (premix fuel, labour and the cost of other inputs) are highly productive under purse seine technology, and that fishers employing it must be mindful of the hours spent during fishing in order to stay more efficient and competitive in the fishing business. In the case of the drift gillnet technology, all the input variables significantly added to the output, implying that a percentage change (increase) in the quantity of any of the input variables would lead to an increase in output. Generally, all but the cost of other inputs under the pool system positively impacted output. Premix fuel, fishing duration, and labor were discovered to be high-yielding inputs in the marine artisanal fisheries subsector. In light of this, expenses on the cost of other inputs (taxes, ice blocks, food, royalties, signal lights, and dry cells) must be reconsidered since more of them reduce output (productivity). The productivity of Labour as an input is manifested in the work of Villano et al. (2010) as they looked at the varietal differences in pistachio production in Iran. Again, a meta-frontier analysis of organic and conventional cocoa production in Ghana by Onumah et al. (2013) revealed the same testimony about Labour productivity.

The meta-analysis saw some levels of production heterogeneities in the two fishing technologies, leading to disparities in the parameters of the meta-frontier estimates and those of the stochastic pooled estimates. The input variables were all positive and added onto the meta-frontier output, a clear confirmation of the a-priori expectations.

Table 4: Parameter Estimates of Stochastic Frontier and Metafrontier Models

Variables	Parameters	Purse Seine (ML)	Drift Gill net (ML)	Pooled (ML)	Meta (LP)
Constant	β0	0.054 (5.72) ***	0.119 (18.9) ***	0.090 (0.80)	6.072 (2.92) ***
LnLabour	β1	0.159 (3.76) ***	0.114 (1.75) *	0.357(3.40) ***	0.552 (0.73)
LnPremix fuel	β2	0.737 (3.08) ***	0.605 (2.65) *	0.475(3.87) ***	5.605 (4.23) ***
LnDuration	β3	-0.086 (-1.64)	0.390 (4.98) ***	0.155(2.34) **	2.551 (-4.13) ***
LnOther cost	β4	0.184 (2.57) *	0.651 (9.87) ***	-0.062(-2.29) ***	1.062(2.39) **
Labour square	β5	-1.156(-3.81) ***	-2.372 (2.80) ***	0.329(1.42)	5.068(-0.73)
Premix square	β6	5.418(1.61)	18.725 (5.33) ***	0.143(0.192)	3.104(0.73)
Duration square	β7	-0.599(-1.49)	20.118 (4.19) ***	1.228(2.27) **	1.745(1.23)
Other cost square	β8	1.084(1.88) *	-3.509 (-5.92) ***	-1.294(-6.73) ***	0.7843(2.49) **
(LnLab)*(LnPre)	β9	0.407(0.39)	0.853 (0.403)	0.165(0.78)	4.506(1.78) *
(LnLab)*(LnDura)	β10	0.727(4.06) ***	3.712 (2.32) *	1.078(3.97) ***	-0.2345(-2.03) **
(LnLab)*(LnOC)	β11	0.832(2.10) *	3.701(6.10) ***	-0.047(-0.24)	-0.047(-0.24)
(LnPre)*(LnDura)	β12	-0.685(-0.84)	13.864 (4.04) ***	-2.867(-7.08) ***	-0.289(-0.32)
(LnPre)*(LnOC)	β13	-4.549(-2.54) *	-3.891 (-2.16) *	-0.788(-1.88) **	-1.432(-2.32) **
(LnDura)*(LnOC)	β14	0.309(1.02)	0.648 (0.517)	0.837(3.86) ***	0.992(1.62)
Sigma-square		0.83	0.79	0.73	
Gamma		0.93	0.81	0.88	
Log-likelihood		167	168	344	

Note: Values in parenthesis are the t-statistics ***, ** and * represent significance at 1%, 5% and 10% levels respectively. ML = Maximum Likelihood estimates, LP = Linear Programming estimates and OC = Other Cost.

Summary Statistics of Output Elasticities and Returns to Scale

Table 5 presents the output response to changes in the respective input usage (labour, premixed fuel, fishing duration, and cost of other inputs) under each of the technologies.

Under purse seine technology, average output elasticity in relation to the respective input use was positive. Except for the fishing duration (hours spent per round of fishing), all the other input variables positively impacted output. In effect, a percentage increase in any of the inputs except fishing duration resulted in a rise in the output of respondents employing the purse seine technology. On the part of the drift gillnet technology, the output response to all the input variables was positive. This implies that all of the input variables (labor, premix fuel, fishing duration, and the cost of other inputs) had a positive influence on output, i.e., a percentage increase in the quantity of premix fuel, labor, the cost of other inputs, and fishing duration will result in an increase in fish caught using drift gillnet technology. The cost of other inputs and labour was also identified to be productive in a related work by Onumah et al. (2013) when comparing the organic and conventional systems of cocoa production in Ghana.

Table 5: Output Elasticities and Return to Scale (RTS)

Variables	Purse Seine	Drift Gill net	Pooled
Labour (man/year)	0.159	0.114	0.357
Premix fuel (litres/year)	0.737	0.605	0.475
Duration (hours/year)	-0.086	0.39	0.155
Other Cost ((GH₵))	0.184	0.651	-0.062
Return to Scale (RTS)	0.994	1.76	0.925

Note: RTS is the sum of the partial elasticities of each technology

The cost of other inputs and labour was also identified as productive in a related study by Onumah et al. (2013) when comparing the organic and conventional systems of cocoa production in Ghana.

In the pooled analysis, only the cost of other inputs turned out to be against output; a percentage increase in the cost of other input variables resulted in a fall in the artisanal fisher's output. This empirical discovery assures artisanal fishermen, especially those employing either of the two technologies under study, that Labour, premix fuel, and duration per fishing trip are highly productive and, when effectively applied, will lead to a sustainable bumper fish catch. Fishermen should be mindful of the amount paid or spent on the cost of other inputs (taxes, ice blocks, food, royalties, signal lights, and dry cells) to stay more efficient and competitive.

Further comparison of the two technologies presents the return to scale analysis in Table 5. Summing up the partial elasticities, we see a total of 1.760 for the drift gillnet, 0.994 for the purse seine, and 0.925 under the pooled system. This revelation implies that purse seiners and the pooled system both exhibited decreasing returns to scale and that a percentage increase in all input factors will result in a 0.925% and 0.994% increase in the output levels of the pooled system and the respondents using purse seine technology, respectively. The return to scale value of 1.760 recorded under the drift gillnet technology implies an increasing return (output) of 1.760% when all inputs used are increased by a percentage. This statistic placed drift gillnetters in an increasing return to scale level, which means that the amount of fish caught (output) increases by a greater proportion than the amount of labor, premix fuel, hours per fishing trip, and money spent on other inputs (taxes, ice blocks, food, royalties, signal lights, and dry cells). In effect, it is worth propounding that fishermen employing the drift gill technology are capable of expanding their production level to ensure a bumper catch (increased output) in the long run.

Technical Efficiency and Technology Gap Ratios (TGR)

Presented in Table 6 is the statistical summary of the metafrontier efficiencies (TE*) and respective technological technical efficiencies (TE). For the stochastic frontier models, the calculated mean technical efficiencies for the drift gillnet and purse seine technologies as well as the pooled system turned out to be 0.79, 0.82, and 0.72, respectively. Although encouraging, these figures show some inefficiency, with respondents operating 21%, 18%, and 28% below their respective potential production capacities (frontiers). They would have to strive to bridge the existing gap (between the current level of fish catch and their respective defined output frontier) in order to catch up with their potential production frontier.

In Table 6, the statistical data on the technology gap ratio for the two technologies is presented in means, where the values 0.74 and 0.78 were recorded for the drift gill net and purse seine, respectively. The significance of this result is that if respondents under the drift gillnet and purse seine were to attain a 100% level of efficiency, they could have increased their output level by filling the gaps of 26% and 22%, respectively, if they duly adopted the most efficient meta technology. A comparative inference from the technology gap ratio statistic puts the respondents under the purse seine technology ahead of their counterparts in terms of efficiency because they are closer to the metafrontier.

Notwithstanding the closeness of the purse seiner to the metafrontier, the estimated mean meta-technical efficiency values of 0.61 and 0.63 for the drift gillnet and purse seine technologies, respectively, also made the purse seiner more efficient. The data and analytical results gathered from this work imply that, on average, marine artisanal fishing businesses involving the use of purse seine fishing technology are more technically efficient compared to drift gillnet technology. Meanwhile, fishermen using the drift gillnet must be strategic in their input use and address some operational lapses to stay more competitive in the fishing business.

Table 6: Summary Statistics of Technical Efficiency Scores and Technology Gap Ratio

Technology/TE/TGR	Mean	Minimum	Maximum	St. Deviation
Technical Efficiency (Stochastic Frontier)-TE				
Purse seine	0.82	0.37	0.98	0.06
Drift gill net	0.79	0.31	0.95	0.20
Pooled	0.72	0.23	0.97	0.22
Technical Efficiency (Meta-Frontier)-TE*				
Purse seine	0.63	0.31	0.96	0.22
Drift gill net	0.61	0.29	0.93	0.24
Pooled	0.58	0.21	0.91	0.25
Technology Gap Ratio (TGR)				
Purse seine	0.78	0.15	0.89	0.16
Drift gill net	0.74	0.07	0.84	0.23
Pooled	0.76	0.11	0.86	0.21

Note: Values in the table are the linear programing estimates for the Metafrontier coefficients.

Determinants of Technical Inefficiency

Policy recommendations based on the efficiency analysis alone are not enough to justify the objectives of this work. Therefore, respondents' demographic, managerial, and fishing operational factors assumed to influence their efficiency levels were modelled and quantified alongside the respective technological stochastic frontier models. Table 7 presents the results of these analyses.

Table 7: Parameter Estimates of the Inefficiency Model

Variables	Parameter	Purse seine	Drift gill net	Pooled
Constant	δ0	0.081 (2.22) **	0.106 (3.48) ***	0.070 (0.02)
Gender	δ1	-0.053 (1.55)	0.047 (3.62) ***	0.045 (3.50) ***
Age	δ2	-0.06 (-2.27) **	-0.08 (-1.20)	-0.001 (-2.55) **
Marital Status	δ3	0.112 (1.61)	0.059 (3.19) ***	0.099 (4.57) ***
Household size	δ4	4.173 (2.49) **	0.004 (1.52)	-0.001 (-1.40)
Resource ownership	δ5	0.017 (2.91) ***	0.059 (3.19) ***	0.020 (0.96)
Business Experience	δ6	0.003(-1.59)	0.005 (1.03)	0.004 (1.73) *
Formal education	δ7	0.002 (-3.53) ***	0.019 (1.34)	-0.011 (-2.22) **
Other Occupation	δ8	0.017 (2.91) ***	0.047 (3.62) ***	0.047 (4.71) ***
Alternative finance	δ9	0.053 (1.55)	0.047 (3.62) ***	0.045 (3.50) ***
Fishing ground depth	δ10	-0.002(-4.53) ***	-0.004 (-2.39) **	-0.005 (-2.68) **
Motor Capacity	δ11	-0.0117 (2.98) **	-0.059 (3.19) ***	0.005 (0.377)

Note: Values in parenthesis are the t-statistics; ***, ** and * means significance at 1%, 5% and 10% respectively.

The gender of the owners of fishing equipment as a variable in the inefficiency model showed a negative influence on inefficiency under the purse seine and a positive significance under the drift gillnet. This implies that owners who are male and employ the purse seine are more technically efficient than their female counterparts, while the opposite happened under the drift gillnet technology, where females were rather more technically efficient. The influence of gender under the pooled system was significantly positive. This outcome implies that fishing resources owned and managed by males are less technically efficient but are rather more technically efficient when in the hands of females. In the work of Onumah and Acquah (2010), the opposite happened, where males were more technically efficient. This may be due to the fact that males being the breadwinners as custom demands might have conflicted fishing business income with household expenditure, thereby affecting the efficient running of the fishing business.

In all three of the inefficiency models specified, age as a variable turned out to be negative, though not significant under drift gillnet technology. This means that as people get older, their efficiency levels rise; thus, older owners of fishing resources were more technically efficient than younger ones. This result may stem from the fact that the younger fishermen may be inadequate in terms of fishing resources (capital, labour etc.) and managerial experience, hence their low productivity.

The effect of marital status on inefficiency was positive for both technologies and the pooled system. This means that married respondents are not technically efficient compared to those who are divorced, separated, widowed, or single. This outcome is in line with the results of Kophy (2019) and Amadu et al. (2021), who concluded that married fishermen have weak associations with livelihood resilience. This outcome may be due to the fact that marriage and its numerous responsibilities (both family and non-family related) may have had a negative impact on the efficiency of the fishing business (reducing the capital base and smoothing fishing operations).

The response of inefficiency to household size as a variable was positive under the two fishing technologies but negative under the pooled system. This means that as the dependents of the respondents increase, inefficiency also increases. In their work, Abdurakhmanova and Abdurakhmanov (2019) observed a contradictory result and proposed that the higher the number of dependents, the more available family labour and increased productivity. This result might be that the increased household size has translated into increased household expenditure (accommodation, food, education, health care, etc.). These financial obligations have conflicted with the demands of the fishing business, hence the dwindling effect on the efficiency levels of respondents.

Resource ownership as a determinant of inefficiency under the business managerial factors was significantly positive under the two fishing technologies. The implication is that solely owned (one-person) fishing businesses turn out to be inefficient as compared to the family and group-owned fishing businesses engaged in the study. This might be because the solely owned fishing businesses are unable to meet their operational financial obligations. According to Ngoasong and Kimbu (2019), privately owned businesses are frequently uncreditworthy for commercial bank financing, and this factor may be evident among marine artisanal fisherfolk.

The outcome of the business experience in the inefficiency model contradicted the stated a-priori expectation as it turned out to be positive and reduced efficiency. In other words, increasing years of ownership in the fishing business leads to a decrease in fish catch output (lowering the level of efficiency). The same result happened in a related study by Onumah et al.

(2013) when comparing the efficiency of organic and conventional cocoa production in Ghana. This could be explained by experienced fishing business owners becoming complacent in their decision-making and diverting profit into non-lucrative ventures.

The effect of formal education on inefficiency was positive under both technologies but turned negative under the pooled system. Even though respondents with some level of formal education look unproductive in their respective operations, the pooled system saw a significant increase in efficiency. This outcome supports that of Twumasi et al. (2021), who saw a positive relationship between a high level of education and technology adoption. This explains the importance of formal education to the fishing community, as it helps reduce inefficiency in marine artisanal fishing.

Determining the effect of "other occupations" (respondents engaging in other unpaid personal, salaried, or waged livelihoods) on inefficiency, it turned out to be positive and significant under both technology and the pooled system. Engaging in any form of work alongside the fishing business reduces output. This result confirms the work of Asmah (2008) and Kumar et al. (2018). They revealed that fishermen who concentrate on their fishing activities make effective and efficient allocations of fishing resources to ensure bumper output. In this case, respondents with alternative livelihoods may be distracted during the allocation of already scarce productive resources, resulting in negative effects on efficiency.

"Alternative finance" was set as a variable in the inefficiency model to determine the effect of seeking financial support from market queens on the efficiency of fishermen. The analysis revealed that fishermen are worse off when they depend on market queens for financial support. This means that the quantum amount sourced from the market queens may not be enough to meet the demand for operational (the purchase of input), maintenance, and expansion expenses. Empirical findings (Binam et al., 2008; Nyagaka et al., 2010; Onumah et al., 2013) have revealed that farmers’ access to credit from financial institutions has been vital for improved productivity.

The depth of the fishing ground was determined by the anchors used to station vessels at sea. Incorporation of this variable in the inefficiency model revealed a negative and significant effect under the purse seine technology and that of the pooled system but the opposite for the drift gillnet. This finding implies that the deeper (74.04m -124m) the purse seiners operate, the more technically efficient (productive) they become and the reverse is realized under the drift gillnet technology. This outcome confirmed expectation and also supports the works of Victorero et al. (2018) and Barros and Clarke (2009) that, fishers’ output increase with increasing depth of the sea.

Outboard motor capacity as a variable in the inefficiency model was set to verify whether using higher capacities (40hp and above) could lead to increased output. It was revealed that outboard motors of higher capacities increase the efficiency of respondents using both technologies. On the contrary, those propelling their fishing craft with lower capacities were less technically efficient. As Amador et al. (2006) spoke about the relationship between outboard motor capacity and craft size, this work also tried to verify the effect of outboard motor capacity on efficiency/inefficiency. Empirically, it has been established that increased horsepower of the outboard motor increases the output of marine artisanal fishermen.

DISCUSSION

Joining the chase to balance the demand and supply of fish in Ghana and the world at large, a technical approach (a stochastic metafrontier model) was specified to compare the technical efficiencies of fishing technologies (drift gillnet and purse seine) widely employed by fisherfolk in the marine artisanal fisheries sector of Ghana.

Hypotheses were set to validate the appropriateness of the specified models (meta-frontier, stochastic frontier, and translog) and to test for inefficiency factors in the fishing business that hamper the fisher’s efficiency (output). All validations went in favour of the methodology adopted and were consistent with the data set. Inefficiencies were revealed to be part of the factors leading to the falling output of the marine artisanal fisheries subsector.

Technical efficiency scores and parameters of the stochastic frontier were estimated for each technology as well as the pooled system. Determinants of inefficiencies in the areas of respondents' demographic, managerial, and operational characteristics were modeled, and their level of effect on inefficiency was estimated. In both technologies (drift gillnet and purse seine), output-input use response estimation saw premixing fuel, labor, and other input costs to be more productive. Generally, under the pooled system, premix fuel, labour and duration of fishing were found to be more productive and, if efficiently and effectively utilized, would enhance output. Contrary to expectations, the duration of fishing negatively affected the productivity of purse seiners. Because of this, purse seiners must try to reduce the hours of fishing as it translates into increased utilisation of the other input factors (premix fuel, food, ice blocks, etc.), hence increasing total cost and reducing profit.

Stochastic efficiency means of 0.79 and 0.82 were recorded under the drift gillnet and purse seine technologies, respectively, while the pooled system had 0.72. These efficiency figures imply that fishermen operating drift gillnets and purse seines as well as the pooled system, were producing 21%, 18%, and 28% below their respective frontiers. The gaps between the metafrontier and the two frontiers for drift gillnet and purse seine technologies were 0.74%

and 0.78%, respectively. This indicates that they could increase output by closing the gap of 26% and 22% if they had produced exactly on their respective group frontiers (i.e., at 100% technical efficiency). Further estimates on the Meta efficiency revealed that purse seiners were more technically efficient (0.63%) and closer to the industry's best potential production frontier than drift gillnetters, who recorded 0.61%. Following up with the pooled meta-efficiency estimation, 0.58% was obtained, which empirically justifies that all the respondents engaged in this work were producing 42% below the industry's best potential production frontier. This calls for effective, efficient, and strategic use of inputs as well as addressing their respective inefficiency factors to stay competitive in the fishing business. Following the inefficiency analysis, owners of the purse seine fishing resource are to be mindful of the following factors that negatively affect their level of efficiency: large household dependence, marriage life and expenses, sourcing financial support from market queens, engaging in alternative livelihoods, and complacency by being educated and/or having experience in the fishing business. On the plus side, the capacity of the outboard motor and depth of the fishing ground reduced inefficiency, which implied that purse seine fishermen fishing in the deep sea with higher horsepower outboard motors made a good catch. Furthermore, women who owned drift-gill fishing resources and operated with high-horsepower outboard motors were found to be more technically efficient. Aside from these two, all the other inefficiency factors reduced the efficiency of the drift gillnetters. The factors of: gender, ownership of the fishing business, gender, business experience, alternative sources of finance, motor capacity, and other occupations were found to reduce efficiency under the pooled system. Generally, this research postulates that artisanal marine fisherfolk can be more efficient if the following factors prevail: they are owned and controlled by older fisherfolk; their households must be small; they must have formal education; and finally, they must operate on the deeper fishing grounds.

Following this empirical findings, it is established that further meta-efficiency research work with other industrialised fishing technologies in other sectors of the fishery industry will help unravel the mysteries stakeholders have attached to the dwindling fishing output in recent times.

CONCLUSION

The study compared the performance of two predominantly employed fishing technologies (purse seine and drift gillnet) among marine artisanal fishers. The metafrontier approach was used to estimate and compare the efficiency levels, technology gap ratio, metafrontier parameters, meta-technical efficiency levels, and test for the presence of inefficiencies. The test of models and parameter estimations proved that the metafrontier and stochastic models (transcendental logarithmic) specified were appropriate and best fit the data set. Furthermore, the output-input elasticities analysis showed premix fuel, labour, and the cost of other inputs to be productive and increase the efficiency levels of fishers under both technologies. Generally, premix fuel, fishing duration, and labour under the pooled system were found to be more productive in the marine artisanal fishing business. Comparatively, owners of the drift gillnet exhibited an increasing return to scale, while purse seine owners and that of the pooled system exhibited a decreasing return to scale.

Fisherfolk operating with purse seine fishing technology were found to operate closer to the maximum industry potential frontier in the technology gap ratio estimations. Again, the metafrontier efficiency estimate revealed that purse seine owners are more technically efficient and operate closer to the maximum potential frontier (metafrontier).

Tests for the presence of inefficiency revealed that 88%, 81%, and 93% of the variation in total outputs of the pooled system and the drift gillnet and purse seine technologies are due to inefficiencies in the input use and other human-related characteristics in managing the fishing business. Given this, the effects of the stochastic factors on the variation of the observed output from the frontiers of the pooled system and those of the drift gillnet and purse seine technologies were, respectively, 12%, 19%, and 7%. These were attributed to poor sea weather conditions, high tidal waves, the effect of the moonlight, and competition with foreign vessels.

Following the findings from this study, it is recommended that fishermen capitalise on the productivity of premix fuel, labour, and duration to increase output while balancing the cost of other inputs to stay competitive in the fishing business. Fisherfolk employing the drift gillnet should take advantage of the increasing return to scale to increase the scale of production through effective allocation and utilisation of inputs while ensuring better management practices. On the flip side, purse seine fishermen should reconsider the level of input used (reducing fishing duration) and some managerial factors that add up to inefficiency. The efficiency estimations saw all two groups operating below their respective frontiers and therefore advised them to reconsider their inefficiency characteristics (demographics, management, and operational). It is a plea to the government and other development partners in the fishing industry to institute a coastal-specific education system in the fishing communities to help solve or minimise the rate of illiteracy among fishermen. Finally, the marine artisanal fishing industry, a major source of livelihood for the coastal section of the country and a key contributor to GDP, should be supported by instituting terminal workshops and fishing trainings for fisherfolk as well as a timely supply of subsidized high-horsepower outboard motors and premix fuel. These recommendations, when well and timely addressed, will boost efficiency and improve productivity.

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CONFLICT OF INTEREST

Authors have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTION

D. K. A.: Conceptualization; Methodology; Investigation; Resources; Writing – original draft; Formal Analysis; Funding Acquisition.

S. T. Y.: Conceptualization; Methodology; Investigation; Resources; Funding Acquisition; Writing – original draft.

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