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Technical efficiency analysis of shrimp farms in Andhra Pradesh, India using stochastic frontier approach

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ABSTRACT

Brackishwater aquaculture sector is dominated by the exotic vannamei shrimp farming, which is the economic engine of Indian aquaculture. In 2019-20, exports of 12,89,651 t of Indian marine products fetched foreign exchange worth ₹46,662.85 crores and farmed shrimps accounted for about two-thirds of the shrimps exported. Shrimp farming is export oriented and market price often fluctuates widely impacting the profitability significantly. We conducted this study to estimate technical efficiency of the shrimp farmers in Nellore District, Andhra Pradesh which tops in shrimp aquaculture in the country. The data were collected through structured questionnaire using personal interview from 80 farmers during COVID 2020 pandemic period. The farm specific technical efficiency varied from 75 to 94% with a mean of 93%. The estimates of the discrepancy parameter γ indicated that 93% of the difference between the maximum possible output and actual output were due to differences in technical inefficiencies of farmers. Feed and labour are the significant variables compared to other variables. The results indicated that farmers need to be encouraged to apply more feed to increase shrimp production.

Keywords: Stochastic production frontier, Sustainability, Technical efficiency, Vannamei shrimp aquaculture

Introduction

In 2019-20, exports of 12,89,651 t of Indian marine products fetched foreign exchange worth ₹46,662.85 crores and farmed shrimps accounted for about two-thirds of the shrimps exported in value terms. Farmed shrimp production touched 7.0 lakh t in 2019, of which 87% was exported, earning foreign exchange of ₹35,000 crores (MPEDA, 2021). Shrimp producers are profit driven and aim at maximising production of the farmed shrimps. Productivity increase is possible either by adopting new technologies or by increasing their production efficiency. It is argued that the improvements in efficiency are more cost-effective than introducing new technology if the producers are not efficient in the use of the existing technology (Shapiro, 1983; Belbase and Grabowski, 1985; Dey *et al.,* 2000). On the other hand, if the producers are reasonably efficient, then new inputs and technology would be required to shift the production frontier upward (Ali and Chaudhary, 1990; Ali and Byerlee, 1991). When information on prevailing production efficiency of shrimp farmers is known, technically feasible and economically viable farm business plans could be formulated to enhance farmed shrimp production to the maximum possible extent subject to land, inputs and other production variables. Therefore, technical efficiency studies are important for planned aquaculture development.

Generally, three approaches are applied in efficiency measurement of aquaculture: Stochastic frontier analysis (SFA), Data envelopment analysis and Meta frontier analysis. Basically, a non-parametric technique, the Data Envelopment Analysis (DEA) can accommodate multiple outputs. However, this technique is deterministic and attributes all deviations from the frontier to inefficiencies, making it less appropriate to case studies where uncontrollable factors (*e.g.* disease outbreaks) account for substantial variation in output (Sharma and Leung, 2003). In contrast, the SFA model utilises parametric techniques, which support the identification of differences in farming efficiency, controlled by two components: Farming technical inefficiency and Stochastic noise (Sharma and Leung, 2003). Gunaratne and Leung (1996) opined that this approach is appropriate for studying agriculture and aquaculture production systems in developing countries where data collected from farm production systems are heavily influenced by measurement errors and other stochastic factors (*e.g.* weather conditions). Finally, meta-frontier analysis allows the measurement and comparison of farming efficiency for several individual countries or regions over separate production frontiers (Gunaratne and Leung, 1996; Sharma and Leung, 2000a, 2000b). This method applies either data envelopment (*e.g.* Nguyen and Fisher, 2014; Rahman *et al*.,, 2019; Ton Nu

Hai *et al*., 2020) or SFA approaches (*e.g.* Gunaratne and Leung, 1996; Onumah and Essilfie, 2020). Battese (2002) and Lau and Yotopoulos (1989) stated that the lack of comparable data and the presence of inherent differences across countries are the two major limitations in using the meta-production function approach. Equivalent differences and data limitations regarding the intensive and extensive systems challenge aquaculture efficiency analyses. Therefore, we applied the stochastic frontier technique for assessing the factors that influence efficiency in the vannamei shrimp production system in Nellore District, Andhra Pradesh which is the hub of aquaculture in general and shrimp farming in particular in India.

Sharma and Leung (2003), Abdullahi Iliyasu *et al.* (2014) and See *et al.* (2021) reviewed the available literature on technical efficiency studies in aquaculture globally. Several studies on technical efficiency of carp aquaculture (Jayaraman, 1997a, b, c; 1998; 1999; 2000; Sharma and Leung, 1998; Sharma, 1999 (a,b); Dey *et al*., 2000; Sharma and Leung, 2000; Roy 2009; Singh *et al.,* 2009; Umamaheswari *et al*., 2013) and tiger shrimp aquaculture (Kumar *et al.,* 2004; Uma Devi and Eswara Prasad, 2004; Reddy *et al.*, 2008; Sivaraman 2014, 2015) in India have been carried out. Very few studies are available on the technical efficiency analysis of vannamei shrimp which accounts for about 90% of shrimps farmed in the country (Kumaran *et al*., 2017; Radhakrishnan *et al*., 2021). The present study investigated the economics of shrimp farming during 2020-21 with a focus on the technical efficiency of the shrimp farms. The study commenced just before the pandemic and was carried out in 2020 when the COVID pandemic set in. Many studies explored impact of pandemic onslaught on aquaculture and shrimp farming specifically. The restrictions imposed due to the Covid pandemic have had impacted economies of many countries in several ways. Border restrictions, transport restrictions along the aquaculture supply chain, closure of restaurants, food retail stores and closure of food production units, led to supply stagnation and decline leading to price increase (Cision, 2020; FAO 2020a,b; IFPRI, 2020; Ivanov, 2020; Kakoolaki *et al*., 2020; Stephens *et al.,* 2020; Waiho *et al.,* 2020; Hasan *et al*., 2021; Kumaran *et al*., 2021; Pazir *et al.,* 2022).

Materials and methods

In this study, we collected farm level cross sectional data from randomly selected 80 shrimp farmers in Nellore District, Andhra Pradesh during 2020. Nellore District was chosen because of the presence of active shrimp farming. The research work commenced before the onset of Covid pandemic and took us by surprise leaving no scope for studying the impact of Covid before and after its onset on the shrimp farming in the study area. The list of farms registered with the Coastal Aquaculture Authority (CAA) was outnumbered by farms not registered with the CAA and hence the farms were considered as one unit and random sampling was used to select the farms for data collection. The data were collected mostly by personal interview and to some extent by telephonic interviews when the pandemic imposed restrictions on travel. An interview schedule was prepared, pretested and used to collect the information from the farmers. Andhra Pradesh alone produced 5,10,794 t from 63,678 ha accounting for about 72% of the shrimp aquaculture production in the country from about 64% of area under shrimp aquaculture (MPEDA, 2021). Andhra Pradesh leads in farmed shrimp production besides freshwater fish farming. The vannamei shrimp farms had ponds with a mean size of about 2 ha each and considered as small farms.

Technical efficiency

The approaches available to study technical inefficiency include the stochastic production function based on the composed error model of Aigner *et al.* (1977), Meeusen and Van den Broeck (1977) and Forsund *et al.* (1980). Consider a stochastic production function model with multiplicative disturbance component:

$$y = f(x_i, \beta)\, e^{\epsilon} \quad \ldots(1)$$

where ϵ is a stochastic error term consisting of two independent elements:

$$\epsilon = \mu + \nu \quad \ldots(2)$$

The symmetric component ν, accounts for random variation in output due to factors outside the farmers' control, such as weather and diseases. It is assumed to be independently and identically distributed as $N(0, s^2)$. A one-sided component $\mu \leq 0$ reflects technical inefficiency relative to the stochastic frontier, $f(x_i, \beta)\, e^{\nu}$. Thus, $\mu = 0$ for a farm whose output lies on the frontier and $\mu < 0$ for one whose output is below the frontier. Assume that μ is identically and independently distributed as $|N(0, \sigma^2_\mu)|$, *i.e.,* the distribution of μ is half-normal.

The stochastic production frontier model can be used to analyse the cross section data. The frontier of the farm is given by combining equations (1) and (2):

$$y = f(x_i, \beta)e^{(\mu + \nu)} \quad \ldots(3)$$

The variance of ϵ is, therefore,

$$\sigma^2 = \sigma^2_\mu + \sigma^2_n \quad \ldots(4)$$

The ratio of two standard errors is defined by

$$\lambda = \sigma_\mu / \sigma_n \quad \ldots(5)$$

Jondrow *et al.* (1982) have shown that measures of efficiency at the individual farm level can be obtained from the error terms $\in = \mu + \nu$. For each farm, the measure is the expected value of μ conditional on ∈, *i.e.*, $E(\mu|\in) = \sigma_m \sigma_v/\sigma\ [(\varphi(\in\lambda/\sigma)/1-\varphi(\in\lambda/\sigma)) - \in\lambda/\sigma]$ ....….(6)

Normal distribution function evaluated at (∈ λ/σ). Estimated values for ∈, λ and o are used to evaluate the destiny and distribution functions. Measures of efficiency for each farm can be calculated as:

$TE = Y_i/Y^*_i = \exp\ [E\{\in|\ \mu\}]$ ....(7)

In this study, the MLE (Maximum-Likelihood Estimation) method was used for estimation.

Model specification

The stochastic frontier production function of the Cobb-Douglas type was adopted for the study. In order to estimate the stochastic production function the following equation was defined as:

$Y_i = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + V_i - U_i$ ……….. (8)

where, i= 1, 2 …n; Y_i = Total shrimp production in kg per ha; X_1= Seed (Number of shrimp post-larvae per ha); X_2= Feed in kg per ha; X_3= Labour in mandays; X_4= Chemicals in kg per ha; U_i = Farm specific technical inefficiency related factor and V_i = Random variable

From the residual, using equation (3), the farm specific technical efficiencies were estimated. Stochastic efficiency frontier estimations were made using FRONTIER 4.1 software developed by Coelli (1996).

Results and discussion

Farm characteristics

The characteristics of the shrimp farms studied are presented in Table 1. The average size of the shrimp farms was 2.07 ha ranging from 0.4 to 12 ha. The mean size of the farm appears to be ideal from farm operational and management point of view (Kungvankij and Chua, 1986). Kongkeo (1997), Milstein *et al.* (2005) and Islam *et al.* (2005) stressed that small cultivation ponds allow better management and lead to increased growth, survival, yields and economic returns of *Penaeus monodon.* Similar findings for *Penaeus vannamei* are also reported (Hernandez-Llamas and Villarreal-Colmenares, 1999; Magallon, 2006). Ruiz-Velazco *et al.* (2010) reported that, in general, greater final weight and biomass production of shrimp are obtained in smaller ponds. High sensitivity of production to final weight explains the importance of obtaining larger shrimp by using small ponds for winter cycles.

Stocking density of the vannamei shrimps followed by the farmers had a mean of 3, 24,385 post-larvae (PL) per ha, with a minimum of 1, 07,167 and maximum of 9,60,000. The effect of stocking density on growth, survival and yields of shrimp has been extensively studied. A negative effect of stocking density on performance of *P. vannamei* was reported (Wyban e*t al.*, 1987; Moss and Moss, 2004; Araneda *et al.,* 2008, Ruiz-Velazco *et al.*, 2010).

Mean level of feed use was 8050 kg with an average feed conversion ratio (FCR) of 1.51. The FCR was estimated to determine the performance of feed and production from stocking to harvest. It was calculated by weight of total feed consumed (kg) divided by the total yield. The feeding frequency can have effects on the FCR, as reported by Aalimahmoudi *et al.* (2016). In a well-managed system, FCR can be reduced to 1.3 to 1.5; however, in poorly managed condition, FCR can be as high as 2.5 (Hung and Huy, 2007). On the average shrimp farm, the FCR ratios of 1.6-1.8 were reported across 174 black tiger shrimp farms in Thailand (Tacon, 1993). The mean expenses on labour, electricity, fuel, chemical and probiotics were ₹60,392; 63,142; 32,987; 52,807 and 28,678, respectively (Table 1).

Stochastic frontier production function analysis

The independent variables included in the model explained 87% of the variation in shrimp production (Table 2). The production elasticities of feed and labour variables had the expected positive sign. The estimated model implied the need for maintaining optimum size

Table 1. Summary statistics of the shrimp production variables

Variable	Minimum	Maximum	Mean	Standard deviation
Shrimp Yield (kg ha^{-1})	2158	9840	5335.75	2149.01
Water spread Area (ha)	0.4	12	2.07	2.62
Stocking density (No. ha^{-1})	107167	960000	324385	216366
Feed (kg ha^{-1})	3507	14617	8050	3250.4
Labour (₹)	8750	125000	60392	22218
Electricity (₹)	25450	100000	63142	21818
Fuel (₹)	19560	65000	32987	16245.34
Chemical (₹)	25000	98620	52807	17310.32
Probiotics (₹)	18956	65890	28678	11625.31
FCR	1.63	1.49	1.51	-

Table 2. Estimates of log linear production function

Variables	Parameters	Coefficients	't' ratio
Intercept	β_0	-0.05(0.72)	-0.07
Seed (X_1)	β_1	0.02 (0.01)	1.35
Feed (X_2)	β_2	0.81 (0.05)	16.82***
Labour (X_3)	β_3	0.08 (0.04)	1.92*
Chemicals (X_4)	β_4	0.02 (0.03)	0.60
R^2	0.88		
F	79.64		
n	80		

* and *** denote levels of significance at 10 and 1% level, respectively.

of shrimp ponds and the scope for enhancing shrimp production by increasing the application of feed. Functional analysis indicated the contribution of feed in increasing farmed shrimp production to be more prominent but feed cost at present accounted for a larger share (19.29%) of the total cost. Therefore, provision of cheaper feed and input subsidy would motivate the farmers to increase feed use and enhance fish production. This observation agrees with that reported by the national level study of Kumaran *et al.* (2017).

The results of stochastic frontier production function presented in Table 3 shows that the estimates λ and θ are statistically significant indicating a good fit and correctness of the specified distributional assumption respectively (Awoyemi *et al*., 2003). The estimates of the discrepancy parameter γ indicated that 93% of the difference between the maximum possible output and actual output were due to differences in technical inefficiencies of farmers. The feed and labour are the significant variables compared to other variables.

Table 3. Maximum likelihood estimates of stochastic frontier production function

Variables	Parameters	Coefficients	't' ratio
Intercept	β_0	0.51(0.71)	0.72^{NS}
Seed (X_1)	β_1	0.00 (0.01)	0.28^{NS}
Feed (X_2)	β_2	0.77(0.04)	17.49***
Labour (X_3)	β_3	0.10(0.04)	2.63**
Chemicals (X_4)	β_4	0.05(0.03)	0.17^{NS}
	$\lambda = \sigma_u / \sigma_v$	3.80***	
	$\gamma = \sigma^2_u/(\sigma^2_u+ \sigma^2_v)$	0.94(0.10)	
	$\theta = \sigma_u+ \sigma_v$	0.12^{NS}	
	Log likelihood value	72.01	
	N	80	

* and *** denote significance at 1 and 10% levels, respectively. NS: Not significant.

Technical efficiency

The frequency distribution of technical efficiency of shrimp farms (Table 4) indicated that the technical efficiency was less than 80% in 2% of the sample farms. About 16% of the farmers had a high technical efficiency between 81-90% with the mean technical efficiency level of 86.51%. The farm specific technical efficiency varied from 75 to 94% with a mean of 93% (Table 4). This implied that by rationalising input use, there exist two options for an average farmer to increase his production or save cost by 39% and for a least efficient farmer to increase his production or save cost by 87%. An effective technology transfer in this regard for convincing farmers on input use and their adoption would elevate them to an optimum level of production efficiency as attained by his counterpart in the same locality.

The study found a mean technical efficiency of 93% which is similar to the findings of other studies conducted earlier. Sivaraman *et al.* (2015) reported 93.06% mean technical efficiency among vanammei shrimp farmers in east Godavari District, Andhra Pradesh while Kumaran *et al.* (2017) reported it as 90.13% for the shrimp farmers of India and 92% for vannamei farmers of Andhra Pradesh State. Radhakrishnan *et al.* (2021) reported a mean technical efficiency of 95% for vannamei farmers of Nellore District, Andhra Pradesh. In the case of tiger shrimp farming (*Penaeus indicus*) Kumar *et al.* (2004), Uma Devi and Prasad Eswara (2004) as well as Reddy *et al.* (2008), reported mean technical efficiency ranging from 59 to 87% and Bhattacharya (2008) reported 61%.

The estimated lambda (λ) shows the relationship between the variance of u_i and v_i. A value larger than one suggests that the variation in u_i is more pronounced than the variation in the random component *v*i. Hence, a value of 3.80 (Table 3) suggests that technical efficiency differences among the farms are important reasons for the variation of vannamei shrimp production in the study area. Ogundari (2010) and Ogundari and Aklnbogun (2010) suggested that a value of λ larger than 1 supports that technical efficiency differences among farms are an important reason for the variation in fish production, which we found to be the case for the shrimp farms in Nellore District, Andhra Pradesh, India.

Table 4. Frequency distribution of technical efficiency of the shrimp farms

Technical efficiency (%)	No. of farms	Percent to total	Cumulative frequency	Mean technical efficiency
71-80	6	7.50	7.50	75.72
81-90	23	28.75	36.25	86.51
91-100	51	63.75	100.00	94.78
Overall	80			93.08

Obviously, this value is comparatively higher than the average of 1.92 obtained under the conventional stochastic frontier model. This, however, underscores the discrepancy associated with the technical efficiency scores when the production risk component is excluded in the SFP model specification.

We could not find out changes in the technical efficiency of the farmers before and after the onset of the pandemic period. However, the farmers reported difficulties in the production and marketing of the shrimps due to travel, transport and border restrictions, fall in demand and prevalent uncertainty. Kumaran *et al.* (2021) investigated the impact of COVID-19 related lockdown restrictions and their cascading effect on the shrimp value chain, from the perspective of stakeholders. They put forth suggestions for interventions that could contribute to developing mitigation measures and policy responses for the resilience of the shrimp farming sector in India which did not address the technical efficiency of the shrimp farmers

It is reported that the main factors affecting farmed shrimp production and fluctuations in the physical and chemical parameters of farm pond water are variations in rain fall, temperature, salinity and pH. They act like precursors to disease outbreaks (Tendencia and Verreth, 2011; Waibel *et al.,* 2017). Tendencia *et al.* (2011) claimed that intensive production is able to minimise shrimp disease risks because of less exposure to the vagaries of the climate and weather. It is believed that intensification of aquaculture may enhance production efficiency with concurrent increase in cost and profits (Leung and Sharma, 2000). Nguyen *et al.* (2020) reported that inspite of the assertion that higher profits are associated with technical efficiency conditions and shrimp intensification's relationship to disease triggered by climatic changes, there are no known studies that investigated the effects of climate change and disease risk factors on technical efficiency, its effects on farm profitability and national production goal attainment. Furthermore, studies on economic efficiency omit the effects of disease and climatic events perception on farm profitability.

There have been studies which included socio-personal and socio-economic indices while estimating technical efficiency in aquaculture (Wang *et al.,* 1996; Rahman, 2011; Rahman *et al*., 2011; Begum *et al.,* 2013; 2015). We did not find any significant role of socio-personal and socio-economic variables in influencing the technical efficiency in shrimp farming and this is in agreement with the observations of Kumaran *et al.* (2017).

In the prevailing fluid situation in many economies across the countries, it is pointed out that shrimp farmers need to be more cost efficient along the production chain. Shrimp farmers cannot control the market prices, that too international market prices, but what they could possibly control is production cost. Therefore, it is important that farmers acquire necessary technical and management skills for successful and sustainable shrimp farming. Capacity building programs towards this will enable them to be more efficient to have more profitable and sustainable shrimp aquaculture.

Policy interventions to slash the production cost of farmed shrimps are needed as the output price is beyond control. Indian shrimp aquaculture industry relies on imports of live feeds like Artemia, SPF shrimp broodstock from CAA approved global suppliers, formulated feeds and growth promoters. Removal of the import duty will help the shrimp farmers and shrimp hatchery operators in a big way. Since shrimp farming is export oriented, import duty need not be imposed.

Also necessary institutional mechanisms need to become operational in domestic marketing of the farmed shrimps. It is important for the development institutions and agencies to figure out the constraints to domestic marketing and evolve and implement suitable strategies for developing domestic marketing of shrimps. This will augur well for all the stakeholders including the farmers in the long run as domestic prices will not be fluctuating as is the case with the export market. The health care concerns of our middle class and upper middle class populace besides the rich segment would drive the demand for fresh, farmed shrimps significantly. It is necessary to create chain of cold storage facilities and public awareness about the benefit of shrimp as healthy food need to be focused. Farmers can harvest in a phased manner considering the local demand. This could be possible by establishing a transparent communication network between all the shrimp farmers in a locality and their regular processors/buyers/fish selling outlets. The call for a minimum support price also needs government attention.

It is also important to minimise disruptions in the aquaculture inputs availability and in maintaining the supply chains smoothly so that the sector becomes vibrant again. Difficulties in the import of SPF broodstock, ensured availability of space or cubicles in the aquatic quarantine facility, diversification of the species farmed instead of depending on vannamei shrimps alone will also facilitate sustainable development of the shrimp aquaculture sector.

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References

Aalimahmoudi, M., Reyshahri, A., Bavarsad, S. S. and Maniat, M. 2016. Effects of feeding frequency on growth, feed conversion ratio, survival rate and water quality of white leg shrimp *(Litopenaeus vannamei*, Boone, 1931*). Int. J. Fish. Aquat. Stud*., 4: 293-297.

Abdullahi Iliyasu, Zainal Abidin Mohamed, Mohd Mansor Ismail, Amin Mahir Abdullah, Salleh Mohamed Kamarudin and Hashim Mazuki 2014. A review of production frontier research in aquaculture (2001-2011), *Aquac. Econ. Manage.*, 18(3): 221-247. DOI: 10.1080/ 13657305.2014.926464.

Aigner, D. J., Lovell, C. A. K. and Schmidt, P. 1977. Formulation and estimation of stochastic frontier production models, *J. Econometrics*, 6(1): 21-37. https://doi.org/10.1016/0304-4076(77)90052-5.

Ali, M. and Chaudhry, M. A. 1990. Inter-regional farm efficiency in Pakistan's Punjab: A frontier production function study, *J. Agric. Econ.,* 41(1): 62-74. https://doi.org/10.1111/j.1477-9552.1990.tb00619.x.

Ali, M. and Byerlee, D. 1991. Economic efficiency of small farmers in a changing world: A survey of recent/evidence, *J. Int. Dev.,* 3: 1-27.

Araneda, M., Perez, E. P., Gasca-Leyva, E. 2008. White shrimp *Penaeus vannamei* culture in freshwater at three densities: Condition state based on length and weight. *Aquaculture,* 283: 13-18.

Awoyemi, T. T., Amao, J. O. and Ehirim, N. C. 2003. Technical efficiency in aquaculture in Oyo State, Nigeria. *Indian J. Agric. Econ*., 58(4): 812-819.

Battese, G. E. and Rao, D. P. 2002. Technology gap, efficiency and a stochastic metafrontier function. *Int. J. Business Econ.,* 1(2): 87-93.

Begum, E. A., Hossain, M. I. and Papanagiotou, E. 2013. Technical efficiency of shrimp farming in Bangladesh: An application of the stochastic production frontier approach. *J. World Aquac. Soc.*, 44(5): 641-654. https://doi.org/10.1111/jwas.12062.

Begum, E., Hossain, M. I., Tsiouni, M. and Papanagiotou, E. 2015. Technical efficiency of shrimp and prawn farming: Evidence from coastal region of Bangladesh, *CEUR Workshop Proceedings*, 1498: 842-857.

Belbase, K. and Grabowski, R. 1985. Technical efficiency in Nepalese agriculture, *Journal of Developing Areas,* 19: 515-525.

Bhattacharya, P. 2008. *Comparative study of traditional vs. scientific shrimp farming in West Bengal: A technical efficiency analysis, Working paper*. Institute for social and Economic Change, Bangalore, Karnataka, India.

Cision 2020. World shrimp industry opportunity assessment 2020-2026. *Research and Markets*. https://www.prnewswire.com/news-releases/world-shrimp-industry-opportunity-assessment-2020-2026 301017221.html (Accessed 21 January 2022).

Coelli, T. 1996. *A guide to FRONTIER version 4.1: A computer program for Stochastic Frontier Production and Cost Function estimation.* CEPA Working Paper 96/07. Centre for Efficiency and Productivity Analysis, University of New England, Armidale, New South Wales, Australia, 33 pp.

Dey, M. M., Paraguas, F. J., Bimbao, G. B. and Regaspi, P. B. 2000. Technical efficiency of Tilapia grow out pond operations in the Philippines. *Aquac. Econ. Manage.*, 4: 49-63.

FAO 2020a. *How is COVID-19 affecting the fisheries and aquaculture food systems. Policy Brief*. Food and Agriculture Organisation of the United Nations, Rome, Italy. https://www.fao.org/family-farming/detailen/c/ 1275283/.

FAO 2020b. *The impact of COVID-19 on fisheries and aquaculture - A global assessment from the perspective of regional fishery bodies: Initial assessment*. Food and Agriculture Organisation of the United Nations, Rome, Italy.

Forsund, F. R., Lovell, C. A. K and Schmidt, P. 1980. A survey of frontier production functions and their relationship to efficiency measurement, *J. Econometrics*, 13: 5-23.

Gunaratne, L. H. P. and Leung, P. S. 1996. *Asian black tiger shrimp industry: A meta- production frontier analysis.* In: Leung, U. P. S. and Sharma, K. R. (Eds.), Network of Aquacutlure Centres in Asia-Pacific (NACA), University of Hawaii at Manoa, Honolulu, Hawaii, 55 pp.

Hasan, N. A., Heal, R. D., Bashar, A., Bablee, A. L. and Haque, M. M. 2021. Impacts of COVID-19 on the finfish aquaculture industry of Bangladesh: A case study, *Mar. Policy,* 130(1): 104577. DOI:10.1016/j.marpol.2021.104577.

Hernandez-Llamas, A. and Villarreal-Colmenares, H. 1999. A software reference to shrimp *Litopenaeus* farming practices. *Aquac. Econ. Manage*., 3: 267- 280.

Hung, L. T. and Huy H. P. V. 2007. Analysis of feeds and fertilisers for sustainable aquaculture development in Vietnam. In: Hasan, M. R., Hecht, T., De Silva, S. S. and Tacon, A. G. J. (Eds.), *Study and analysis of feeds and fertilisers for sustainable aquaculture development.* Food and Agriculture Organisation of the United Nations, Rome, Italy, p. 331-361.

IFPRI 2020. *Global food policy report: Building inclusive food systems,* International Food Policy Research Institute (IFPRI), Washington, DC, USA.

Islam, M., Milstein, A., Wahab, M. A., Kamal, A. H. M. and Dewan, S. 2005. Production and economic return of shrimp aquaculture in coastal ponds of different sizes and with different management regimes. *Aquac. Int.,* 13(6): 489-500. https://doi.org/10.1007/ s10499-005-9000-7.

Ivanov, D. 2020. Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case, *Transp. Res. Part E: Logist. Transp. Rev*., 136(2020): 101922.

Jayaraman, R. 1998. Economics and technical efficiency in carp culture in Thanjavur District, Tamil Nadu State, India. *Proceedings of the 9th International Conference of the International Institute of Fisheries Economics and Trade*, 8-11 July 1998, Tromso, Norway, p. 71-82.

Jayaraman, R. 1999. Economics and technical efficiency in carp culture. *Proceedings of the XIth Annual Conference of the European Association of Fisheries Economists,* Dublin, 06-10 April 1999. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.507.2003&rep=rep1&type=pdf. (Accessed 15 March 2021).

Jayaraman.R. 2000. Measurement of technical efficiency in cultured carp production-Frontier function approach, *Indian J. Fish*., 47(2): 129-134.

Jondrow, J., Lovell, C. A. K., Materov, I. S. and Schmidt P. 1983. On the estimation of the technical inefficiency in the stochastic frontier production function model, *J. Econometrics*, 19(2): 233-238.

Kakoolaki, S., Ebne al-Torab, S., Ghajari, A., Anvar, A., Sepahdari, A., Ahari, H. and Hoseinzadeh, H. 2020. Socio-economic impacts of Coronavirus (COVID-19) outbreak on world shrimp aquaculture sector, *Iran. J. Aquat. Anim. Health,* 6: 1-18.

Kongkeo, H. 1997. Comparison of intensive shrimp farming systems in Indonesia, Philippines, Taiwan and Thailand. *Aquac.. Res*. 28: 789-796.

Kumar, A., Birthal, P. S. and Badruddin 2004. Technical efficiency in shrimp farming in India: Estimation and implications, *Ind. J. Agri. Econ*., 59(3): 413-420.

Kumaran, M., Anand, P R., Ashok Kumar, J., Ravisankar, T., Johnson Paul, Kumaraguru Vasagam, K. P., Deboral Vimala, D. and Ananda Raja, K. 2017. Is Pacific white shrimp (*Penaeus vannamei*) farming in India is technically efficient? - A comprehensive study, *Aquaculture*, 468: 262-270. https://doi.org/10.1016/j.aquaculture.2016.10.019.

Kumaran, M., Geetha, R., Antony, J., Kumaraguru Vasagam, K., Anand, P., Ravisankar, T., Angel, J. R. J., De, D., Muralidhar, M. and. Patil, P. K 2021. Prospective impact of Corona virus disease (COVID-19) related lockdown on shrimp aquaculture sector in India - A sectoral assessment, *Aquaculture,* 531: 735922.

Kungvankij, P. and Chue, M. 1986. *Shrimp culture: Pond design, aeration, and management. FAO, NACA training manual Series No.20*. Food and Agriculture Organisation of the United Nations, Rome, Italy and Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.

Lau, L. J. and Yotopoulos, P. A. 1989. The meta-production function approach to technological change in world agriculture. *J. Dev. Econ.*, 31(2): 241-269. https://doi.org/10.1016/0304-3878(89)90014-X.

Magallon, F. J. 2006. *Development and application of a methodology to evaluate the variability in the carrying capacity of shrimp aquaculture in the region of the Gulf of California*. Doctoral Thesis. University of Havana, Havana, Cuba (In Spanish).

Meeusen, W. and van den Broeck, J. 1977. Efficiency estimation from Cobb-Douglas production function with composed error. *Int. Econ. Rev.*, 18: 435-444.

Milstein, A., Islam, M. S., Wahab, M. A., Kamal, A. H. M., Dewan, S. 2005. Characterisation of water quality in shrimp ponds of different sizes and with different management regimes using multivariate statistical analysis. *Aquac. Int*., 13: 501-518.

Moss, K. R. K. and Moss, S. 2004. Effects of artificial substrate and stocking density on the nursery production of Pacific white shrimp *Litopenaeus vannamei*. *J. World Aquac. Soc*., 35: 536-542.

MPEDA 2021. *Marine Products Export Development Authority*, Kochi, India. https://mpeda.gov.in/?page_id=438# (Accessed 06 March 2021).

Nguyen, K. A. T. and Fisher, T. C. G. 2014. Efficiency analysis and the effect of pollution on shrimp farms in the Mekong River Delta. *Aquac. Econ. Manage.*, 18(4): 325-343. https://doi.org/10.1080/13657305.2014.959209.

Nguyen, K. A. T., Nguyen, T. A. T., Jolly, C. M. and Nguelifack, B. M. 2020. Economic efficiency of extensive and intensive shrimp production under conditions of disease and natural disaster risks in Khanh Hoa and Tra Vinh provinces, Vietnam. *Sustainability*, 12(5): 2140.

Ogundari, K. 2010. Modeling technical efficiency with production risk: A study of fish farms in Nigeria, *Marine Res. Econ.*, 25: 295-308. https://doi.org/10.5950/0738-1360-25.3.295.

Ogundari, K. and Akinbogun, O. O. 2010. Modelling technical efficiency with production risk: A study of fish farms in Nigeria. *Mar. Res. Econ.*, 25(3): 295-308. https://doi.org/10.5950/0738-1360-25.3.295.

Onumah, E. E. and Essilfie, F. L. 2020. Regional analysis of fish farms in Ghana: A stochastic metafrontier approach. *Aquac. Stud.,* 20(2): 99-111. https://doi.org/10.4194/2618-6381-v20_2_04.

Pazir, M., Ajdari, A. and Ghawampour. A. 2020. The effect of gradually decline of salinity on haemolymph parameters of adult shrimp *Litopenaeus vannamei* (Boone, 1931). *Iran. J. Aquat. Anim. Health,* 6 : 19-28.

Radhakrishnan, K., Sivaraman, I. and Krishnan, M. 2021. Evaluating input use efficiency in shrimp farming by stochastic production frontier approach. *Aquac. Res.*, 52(2): 859-870. https://doi.org/10.1111/are.14940.

Rahman, S. 2011. Resource use efficiency under self-selectivity: The case of Bangladeshi rice producers. *Aust. J. Agric. Res. Econ.*, 55(2): 273-290. https://doi. org/10.1111/j.1467-8489.2011.00537.x.

Rahman, S., Barmon, B. K. and Ahmed, N. 2011. Diversification economies and efficiencies in a "blue-green revolution" combination: A case study of prawn-carp-rice farming in the "gher" system in Bangladesh. *Aquac. Int.,* 19(4): 665-682. https://doi. org/10.1007/s10499-010-9382-z.

Rahman, M. T., Nielsen, R., Khan, M. A. and Asmild, M. 2019. Efficiency and production environmental heterogeneity in aquaculture: A meta-frontier DEA approach. *Aquaculture*, 509: 140-148. https://doi.org/10.1016/j.aquaculture.2019.05.002.

Reddy, G. P., Reddy, M. N., Sontakki, B. S. and Bala Prakash, D. 2008. Measurement of efficiency of shrimp (*Penaeus monodon*) farmers in Andhra Pradesh, *Indian J. Agric. Econ*., 63(4): 653-657.

Roy, A. K. 2008. Econometric approach of estimation of technical efficiency of fish culture farms. *J. Indian Soc. Agric. Stat*., 62(1): 96-107.

Ruiz-Velazco, J. M. J., Hernandez-Llamasc, A. and Gomez-Mu˜noz, V. M., 2010. Management of stocking density, pond size, starting time of aeration and duration of cultivation for intensive commercial production of shrimp *Litopenaeus vannamei*. *Aquac. Eng.,* 43: 114-119. doi:10.1016/j.aquaeng.2010.08.002.

See, K. F., Ibrahim, R. A. and Goh, K. H 2021. Aquaculture efficiency and productivity: A comprehensive review and bibliometric analysis, *Aquaculture,* 544: 736-881. https://doi.org/10.1016/j.aquaculture.2021.736881.

Shapiro, K. H. 1983. Efficiency differentials in peasant agriculture and their implications for development policies, *J. Dev. Stud.,* 19 (2): 179-190. https://doi.org/10.1080/00220388308421857.

Sharma, K. R. 1999. Technical efficiency of carp production in Pakistan. *Aquac. Econ. Manage.*, 3(2): 131-141. https://doi.org/10.1080/13657309909380240.

Sharma, K. R. and Leung, P. S. 1998. Technical efficiency of carp production in Nepal: An application of the stochastic frontier production function approach. *Aquac. Econ. Manage.*, 2: 129-140.

Sharma, K. R. and Leung, P. S. 2000a. Technical efficiency of carp production in India: A stochastic frontier production function analysis. *Aquac. Res.,* 31(12): 937- 947. https://doi.org/10.1046/j.1365-2109.2000.00521.

Sharma, K. R. and Leung, P. S. 2000b. Technical efficiency of carp pond culture in South Asia: An application of a stochastic meta-production frontier model. *Aquac. Econ. Manage.*, 4(3-4): 169-189. https://doi.org/10.1080/13657300009380268.

Sharma, K. R. and Leung, P. S. 2003. A review of production frontier analysis for aquaculture management. *Aquac. Econ. Manage.*, 7(1-2): 15-34. https://doi.org/10.1080/13657300309380329.

Singh, K., Dey, M. M., Rabbani, A. G., Sudhakaran, P. O. and Ganesh Thapa 2009. Technical efficiency of freshwater aquaculture and its determinants in Tripura, India *Agric. Econ. Res. Rev.,* 22 :185-195.

Sivaraman, I. 2014. *A critical analysis of better management practices in shrimp farming in Andhra Pradesh*, Ph. D Thesis. ICAR-Central Institute of Fisheries Education, Mumbai, India.

Sivaraman, I., Krishnan, M., Ananthan, P. S., Satyasai, K. J. S., Krishnan, L., Haribabu, P. and Ananth, P. N. 2015. Technical efficiency of shrimp farming in Andhra Pradesh: Estimation and implications. *Curr. World Env.,* 10(1): 199-205. DOI:10.12944/CWE.10.1.23.

Stephens, E. C., G. Martin, M. van Wijk, J. Timsina and Snow, V. 2020. Impacts of COVID-19 on agricultural and food systems worldwide and on progress to the sustainable development goals, *Agric. Syst*., 183: 102873. doi: 10.1016/j.agsy.2020.102873.

Tacon, A. G. T. 1993. Feed formulation and on-farm feed management. In: New, M. B., Agt, T., Csavas, I. (Eds.), *The FAO/ AADCP Regional Expert Consultation on farm-made aquafeeds*. 14-18 December 1993, Bangkok, Thailand.

Tendencia, E. A. and Verreth, J. A. 2011. Temperature fluctuation, low salinity, water microflora: Risk factors for WSS Voutbreaks in *Penaeus monodon*. *Isr. J. Aquac. Bamidgeh,* 63: 63-548.

Ton Nu Hai, A., Van Meensel, J. and Speelman, S. 2020. The factors influencing environmental performance of marine aquaculture: A combined material balance-based and meta-frontier approach. *J. Cleaner Prod.,* 269: 122342. https://doi.org/10.1016/j.jclepro.2020.122342.

Uma Devi, K. and Eswara Prasad, Y. 2004. A study on technical efficiency of shrimp farms in coastal Andhra Pradesh, *Agric. Econ. Res. Rev.,* 17(2): 175-186.

Umamaheswari, L., Chandrasekar, V., Swaminathan, N. and Poonguzhalan, R. 2013. Technical efficiency of freshwater aquaculture farms in the Union Territory of Puducherry:

Frontier production function approach, *Indian J. Fish.,* 60(2): 93-98.

Waibel, H., Pahlisch, T. H., Volker, M. 1987. Farmers' perceptions of and adaptations to climate change in South-east Asia: The case study from Thailand and Vietnam. In: Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., Branca, G. (Eds.), *Climate smart agriculture*. Springer: Cham, Switzerland.

Waiho, K., Fazhan, H., Ishak, S. D., Kasan, N. A., Liew, H. J., Norainy, M. H. and Ikhwanuddin, M. 2020. Potential impacts of COVID-19 on the aquaculture sector of Malaysia and its coping strategies, *Aquac. Rep.*, 18: 100450. https://doi.org/10.1016/j.aqrep.2020.100450.

Wang, J., Cramer, G. L. and Wailes, E. J. 1996. Production efficiency of Chinese agriculture: Evidence from rural household survey data. *Agric. Econ.*, 15(1): 17-28. https://doi.org/10.1016/S0169 -5150(96)01192-9.

Wyban, J. A., Lee, C. S., Sato, V. T., Sweeney, J. N., Richards and W. K. 1987. Effect of stocking density on shrimp growth rates in manure-fertilized ponds. *Aquaculture,* 61:23-32. https://doi.org/10.1016/0044-8486(87)90334-6.

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