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Impact of control measures in fisheries management: evidence from Bangladesh's industrial trawl fishery

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Abstract

This paper examines the effectiveness of different management tools, particularly input and quality controls on Bangladesh's industrial trawl fishery using Stochastic Frontier Analysis (SFA). Results show that the efficiency of the industrial trawl fishery comes from multiple owner managed vessels, export oriented vessels and registered vessels that are mainly engaged in double rigger trawling. Results also indicate that freezer vessels with small storage capacity, using small gear, are relatively less efficient. This study also shows that over the period shrimp vessels are technically more efficient than fish vessels.

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1. Introduction

The market for fish and fish protein is one of the world's fastest growing international commodity markets. For developing countries, fishery product exports generate more revenue than the combined earnings from other agricultural exports such as coffee, bananas, rice and tea. But fisheries production and yield are constrained by various factors. Without research on these constraints, any decision and policy implementation could generate inefficiency. Various control measures (e.g., input control and output controls) have been considered in fisheries management to maintain the target species at or above levels necessary to ensure their continued productivity. This paper examines the effectiveness of different management tools, particularly input and quality controls on Bangladesh's industrial trawl fishery during the period 2001-05. Stochastic Frontier Analysis is used to measure the efficiency of 103 industrial vessels. Different input and quality control measures have been introduced since 1983 for managing Bangladesh's industrial fishing sector; actions taken without any research based evidence. Hence, the objective of this research is to measure the effectiveness of input control and quality control measures. A good deal of research has been done on efficiency and fishery, although the number of studies measuring technical efficiency in an industrial trawl fishery is limited. No research has been done on measuring the efficiency of the industrial trawl fishery of Bangladesh. This is the first study to do so.

This paper is divided into seven sections. Section 2 gives some background information. Section 3 describes a theoretical framework followed by data sources and variables in Section 4. The econometric specification is described in Section 5. Section 6 presents results and discussion. Section 7 offers some conclusions.

2. Background

Bangladesh's marine capture fisheries are sub-divided into artisanal[1] and industrial[2] fisheries. Development of the industrial trawl fishery was established in 1974. At present 116 registered vessels and 30 unregistered vessels are engaged in fishing (MFD 2009). Industrial fishing vessels are divided into two broad categories, shrimp and fish, which have been exploited to different levels. Shrimp vessels are double-rigged vessels and trawls occur beyond 40 meters depth within the EEZ of Bangladesh to catch shrimp and fish (depending on the license requirements). On the other hand, fish vessels are stern vessels and trawls occur in four different fishing areas beyond 40 meters depth within the EEZ of Bangladesh to catch fin fish and shrimp (by catch).

The industrial fishery of Bangladesh is managed by both input controls and quality controls under the Marine Fisheries Ordinance 1983, the Marine Fisheries Rules 1983 and the Fish and Fish Products (Inspection and Quality Control) Ordinance 1983. The Marine Fisheries Ordinance 1983 regulates the management, conservation and development of marine fisheries. Input control measures in the industrial fishery sector in Bangladesh were introduced in 1983 and modified several times between 1983 and 2004 to protect fish stock for both shrimp and fin fish (by catch) and to reduce sea water pollution. The Fish and Fish Products (Inspection and Quality Control) Ordinance 1983 regulates the issuance of licenses for export oriented fishing vessels.

[1] An artisanal fishery is a small scale onshore fishery and fishing occurs up to 40 meters depth with mechanized and non mechanized boats.

[2] An industrial fishery is a large scale offshore fishery and fishing occurs beyond 40 meters depth within the EEZ of Bangladesh with industrial vessels.

Quality control measures were also introduced in 1983 to ensure food safety requirements for exportable fish products and to increase the quality of catch and export volume.

3. Theoretical frameworks

A stochastic production frontier is used in this study to measure efficiency. Efficiency measures were introduced by Farrell (1957) who suggested that efficiency could be measured with both parametric and non-parametric functions. Stochastic production frontiers were developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). Their specification allows for a non-negative random component in the error term to generate a measure of technical inefficiency, or the ratio of actual to expected maximum output, given inputs and the existing technology. The idea can be applied to cross section data (Kalirajan and Shand 1994) and panel data (Battese and Coelli 1995 and Coelli et al. 2005). Following Battese and Coelli (1995) and Coelli et al. (2005) and indexing vessels by *i=1,2,3, n* the stochastic output frontier is given by:

$$Y_{it} = f(X_{it}, \beta)e^{v_{it} - u_{it}} \qquad (1)$$

for time *t= 1,2, T*; Y_{it} output, X_{it} a $(1 \times k)$ vector of inputs and β a $(k \times 1)$ vector of parameters to be estimated. As usual, the error term v_{it} is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$ and captures random variation in output due to factors beyond the control of vessels. The error term u_{it} captures vessel-specific technical inefficiency in production, specified by:

$$u_{it} = z_{it}\delta + w_{it} \qquad (2)$$

For z_{it} a $(1 \times m)$ vector of explanatory variables, δ a $(m \times 1)$ vector of unknown coefficients and w_{it} a random variable. u_{it} is obtained by a non-negative truncation of $N(z_{it}\delta, \sigma_u^2)$. The condition $u_{it} \geq 0$ in equation (1) guarantees that all observations lie on or beneath the stochastic production frontier.

A trend can also be included in equations (1) and (2) to capture time-variant effects. Battese and Corra (1977) parameterize variance terms by replacing σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2}$. A value of γ close to zero denotes that deviation from the frontier is due entirely to noise while a value of γ close to one would indicate that all deviations are due to inefficiency. So $\gamma = 0$ implies there are no deviations in output due to inefficiency and $\gamma = 1$ implies that no deviations in output the result of stochastic random effects with variance. In other words, deviations in output are due to technical inefficiency effects.

The technical efficiency of the *i*-th vessel in the *t*-th period can be defined as:

$$TE = \frac{E(Y_{it} | u_{it,} X_{it})}{E(Y_{it} | u_{it} = 0, X_{it})} = e^{-u_{it}} = e^{-z_{it}\delta - w_{it}} \qquad (3)$$

and must have a value between zero and one. The measure of technical efficiency is based on the conditional expectation given by equation (3), given the values of $v_{it} - u_{it}$ evaluated at the maximum likelihood estimates of the parameters in the model, where the expected maximum value of Y_{it} is conditional on $u_{it} = 0$.

Efficiency can be calculated for each individual vessel per year by:

$$E\left[e^{u_i} \middle| v_i + u_i\right] = \frac{1 - \phi\left(\dfrac{\alpha_a + \gamma(v_i + u_i)}{\sigma_a}\right)}{1 - \phi\left(\dfrac{\gamma(v_i + u_i)}{\sigma_a}\right)} e^{\gamma(v_i + u_i) + \frac{\sigma_a^2}{2}} \tag{4}$$

for $\sigma_a = \sqrt{\gamma(1-\gamma)\sigma^2}$ and $\phi(.)$ the density function of a standard normal variable (Kompas et al. 2004).

4. Data and variables

In this study the unbalanced panel data set consists of 103 vessels over the period 2001-05. The total number of observations is 418 with 97 missing observations. Fishing log book data, license renewal data and other office based records and primary data for the period 2001-05 are collected from Marine Fisheries Department (MFD) under Department of Fisheries (DoF) of Bangladesh.

The aggregate value of total catch is used for the output variable in the production function. Both shrimp and fish vessels catch shrimp and fish. The amount of shrimp and fish catch (kilogram per year) is converted into values (US dollar per year) using shrimp and fish prices. The shrimp price is measured in taka and converted into US dollars using the annual exchange rate. The average total value of catch per vessel for 2001-05 is USD 300,680.1 per year with the average of 148.299 fishing days per year.

Fuel is measured in liters per year and varies from 3,000 to 1,270,500 liters with an average of 270,008.5 liter per year. The size of crew varies between 22 and 46 with an average of 34.11005 and the standard deviation is 6.336098. Vessel specific total crew data used in this study as quality/category specific crew size is not available. The Material input variable is a sum of expenditure on hygiene and quality control, quality and laboratory certificates and the average cost per trawler is USD 9385.78. All expenditure are drawn in taka and converted into US dollar using annual exchange rate.

Gear length is measured in meters and varies from 20 to 42 meters with a standard deviation of 6.0555 meters and average of 27.44019 meters. Engine power is measured in break horse power (bhp) and varies between 360 and 1,250bhp with an average of 640.3404 bhp and the standard deviation is 200.1249. Storage capacity is measured in kilogram per day and varies 25 and 290.31 kilogram with an average of 81.21883 kilogram and the standard deviation is 40.5633. A time trend is used to capture the non-specific effects over time on harvest. Non-specific effects could be either changes in stock, or technological innovation, changes in regulations, or changes in fishing pattern and practices and so forth (Vestergaard et al 2002). Binary variables for the year 2002, 2004 and 2005 are used to measure possible weather variations. Export orientation is used to capture whether the vessel is export oriented (one) or not (zero). Since the main export product of marine fisheries is shrimp, this binary variable considers only shrimp exports.

The binary variable for private management indicates whether the vessel is single owner (one) managed or company/multiple owner (zero) managed. Gear type indicates whether the vessel is double rigger (one) or other (zero) gear. Vessel type indicates whether the vessel is freezer (one) or non-freezer (zero). Freezer vessels can fish from 20 to 25 days per trip with 30 days sailing permission. On the other hand, non-freezer vessels can fish 10 to 12 days per trip with 15 days sailing permission (MFD 2009). Registration indicates whether the vessel is registered (one) or not (zero).

5. Econometric specifications

The specification of the log-linear Cobb-Douglas production function[3] is:

$$\ln Q_{it} = \beta_0 + \beta_1 \ln F_{it} + \beta_2 \ln C_{it} + \beta_3 \ln Fd_{it} + \beta_4 \ln Mi_{it} + \beta_5 t + \beta_6 Y_{02} + \beta_7 Y_{04} + \beta_8 Y_{05} + v_{it} - u_{it} \tag{5}$$

where, Q_{it} is the value of total catch, F_{it} is the amount of fuel used and a proxy of capital, C_{it} is the total number of crew, Fd_{it} is the number of fishing days, Mi_{it} is the expenditure for hygiene and quality control, quality and laboratory certificate and t is time trend of stock. The value of Y_{02}, Y_{04} and Y_{05} are weather dummies for 2002, 2004 and 2005.

Vessel specific factors are used in the technical inefficiency model:

$$\ln u_{it} = \delta_0 + \delta_1 \ln G_{it} + \delta_2 Gt + \delta_3 \ln Ep_{it} + \delta_4 R + \delta_5 \ln Sc_{it} + \delta_6 Vt + \delta_7 Ex + \delta_8 M + w_{it} \tag{6}$$

where, G_{it} is the length of gear, Ep_{it} is the engine power and Sc_{it} is the storage capacity. Gt, Vt, R, Ex and M are dummy variables for gear type, vessel type, registration, export orientation and management of the vessel respectively. Gear length, gear type, engine power and registration are used as input control measures. Storage capacity, vessel type, export orientation and management are used as quality control measures.

Generalized likelihood ratio tests are used to confirm the functional form and specification, with the relevant test statistics given by:

$$LR = -2\{\ln[L(H_0)] - \ln[L(H_1)]\} \tag{7}$$

Where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the null and alternative hypotheses. The correct critical values for the test statistics are drawn from Kodde and Palm (1986) and four different hypotheses are tested to confirm the functional form and the specification. At a 5 per cent level of significance the generalized likelihood ratio tests show the inefficiency effects are stochastic and the stochastic production frontier is appropriate

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[3] As a pre test the null hypothesis of a Cobb-Douglas form of the production function was tested against general translog specification by setting the relevant parameters for squared and interaction terms in the translog form equal to zero ($H_0 : \beta_9 = ... = \beta_{18} = 0$). The resulting test statistic was 2.38 compared to a critical value of 17.67, which is described in Table 4. The test rejects the translog production function and Cobb-Douglas functional form was thus selected.

(i.e., $H_0 : \gamma = 0$ is rejected). The tests also show the Cobb-Douglas functional form of the production function is suitable (i.e., cannot reject $H_0 : \beta_9 = ... = \beta_{18} = 0$) and confirms the presence of non- negative truncated technical inefficiency (i.e., $H_0 : \gamma = \delta_0 = ... = \delta_8 = 0$ is rejected). The test also confirms that the vessel specific input control and quality control variables affect technical inefficiency (i.e., $H_0 : \delta_1 = ... = \delta_8 = 0$ is rejected). Thus, the Cobb-Douglas production function and the technical inefficiency effect model are confirmed.

6. Results

Maximum likelihood estimates are obtained using Frontier 4.1 (Coelli 1996). Results are reported in Table 1:

Table 1 **Parameter estimates of the stochastic production frontier and technical inefficiency model**

	OLS			MLE		
	coefficient	standard-error	t-ratio	coefficient	standard-error	t-ratio
Stochastic Production Frontier						
Constant	4.78	0.67	7.04	6.01	0.65	9.28
Fuel	0.29	0.09	3.23	0.20	0.08	2.52
Crew	-0.06	0.16	-0.40	-0.08	0.13	-0.61
Fishing days	0.90	0.10	8.65	1.03	0.09	11.81
Material inputs	-0.02	0.04	-0.40	-0.08	0.04	-1.76
Time trend	-0.01	0.04	-0.30	-0.002	0.04	-0.05
Year2002	-0.12	0.07	-1.71	-0.11	0.07	-1.52
Year2004	0.23	0.12	2.18	0.16	0.10	1.64
Year2005	0.05		0.35	0.004	0.13	0.03
Technical Inefficiency Effects Model						
Constant				22.71	3.26	6.96
Gear length				-6.34	0.60	-10.62
Gear type				-1.95	0.22	-8.85
Engine power				0.14	0.33	0.42
Registration				-0.65	0.23	-2.77
Storage capacity				-0.66	0.18	-3.77
Vessel type				0.33	0.23	1.39
Export orientation				-0.31	0.24	-1.27
Private management				0.91	0.17	5.40
Sigma square	0.25			0.38	0.04	10.68
Gamma				0.60	0.06	9.23
LLF	-300.64			-251.04		
Mean efficiency (%)				82.25		

Source: Author's calculation.

All input variables in the stochastic production frontier except crew are significant. The capital variable fuel (0.20) and the effort variable for fishing days (1.03) show a significant positive effect on production, which is supported by the previous studies (Kompas et al 2004; Kompas and Che 2005; Vestergaard et al 2002; Felthoven 2002 and Alvarez and Schmidt 2006) . The negative effect of the size of crew (-0.08) on production is insignificant. This insignificant negative result may be due to the use of vessel specific raw total crew data, as quality/category specific crew size is not available. This finding is similar to Kompas et al (2004) and Felthoven (2002)'s findings. But Kirkley et al (1998) and Sharma and Leung (1999) show a significant negative effect and Kirkley et al (1995); Kompas and Che (2005); Hoyo et al (2004) and Vestergaard et al 2002 show a significant positive effect of crew on production. The finding of Campbell and Hand (1998) shows an insignificant positive effect of crew-days on production.

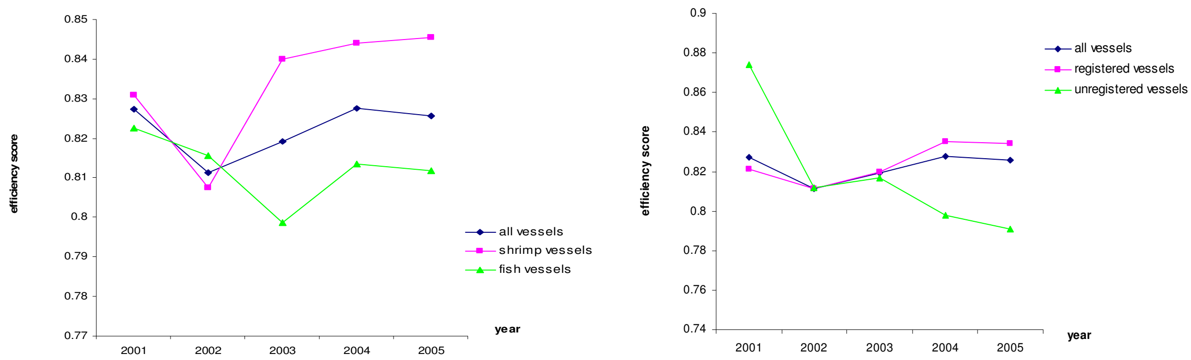
The material input shows a significant negative (-0.08) effect on production. The time trend shows there is an insignificant negative growth rate (0.2 %) in production over the period of analysis. This insignificant negative growth rate is very low compared with Kompas et al (2004). Fish production was significantly lower in the year 2002 as the weather dummy shows there was a significant negative effect on production due to the variation in weather in the year 2002 (-0.11). On the other hand, the weather effect on production in the year 2004 and 2005 are both positive and the weather effect in the year 2004 is significant. The value of gamma is 0.60 and also significant. Gamma shows that the deviation in output is due to inefficiency effects (u_{it}), although the random effect (v_{it}) still clearly matters. The mean technical efficiency (82.25) indicates that there is scope to increase output without increasing any inputs.

All input control variables in the technical inefficiency model except engine power significantly reduce inefficiency and hence increase production. The only input control variable, engine power (0.14) that increases inefficiency is insignificant. This result is opposite to findings of Kompas et al (2004); Fouekis and Klonaris (2003) and Felthoven (2002) which show engine capacity increases production. It is possible that the use of very old engines in this fishery generates this result. Gear type (-1.95) and registration (-0.65) variables are both negative and significant. These two variables show that efficiency of industrial trawl fishery comes from registered vessels and double rigger trawl (shrimp) vessels. The mean efficiency of shrimp and fish vessels in Figure 1 (a) also shows that the mean efficiency of shrimp vessels is much higher than fish vessels. On the other hand, the mean efficiency of registered and unregistered vessels in Figure 1(b) shows there was a sharp decline in unregistered vessels efficiency and the mean efficiency of unregistered vessels were much lower than registered vessels.

Two quality control variables, vessel type (0.33) and private management (0.91), are positive and significant, which shows freezer vessels and single owner managed vessels significantly increase inefficiency and hence reduce production. The variable, private management confirms multiple/company ownership also important for increasing efficiency rather than single/individual ownership as the expenditure on managing hygiene and quality control measures is always high and for single owners the expenditure is unmanageable.

Figure 1. **Mean efficiency of vessels, 2001-05**

(a) Fish and shrimp vessels **(b) Registered and unregistered vessels**



Source: Author's calculation.

Variables, vessel type (0.33) and storage capacity (-0.66), show freezer vessels with less storage capacity are relatively less efficient. Larger storage capacity induces vessel operators to fish more and can reduce the cost of production by fishing longer than non-freezer vessels. Storage capacity and freezing capacity is important to preserve a high volume of catch and to increase export volume. Variables, vessel type (0.33) and gear length (-6.34), show freezer vessels with small gear are also less efficient. Smaller gear reduces the opportunity to catch more fish and increases the cost of production. Variable export orientation (-0.31) is negative and significant and shows that efficiency of industrial trawl fishery comes from export oriented vessels and confirms export orientation is important in increasing the efficiency of export oriented fishing vessels.

7. Conclusions

To manage all constrains in fisheries production, research based effective management control measures are appropriate. This paper examines the effectiveness of different management tools, particularly input and quality controls on Bangladesh's industrial trawl fishery using Stochastic Frontier Analysis (SFA). Results show that the efficiency of the industrial trawl fishery comes from multiple owner managed vessels, export oriented vessels and registered vessels that are mainly engaged in double rigger trawling. Results also indicate that freezer vessels with small storage capacity, using small gear, are relatively less efficient. This study also shows that over the period shrimp vessels are technically more efficient than fish vessels.

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