HARVEST PRODUCTION AND ECONOMIC EFFICIENCY OF BANGLADESHI INDUSTRIAL TRAWLERS IN THE BAY OF BENGAL

ABU BAKER SIDDIQUE

Master Thesis in Fisheries and Aquaculture
Management and Economics
(30 ECTS)

The Norwegian College of Fishery Science
University of Tromso, Norway
&
Nha Trang University, Vietnam

ABSTRACT

Since the 1990's development of industrial trawl fisheries of Bay of Bengal, Bangladesh has attracted due to its high demand and abundance of fish and shrimp resources. This paper investigates Bangladeshi industrial trawl fishery by employing a bioeconomic model and an input-oriented Data Envelopment Analysis. The fundamental objective of this paper is to provide the technique through which long run sustainability can reach an optimum utilization of the resource efficiently to protect marine biodiversity and regenerate fish stocks. For this purpose, a conventional economic model is used simultaneously with a biological population growth model to develop a bioeconomic model. In order to achieve optimal steady state solutions, i.e., optimum levels of stock, harvest and effort are determined and efficiency is compared for five years. This study demonstrates that engine power, and fishing experience strongly affect technical efficiency. Results show that the Bangladesh trawl fishery is not managed and operated optimally and efficiently. Present situation of high effort level, less harvest amount and less fish stock signifies that the danger of depletion of the resource cannot be excluded . Finally, the study will propose some fishery strategies for Bangladesh, such as banning the inefficient trawlers to protect the resource.

DEDICATION

This work is dedicated to my mother and my wife who have supported me greatly in my endeavors. The most important dedication is to my daughter, Nihan, and my sons, Abir and Tamim who represent my future.

ACKNOWLEDGEMENT

My appreciation goes to my supervisors, Associate Professor Arne Eide and Professor Terje Vassdal, who have made a great effort to support me in this thesis. Their profound comments have been really helpful, not only in completing this study but also in improving my methodology for bioeconomic model and DEA analysis. I am very much indebted to them, not only for their close supervision but also for their kind, unreserved devotion to my study.

I'm also grateful to Ms. Corinne, one of our friends, for English.

This study could not have been finished without the cooperation and support of the local DOF inspectors Mr. Abdur Razzaque, Mr. Sajjad Uddin, Md,Zahirul Haque, Md.Monjur Alam and special thanks to Dr.Sarif for sharing his knowledge and authorities in Marine Fisheries Department,Chittagong, Bangladesh. Many thanks go to them.

.

Finally, I'm very grateful to my wife, Shamima Akter, who always encouraged me and created favorable conditions for me during the time I was conducting this study.

Abu Baker Siddique

Chittagong, Bangladesh, 2011

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION

AE	Allocative Efficiency
CPUE	Catch Per Unit Effort
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
EE	Economic Efficiency
DOF	Department of Fishery
DMU	Decision Making Unit
DT	Demersal Trawlers
EEZ	Exclusive Economic Zone
FT	Fish Trawler
GS	Gordon Schaefer
HP	Horsepower
KWH	Kilo Watt Hour
MEY	Maximum Economic Yield
MSY	Maximum Sustainable Yield
MFT	Modern Fish Trawler
MWT	Mid Water Trawlers
MEY	Maximum Economic Yield
MSY	Maximum Sustainable Yield
RL	Regression Line
OY	Optimal Yield
OAE	Open Access Equilibrium
OLS	Ordinary Least Square
PI	Personal Interview
PPS	Production Possibility Set
SE	Scale Efficiencies
ST	Shrimp Trawler
TE	Technical Efficiency
VRS	Variable Returns to Scale

1. INTRODUCTION

Bangladesh is located in South Asia gifted with vast marine, coastal and inland waters having remarkable fisheries potential. According to annual report of DOF, 2010, Bangladesh has a 710 km long coastal line on southern zone of the country and the nation's economic zone extends 320 km out from the coastline. The territorial waters of Bangladesh extend 22 km and the nation's economic zone extends 370 km out from the coastline which covers 166,000 km² of open sea including the exclusive economic zone (EEZ) waters for marine fisheries (DOF, 1999). Fish is an important source of protein and plays a major role in creating rural and coastal employment in Bangladesh. The fisheries sector is the second largest employer involving 13 million people or about 8% of the total labour force. At present this sector is the second largest export sector (DOF, 2010), within the overall agro-fishery-based economy of the country. The contribution of the marine fishery sector has been considered promising for creating jobs, earning foreign exchange supplying food, and supporting the economic and social well being of the Bangladeshi people. To conserve and manage marine fisheries resources through proper utilization needs to ensure sustainability and economic efficiency of this sector. In order to expand the economy of a developing country natural, economic and social capital must be used efficiently. Annual performance must be measured in order to assess the current fisheries policies and to improve upon them (Kim Anh *et al.*, 2006). This paper studies the harvest production and economic efficiency of Bangladeshi industrial trawlers in the Bay of Bengal.

Artisanal and industrial fisheries are two subsectors of marine fisheries (Khan, 2007). The artisanal fisheries in Bangladesh generally operate in coastal waters at an average depth of 40 meters constituting about 92% of the marine capture fisheries. On the other hand, industrial fishing trawlers are fishing in the EEZ water and contributing about 7.26% of the total marine production (DOF, 2010). After the independence of Bangladesh in 1971, industrial trawl fisheries suffered from poor investment because of the lack of knowledge and information on the availability of the size of different fish stocks. In the year 1978 the government took some initiatives to develop industrial trawl fisheries and fishing in the EEZ water has extended quickly (Islam, 2003). In spite of limited regulations this has gone on without any real control or management. Because of an unplanned increase in fishing efforts, many species of the marine fish and shrimp stocks have already declined (Khan and Hoque, 2000a; Khan, 2000). The biodiversity impacts of mangrove exploitation are reflective on the wild fish stock. It has been reported that about 12 fish species are categorized as endangered or threatened due to their decline as a result of change or conversion of habitat (Islam, 2003).

To improve the efficiency of this sector, the Government declared this sector a major industry in 1991. Loan rate for industry is lower than normal rate so that the industrial trawl fishery is getting lower rate loan facilities from the Government .At present, industrial trawl fishing is a big industry in the Bay of Bengal. Current rules dictate that one must fish outside of a 40 meter depth, which is 175 km far from the shore line. The Allotted harvesting area, however, is very little for present trawl fisheries and most of the trawlers fish at depths below 40 meter because of improper enforcement of laws and regulations (DOF, report, 2007). This creates habitat and resource destruction and lower overall catches by damaging the nursery grounds in the Bay of Bengal. Fishing is thus concentrated in coastal waters which has resulted in heavy pressure on areas below 40 meters in depth. Department of fishery (DOF) data shows that during the last three decades there has been nearly a three times increase in the aggregate horsepower (HP) of the fishing trawlers as against a catch increase of only half of this amount. Recent decrease in catch per unit effort (CPUE) shows the increasing resource problems faced by coastal citizens, particularly fisher communities which create great negative impacts on artisanal boat fisheries. So, in order to protect fisher communities and fish resources of the Bay of Bengal, policy-makers need to know more about the harvest production and economic conditions of the industrial trawlers. Some questions may come up, such as: ‘what is the actual and optimum level of harvest? Which type of trawler is the more efficient? The answer to these questions will provide essential and useful information not only for the fishers themselves, but also for policy makers and the fisheries department.

In this thesis we will make use of catch and effort data of the trawler fleet to estimate parameter of assumed harvest equations. A bioeconomic model of Bangladesh trawl fishery is parameterised on the basis of time series data of catch and effort. Then we will estimate the optimal stock, harvest and effort level through the model that ensures the long run sustainability of the resource and maximum benefit. Beside this, the data also reflects relative changes and relations between different species for recent years. Finally, a non-parametric data envelopment analysis (DEA) model is used to measure the efficiency of trawlers to ensure sustainable and efficient trawlers for these fisheries.

The outline of the thesis. The following chapter gives an over view of the marine fisheries of Bangladesh. Thereafter, the model chapter firstly presents and discusses the harvest model to be estimated and how this links to bio economic theory and the models which will be used. Secondly, non-parametric DEA efficiency model is briefly discussed. Beside this DEA efficiency model is used to measure efficiency of trawlers to ensure sustainable and efficient trawlers of these fisheries. Then the data chapter depicts data and data sources used. In the results section estimation findings will first be presented, in addition DEA efficiency comparison is presented using catch and effort data with available economic data. Finally, in the conclusion chapter will include a brief summary of the paper, together with some idea of further work.

2. OVERVIEW OF MARINE FISHERIES IN THE BAY OF BENGAL

The Bay of Bengal is the largest bay in the world, located in the northeastern part of the Indian Ocean. It resembles a triangle in shape occupies an area of 2,172,000 km². It is bordered by Bangladesh, India and Sri Lanka to the west, Myanmar, the Andaman and Nicobar Islands to the east (Wikipedia,2011). The total fish catch of the Bay of Bengal is 3,348,911 tons of which Bangladesh 169087, Sri Lanka 241030, Myanmar 695950 and India 2,242,890 tons (FAO stat, 2009).

The Bangladeshi part of the Bay of Bengal covers an area of 166,000 km^2 and has four well defined and identified fishing grounds. On the south side of Bangladesh there is the biggest fishing ground in the Bay of Bengal named south patches, in the EEZ water an area of 6200 km^2. Another three fishing grounds are south of the south patches 2538 km^2, middle ground 4600 km^2, swatch of no ground 3800 km^2 (DOF,2009) shown in figure 2.1

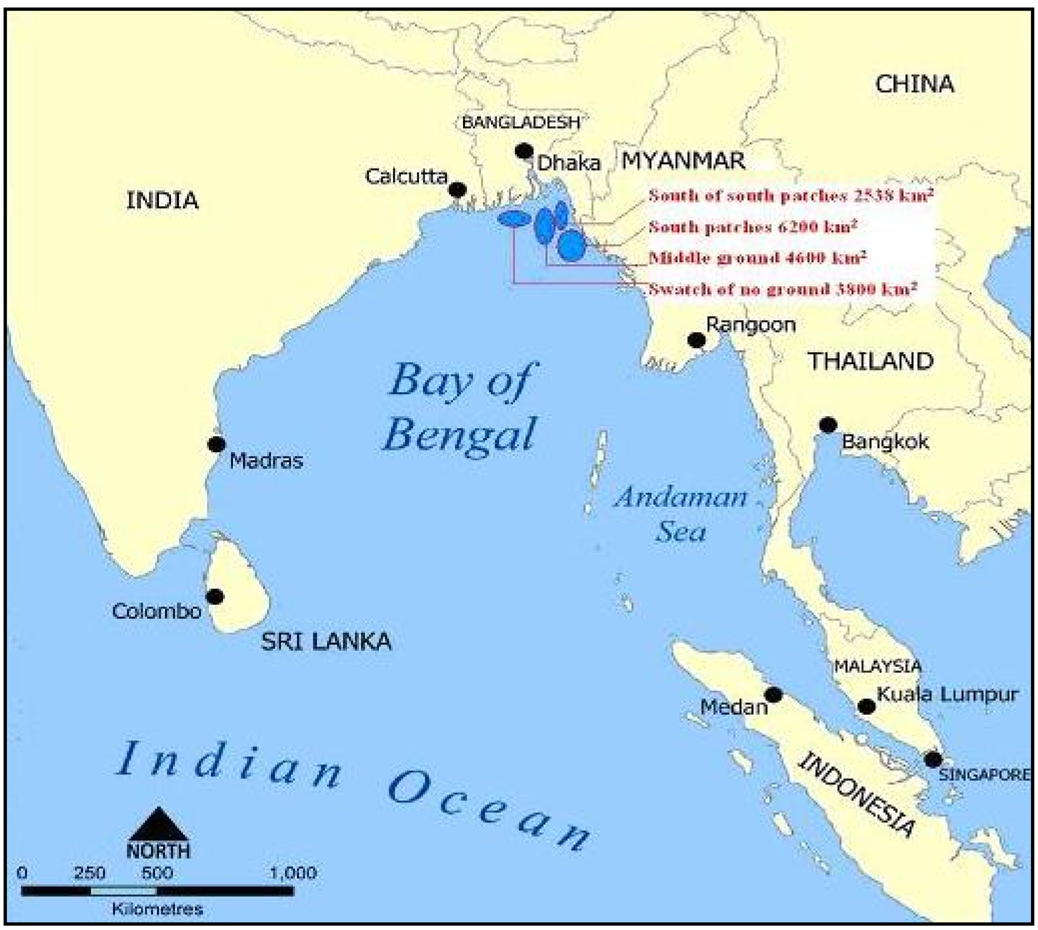


Figure: 2.1 Marine fishing zones of Bangladesh in the Bay of Bengal

Source: http://www.geog.ucsb.edu/img/news/2010/Bay_of_Bengal_map.png

2.1 ARTISANAL FISHERIES

Bangladeshi artisanal fisheries generally carry out their operations in coastal waters, at an average depth of 40 meters. At present 43,136 mechanized and non-mechanized boats operate in this area; directly and indirectly involving 2.5 million people. The costal boats are using traditional gears such as gill nets, hooks and lines, push nets, traps etc. Catches from these gears make up about 92% the total marine captures.

Table 2.1 Number of mechanized and non-mechanized boats

Area	Mechanized boat	Non mechanized boat	Total
Chittagong	10,053	1,692	18,124
Barisal	10,590	19,374	29,964
Khulna	373	1,054	1,427
Total	21,016	22,120	43,136

Source: DOF, 2009

The catch per unit of effort (CPUE) in 2005 for mechanized boats was 139.23 kg/day, while in 2009 it was reduced to 25.00 kg/day. The main species harvested are Hilsha (*Hilsa ilsha*), Bombay duck (*Harpondon nehereus*), Jew fish (*Johnius argentatus*, *Lambu*, *Kaladatina* etc), Exotic carp (*Hypophthalmichthys molitrix*, *Ctenopharyngodon idellus*), Shrimp (*Penaeus monodon*), Snapper (*Lutjanus spp*), Snake head (*Channa punctatus*, *Channa marulius*), Prawn (*Macrobrachium rosenbergii*), Mola (*Amblypharyngodon mola*) and Baila (*Glossogobius giuris*).

2.2 INDUSTRIAL TRAWL FISHERY

Bangladeshi industrial trawlers of the Bay of Bengal carry out their operations beyond 40 meters of depth zone i.e. EEZ water with 165 fishing trawlers and contribute about 7.26% of the marine production. These industrial trawlers are generally harvesting demersal fish and shrimp resources. Recently, industrial trawlers increased their catches by 238% from 95,000 tons in 1976 (Islam, 2003) to 321,110.78 tons in 2010 (DOF, 2010). Still the industrial catches are modest compared with those of the artisanal fisheries. Figure 2.2 illustrates the relation between the two fisheries. In the figure trawl catch amounting 7.26% is the total catch of industrial trawlers and artisanal fishery contributing 92.74% in total.

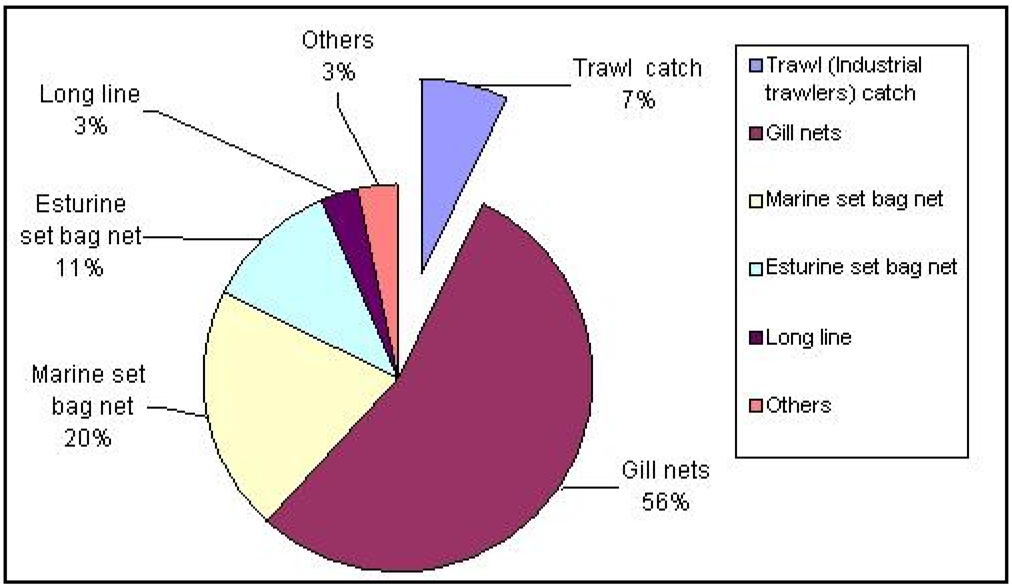


Figure: 2.2 Gear wise catch distribution of fish and shrimp in the Bay of Bengal

Source: DOF, 2009

These industrial trawlers are mainly harvesting demersal fish and shrimp resources. During the last two decades additional more than 50 fishing trawlers of different categories have entered into the industrial trawl fisheries.

2.3 ARTISANAL AND INDUSTRIAL TRAWL CATCH

The Government of Bangladesh marks their economic year from July to June and the inspector of DOF collect their data for each economic year. Here, to simplify and explain the data easily, the economic year has been written as single year 1985 for July 1984 to June 1985 and so on for all the consecutive years. Artisanal and industrial trawl catch of fish and shrimp trawlers is shown in table 2.2.

Table 2.2 Comparison between industrial and artisanal catches in tons

Year	Shrimp Catch (tons)		Fish catch (tons)		Industrial catch total (tons)	Artisanal catch total (tons)
	Industrial	Artisanal	Industrial	Artisanal		
2005	3,076	30,337	30,933	358,255	34,009	388,592
2006	3,310	37,640	30,640	368,893	33,950	406,533
2007	3,404	41,271	33,215	367,836	36,619	409,107
2008	2,174	47,520	31,538	370,815	33,712	418,335
2009	2,620	47,966	32,497	380,331	35,117	428,297

Source: DOF, 2009

2.4 TARGET SPECIES AND BYCATCH OF FISH AND SHRIMP TRAWLERS

Bangladesh started industrial trawl fishing after liberation war in 1973 with a fleet of 10 shrimp trawlers (Khan, 2007). The numbers of shrimp trawlers increased rapidly from 1973 to 1991 and the last two decades there has been a moderate increase in number of fish trawlers. The total number of trawlers in 2006 was 123 of which 41 were shrimp trawlers and the remaining different kinds of fish trawlers. The government does not allow any new licenses for shrimp trawler. There was an increasing trend to 165 fish trawlers, of which about 41 shrimp trawlers are stable for last two decades. This may have been the result of fishing is more profitable business because of higher demand and increase of population as well. But the total number of fishing hours has decreased from 454,560 to 392,016 during the last five years. The target species and bycatch of different trawlers has increased from 1986 to 2010.

Table 2.3 Fish trawlers, annual fishing hours and catches

Year	No of fish trawlers	Fishing hours	Target species (Tons)
1986	14	42,792	5,500
1987	18	56,424	4,769
1988	19	55,944	4,393
1989	8	14,808	931
1990	8	23,760	2,105
1991	12	17,304	1,532
1992	14	34,104	1,974
1993	12	37,080	2,545
1994	11	29,472	3,305
1995	14	32,496	4,404
1996	12	34,368	4,568
1997	14	39,744	5,793
1998	13	44,544	7,515
1999	18	51,264	6,680
2000	21	60,408	8,017
2001	31	92,904	16,027
2002	36	116,184	16,586
2003	42	129,936	19,428
2004	49	150,816	23,207
2005	68	204,840	25,895
2006	78	275,256	27,096
2007	88	275,088	29,446
2008	95	320,832	29,176
2009	107	331,800	31,033
2010	120	282,072	29,654

Source: DOF, 2009

Table 2.4 Shrimp trawlers, fishing hours and target species

Year	No of shrimp trawlers	Fishing hour	Target species (tons)
1986	31	139,056	3,716
1987	31	154,296	4,178
1988	33	159,408	3,361
1989	42	187,344	4,830
1990	44	177,456	3,134
1991	42	135,792	3,652
1992	46	132,696	2,621
1993	37	158,112	3,903
1994	40	170,712	3,453
1995	43	160,584	2,391
1996	41	156,048	3,554
1997	41	165,936	3,508
1998	48	169,056	2,419
1999	41	183,480	3,709
2000	44	171,648	2,908
2001	44	174,936	3,155
2002	44	166,440	3,142
2003	45	169,656	2,455
2004	45	178,608	3,059
2005	45	188,784	3,272
2006	41	179,184	3,337
2007	39	142,056	2,138
2008	38	143,256	2,579
2009	42	142,944	2,878
2010	41	109,944	2,457

Source: DOF, 2010

2.5 TARGET SPECIES

A particular size or sex or a group of species that is mainly sought in a fishery, for example shrimp in a shrimp fishery or full-grown female fish in a roe fishery is called target species. The meaning of targeted catch within a fishery is not static, since in a multispecies fishery, the mix of species targeted and caught can change over time .On the other hand, bycatch is the total catch of non-target animals (FAO, 2005). According to NMFS (1998), bycatch can be defined as discarded catch of any living marine resource in addition to retained incidental catch as well as unobserved mortality because of a direct encounter with fishing gear. According to DOF, targeted different species of fish trawlers are jew, pomfret, grunter, ribbon, big eye, eel, rupban, snaper, red fish, mackerel, cat fish, bombay duck, ailla and bycatch are different shrimps and other species. However, tiger shrimp, white shrimp and brown shrimp are the target specie of shrimp trawler and fish and other species are the bycatch of this type of trawler.

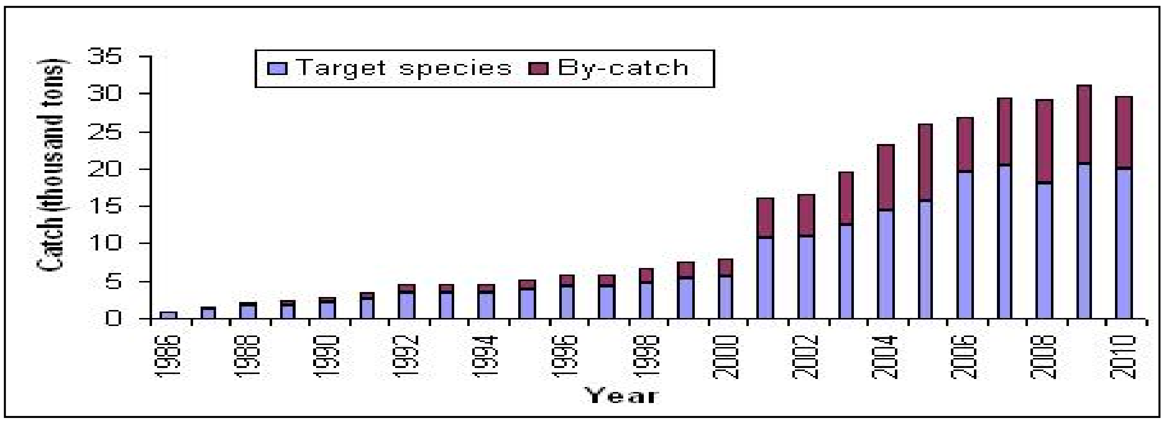


Figure : 2.3a Target species and by catch of fish trawlers

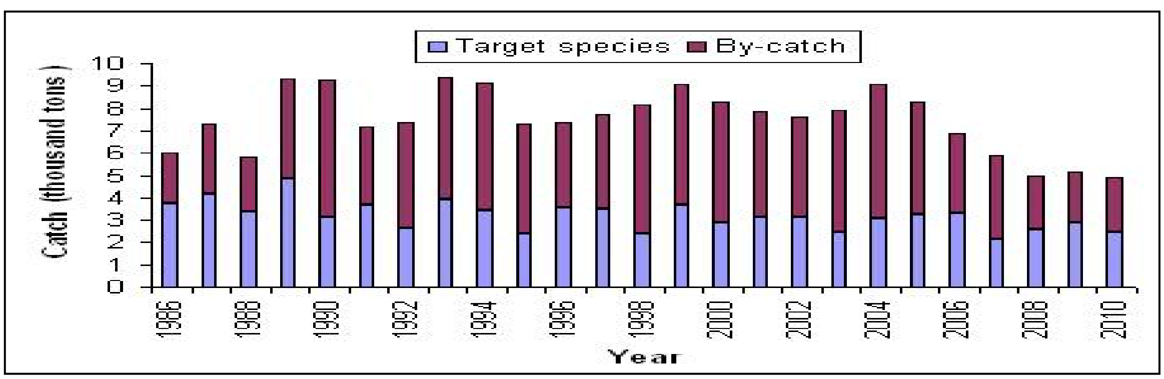


Figure: 2.3b Target species and by catch of shrimp trawlers

2.6 GEAR WISE CATEGORY OF INDUSTRIAL TRAWLERS

Bangladeshi industrial trawlers are harvesting demersal fish and shrimp resources. According to DOF there are four categories of fish trawlers such as: older fish trawler, modern fish trawler, mid-water trawler, and demersal trawler Older and modern fish trawlers run their operation by bottom trawling but modern fish trawlers have highly technical and new equipment. Demersal trawlers are also bottom trawlers but different from fish trawlers by their doors of the gear. Mid water trawlers are fishing in the middle depth of the water. Shrimp trawlers run their operation by bottom trawling beneath 40-meter depth zone.

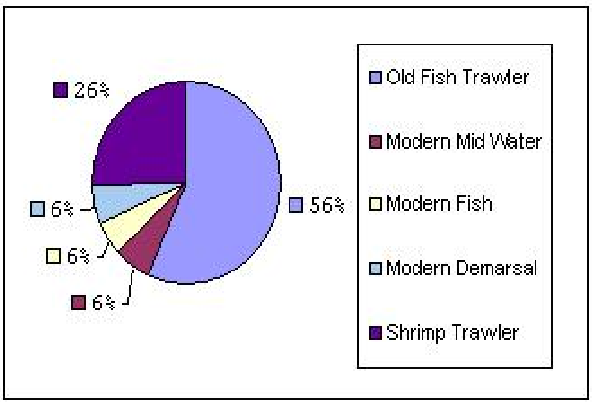


Figure: 2.4a Share of different gears in 2006

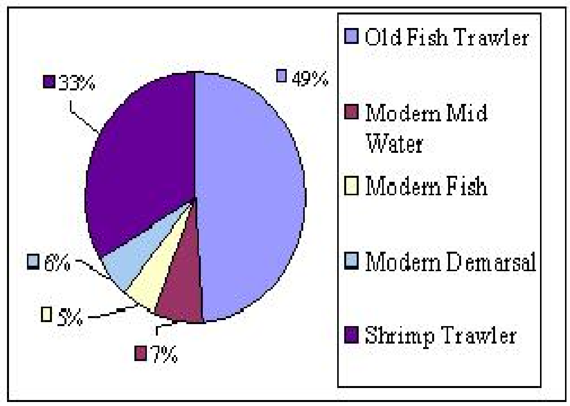


Figure: 2.4a Share of different gears in 2010

3. MODELS

The industrial trawl fisheries of Bay of Bengal have multi-species, tropical fisheries characteristics. Surplus production model is useful in exploring current state and potential of a stock when time series of catch and effort data are available. The main objectives of this study are to investigate optimum economic and sustainable effort and stock of Bay of Bengal's industrial trawl fisheries and the efficiency of the industrial trawlers. In the first step, Gordon-Schafer surplus production model (GS) has been selected for this study. In the second stage, DEA is used to identify more efficient trawlers for sustainable fisheries.

3.1 LOGISTIC GROWTH MODEL AND BIOECONOMIC MODEL

Consequences of different exploitation patterns on fish stocks and ecosystems can be explored by employing bioeconomic models. Surplus production models assume the existence of equilibriums at any fixed fishing mortality or fishing effort, often expressed in a linear negative relationship between fish stock equilibrium biomass and long term levels of fishing effort. The growth of biomass (surplus production) is zero at stock biomasses equal zero and the carrying capacity of the stock, often referred to as the natural equilibrium. Consequently, surplus production is maximized at a stock biomass value between these two. Thus, if the stock yield is less than surplus production then the stock biomass will increase but if yield is greater than surplus production then biomass will decrease. In the following section a simple biological model is presented. Then, economic and sustainable optimum stock, effort, harvest and profit of the fisheries are presented.

3.1.1 LOGISTIC GROWTH MODEL

First consider the logistic growth equation

$$F(X) = rX(1-\frac{X}{k}) \qquad (3.1.1)$$

Where, F(X) is the surplus production per unit of time; X the stock biomass, r the intrinsic growth rate and k the environmental carrying capacity in stock biomass units. The equation describes a parabolic curve as a function of X.

The logistic function is strictly concave from lower and shows positive growth for all positive values of 0 < X < k.

A general growth model for an exploited stock can be expressed by

$$\frac{dX}{dt} = F(X) - H(E, X) \qquad (3.1.2)$$

Where, H(E, X) is the short term harvest function which depends on fishing effort (E) and stock biomass (X). In equilibrium, $\dot{X} = \frac{dX}{dt} = 0$, the natural growth F(X) equals the sustainable yield of a fixed stock level X (Clark, 1990). Hence, at the equilibrium conditions, the sustainable yield can be derived from the function:

$$F(X) \equiv H(E, X)$$

The short-term harvest function is assumed to be:

$$H(E, X) = qEX \qquad (3.1.3)$$

Where, q is the catchability coefficient.

Population growth is then described by

$$\frac{dX}{dt} = rX(1 - \frac{X}{k}) - qEX \qquad (3.1.4)$$

Often referred to as the Gordon-Schaefer model.

At equilibrium, the stock biomass is

$$X_E = \frac{k}{r}(r - qE)$$

Thus, harvesting at equilibrium is obtained by:

$$H(E) = qkE(1 - \frac{qE}{r}) = qEk - \frac{q^2E^2k}{r}$$

$$CPUE = \frac{H}{E} = qk - \frac{q^2k}{r}E \Leftrightarrow CPUE = a + bE \qquad (3.1.5)$$

$$\Leftrightarrow H = aE + bE^2 \qquad (3.1.6)$$

Here, $a = qk$ or k = a/q and $b = -\frac{q^2k}{r}$ or b = (-aq)/r or r= (-aq)/b (3.1.7)

3.1.2 BIOECONOMIC MODEL

In this section, this study is mainly concerned to determine the appropriate level of trawl fishing effort in the Bangladesh. In this consequence, we need to know what would be the minimum point of effort require to attain optimal yield (OY) in the fisheries. And what point of effort would draw the maximum benefits to the fisheries. By differentiating yield with respect to effort and putting the result to zero, the level of effort and the corresponding harvest at maximum sustainable yield (MSY) can be determined.

$$E_{MSY} = \frac{r}{2q} \;, H_{MSY} = \frac{rk}{4} \text{ and } X_{MSY} = \frac{k}{2} \qquad (3.1.8)$$

Bangladeshi trawl fishery is yield dependent and also depends on the growth rate of the species, as well as the costs of harvesting, the prices of the specimens. Catch-effort relationship is used to identify revenues and costs as a function of fishing effort assuming linear relationship between cost and fishing effort, total cost of fishing effort is defined as:

TC(E) = cE

Where, c is a constant reflecting the unit cost of fishing effort. Assuming a constant unit price of harvest, total revenue of the fishery is found by:

TR(E) = pH(E),

Where, p denotes the unit price of the fish.

The difference between total revenue from the fishery and total fishing costs is the sustainable economic rent (abnormal profit) from the fishery at given level of fishing effort E. Thus the sustainable economic rent is

π(E) = TR(E) − TC(E).

In open access and an unregulated fishery, the individual fishers take steps to maximize their income using maximum level of fishing effort. Thus the bionomic or open access equilibrium (OAE) can be determined from the fishery when no economic rent is got from the fishery or abnormal profit is zero, i.e., AR(E) = MC(R), which gives pH(E) = cE implying

$$E_{OAE} = \frac{r}{q}(1 - \frac{c}{pqk}) \,,\; H_{OAE} = \frac{rc}{pq}(1 - \frac{c}{pqk}) \qquad (3.1.9)$$

Since average revenue is equal to marginal cost in open access equilibrium,

$$\frac{pH}{E} = c$$

$$\frac{H}{E} = \frac{c}{p}$$

We can get open access level of the fisheries:

$$H_{\infty} = qE_{\infty}X_{\infty}, \; X_{\infty} = \frac{c}{qp} \qquad (3.1.10)$$

Maximum economic yield (MEY) is found where MR(E) = MC(E)

$$\frac{dTR(E)}{dE} = \frac{dTC(E)}{dE}$$

Thus, $\frac{d}{dE}[p(qEk - \frac{q^2E^2k}{r})] = \frac{d}{dE}(cE)$

Can get $p(qk - \frac{2q^2k}{r}E) = c$

$$E_{MEY} = \frac{r}{2q}(1 - \frac{c}{pqk}), H_{MEY} = \frac{r}{4}(k - \frac{c^2}{p^2q^2k}), X_{MEY} = \frac{k}{2} + \frac{c}{2pq} \qquad (3.1.11)$$

From an economic point of view MSY doesn't involve efficient harvesting, involving efficiency to maximizing the net benefit from the use of economic resources, i.e., maximizing the resource rent. Resource rent is maximized at a lower level of effort than the MSY effort. The MEY point yet depends on prices and costs, and therefore it varies as price of fish and cost of input change.

The stock biomass that maximises the discounted flow of rent over all future in the logistic model is (Clark, 1990; Clark & Munro, 1975):

$$X^* = \frac{k}{4}\left[\left(\frac{a}{pqk} + 1 - \frac{\delta}{r}\right) + \sqrt{\left(\frac{a}{pqk} + 1 - \frac{\delta}{r}\right)^2 + \frac{8a\delta}{pqkr}}\right] \qquad (3.1.12)$$

3.1.3 GRAPHICAL MODELS CHOICE AND DESCRIPTION

The overall target of fisheries management is defined by the management objectives. The three reference equilibriums; open access (OA), maximum economic yield (MEY) and maximum sustainable yield (MSY), may correspond to different management objectives. MEY may be obtained in different ways, i.e. by limited entry, quota regulation or by other means. The Gordon-Schaefer model taken from Gordon (1954) and Schaefer (1957, explained in Flaaten, 2010) is utilised in this study. This model has the advantage of being less data demanding that most other fisheries models. This model also may provide a rough guidance on fleet size and may also be used on single species fisheries as well as for multi-species fishery.

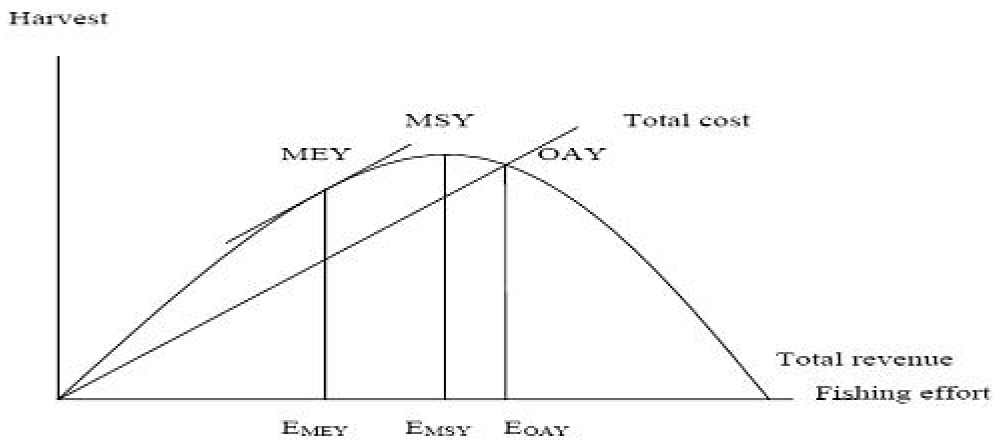


Figure 3.1.1 A catch-effort curve

Source: Flaaten Ola, 2010

3.2 DEFINITIONS AND CONCEPTS OF EFFICIENCY

In the management science literature, productivity and performance measurement have usually been concerned with some factors such as inputs and outputs, processes rather than the organizational whole. Productivity research led to the improvement of other measures that incorporated all the essential factors in aggregated form. These measures presented more insight about technical and financial performance of an organization. The idea of technical efficiency introduced by Farrell (1957) is a result of these concerns. Charnes *et al*. (1978) further expanded Farrell's (1957) work and developed a mathematical programming approach to measure relative efficiency of decision-making units (DMU). Basic concepts and their definitions are summarized below.

3.2.1 PRODUCTION TECHNOLOGY

A production technology is presented as the set (X, Y) such that inputs $X = (x_1, x_2, \dots x_m) \in R^m_+$ are transformed into outputs $Y = (y_1, y_2, \dots y_s) \in R^s_+$. Fare *et al.* (1994) describe production technology with the following notation. Define first a production possibility set (PPS) called T.T is defined such that

$$T = \{(x, y) \in R_+^{m+s} \mid x \text{ can produce } y\}$$

L(y) is the input set such that:

$$L(y) = \{x: (y, x) \in T\},$$

Isoquant *Isoq*L(y) is defined as:

$$IsoqL(y) = \{x: x \in L(y), \lambda x \notin L(y), \lambda < 1)\},$$

And an efficient subset *Eff*L(y) such that:

$$EffL(y) = \{x: x \in L(y), x' \notin L(y), x' \leq x\}$$

Here , $x_i' \leq x_i$, $\forall$ i = 1,…,m and $x_i' < x_i$, for at least one component i.

Similarly as just shown for inputs, an output set can be defined for an output set, an output isoquant and an efficient subset of the output set. AS the rest of this thesis will deal with input sets and input efficiency , output set definitions will not be presented here. A production function can be explained as the relationship between the outputs and inputs of a production technology. A certain set of all technically feasible combinations of output and inputs, only the combinations covering a maximum output for a particular set of inputs would form the production function.Therefore it can be explained by a non-mathematical explanation of the formulas with isoquant. An isoquant is outlined as the locus of points that represent all possible input output combinations that describes the production function for a constant level of output or a constant level of input. Each point on the isoquant corresponds to a unique production technology.

For instance, the isoquant input orientation for output level Y^0 (a given realization of output Y) from input X is:

$$Y^0 = g(X) \qquad (3.2.1)$$

This isoquant is shown in figure 3.2.1. In this case, further the isoquant is from the origin in the positive quadrant, the larger is the output level.

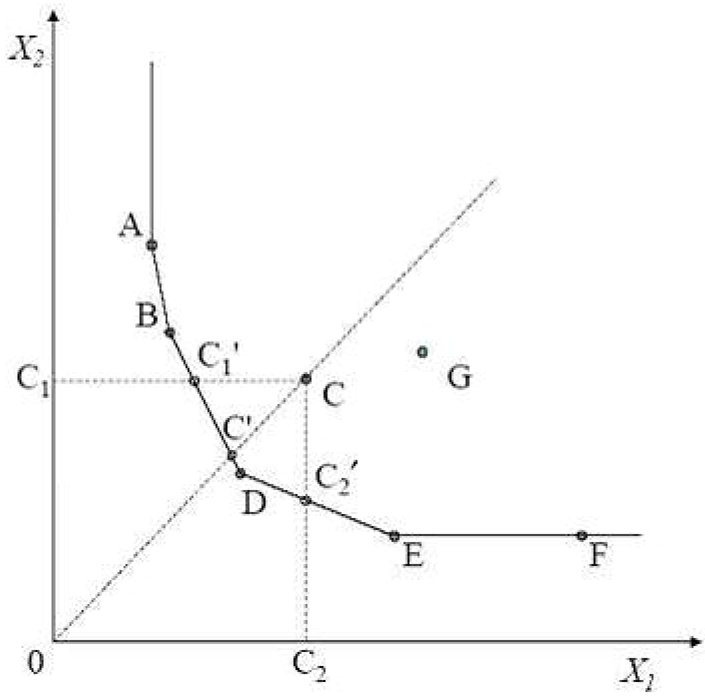


Figure 3.2.1 Isoquant for output level Y^o

All firms on the isoquant with output level Y^0 as efficient. However, firm F is as inefficient. This is due to the fact that while firm F lies on the iso-quant it does not lie on the efficient subset of the isoquant outlined by ABDE. In other words, E gives the same output with fewer inputs (lesser amount of x_1) than F, and consequently F is inefficient. This case emphasizes the situation where a unit may lie on the isoquant but still eat excess inputs compared to other units on the isoquant.

3.2.2 MEASUREMENTS OF EFFICIENCY

Efficiency generally describes the level to which time or effort is well used for the planned task or purpose. It is frequently used with the particular gloss of relaying the capability of a specific application of effort to create a specific outcome effectively with a minimum amount or quantity of misuse, cost, or excessive effort. Efficiency has extensively varying meanings in different disciplines. Economic Efficiency (EE) is divided into two components: Technical Efficiency (TE) and Allocative Efficiency (AE). Technical efficiency (TE) is the ability of a firm to get maximum output from a given set of inputs. According to Farrell (1957) technical efficiency, is described in relation to a certain set of firms, in respect to a specific set of factors measured in a definite way, and any modify in these specifications will affect the measure. This is predictable in any such measure. But with these qualifications it roles in a natural and satisfactory way as determine of efficiency, whereas allocative efficiency is the capacity of a firm to use the inputs in optimal firm to utilize the inputs in optimal proportions, given their relevant prices proportions, given their relevant (Lovell, 1993). Price efficiency (allocative efficiency) is very precise to the introduction of new observations and to residuals in estimating factor prices (Farrell, 1957). Farrell thus proposed against estimating allocative efficiency. Later, an alternative of allocative efficiency, like cost efficiency, income efficiency and profit efficiency have been initiated in DEA models, and is in common use in empirical studies.

3.2.3 RETURNS TO SCALE

In production theory the change in output levels owing to changes in input levels is named as returns to scale. Returns to scale can be classified into constant or variable. Constant returns to scale (CRS) means that an increase in input levels by a particular proportion results in an increase in output levels by the equal proportion. Figure 3.2.2 illustrates this linear relationship between the inputs and outputs. Variable returns to scale (VRS) means that an increase in the input levels need not essentially result in a proportional increase in output levels i.e., the output levels can rise (increasing returns to scale) or the output levels can reduce (decreasing returns to scale) by a different proportion than the input augmentation.

Geometrically, this indicates that the linear relationship between inputs and outputs in the case of CRS is replaced by a curve with a changing slope. Figure 3.2.2 demonstrates the piece wise linear curve with varying slopes. As the slope of the curve increases the production technology shows increasing returns to scale (*as is the case for the point p*). Where the slope of the curve decreases the production technology shows decreasing returns to scale. (*as is the case for point G)*. DEA can be defined under the assumption of constant returns to scale (CRS) or variable returns to scale (VRS). The CRS assumption is only suitable when all firms are functioning at an optimal scale. The use of the CRS condition when all firms are not operating at the optimal scale results in computes of TE, which are confounded by scale efficiencies (SE). The practice of the VRS specification permits the computation of TE devoid of these SE effects. We can assess both the CRS and VRS models and expressing at the difference in scores can calculate SE which shown in figure 3.2.3. Along with the information that a firm is technically inefficient, then the question come up, the firm is too large or too small and this information can be achieved by examining scale efficiency.

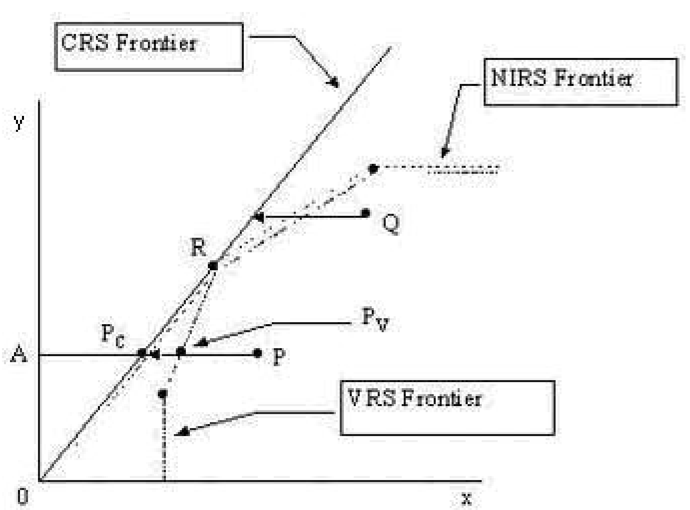


Figure 3.2.2 Constant and Variable Returns to Scale

Technical efficiency of constant returns to scale,

$$TC_{CRS} = AP_C / AP$$

Technical efficiency of variable returns to scale,

$$TE_{VRS} = APc / AP_V \qquad (3.2.2)$$

Scale efficiency,

$$SE = AP_C / AP_V$$

Technical efficiency of constant returns to scale,

$$TE_{CRS} = TE_{VRS} \times SE$$

3.2.4 DEFINITIONS OF TECHNICAL EFFICIENCY

Farrell (1957) proposed a provocative idea to define the output of the most efficient firm as the production frontier for all firms. The idea of technical efficiency concept described with two definitions in the literature of Fare and Lovell, 1978. The input oriented measure of technical efficiency for a unit is described as the difference between unity (100% efficiency) and the maximum equi-proportional decrease in inputs (while maintaining the production of originally particular output levels). When this difference is zero then the unit is efficient moreover it is inefficient. The output-oriented measure of technical efficiency is described as the difference between unity (100% efficiency) and the maximum augmentation of outputs (while still utilizing the originally specific input levels). Again, the unit is efficient when this difference is zero besides it is inefficient. The second one is Koopman's (1951) definition of technical efficiency. The firm is technically efficient if and only if a rise in one output results in a decrease in another output so as not to compromise the input level otherwise results in the increase of at least one input. Stated or else, the definition means that a reduce in one input must result in an rise in another input so as not to compromise the output, otherwise must result in the decrease of at least one output.

3.2.5 TECHNICAL EFFICIENCY:

Farrell (1957) suggested a measure of technical efficiency that incorporated all inputs in an aggregated scalar form and as well overcame the difficulty of converting multi-component input vectors into scalars. Therefore the technical efficiency formulation for multiple input-output configurations is:

$$TE = \frac{\text{Aggregate Input Measure}}{\text{Aggregate Output Measure}} \qquad (3.2.3)$$

The inputs are all resources that are used to generate the outputs. From equation (3.2.3) it can be observed that technical efficiency for a firm relates to its ability to:

(i) Create maximum outputs for a constant input usage (output-increasing efficiency, or

(ii) Apply minimum inputs to generate a constant output production (input reducing efficiency). Technical efficiency measurement involves comparing a decision making unit's (DMU's) production plan to a production plan that lies on the efficient production frontier or isoquant. As described in section 3.2.1, a production plan for a DMU denotes its input usage and output production. The idea of a production plan stimulates two types of technical efficiency measurement, input- reducing and output-increasing. Input-reducing efficiency means the production of a constant output set while reducing the level of inputs used to the least possible. Output-increasing efficiency means maintaining a fixed level of inputs while producing the maximum possible set of outputs.

The concept of comparisons of production plans leads to the need for deriving a "standard of excellence" to perform as a benchmark. This standard must signify that level of technical efficiency that is accomplish with (i) the least amount of inputs and constant outputs (for input-reducing efficiency) and (ii) the maximum production of outputs with constant inputs (for output-increasing efficiency). The literature reports three methods to measure technical efficiency: (i) the index numbers method (ii) the econometric method, and (iii) the mathematical programming method. The index numbers method includes multi-factor productivity models, financial and operational ratios, Parkan (1997). The econometric method presupposes a theoretical production function to provide as the standard of technical efficiency. The Cobb-Douglas, Translog, and Leontief type functions are most generally used to approximate the production function since they are easily transformed into linear forms. Econometric models are further separated into deterministic and stochastic models. For a detailed discussion of the econometric method the reader is referred to Lovell (1993). The mathematical programming method does not require the use of a particular functional form for the production data. Charnes et al. (1978) construct the efficient frontier as an envelopment of the data by using Linear Programming (LP) methods. The consequential model is called Data Envelopment Analysis (DEA). DEA measures the relative efficiency in the existence of not only single input-output but also multiple input and output factors at vessel level or decision making units (DMUs).

While econometric approaches such as, regression analysis employ average observations; mathematical programming approaches e.g., DEA use production frontiers or best practice observations for efficiency analysis. A detailed discussion of input and output orientations of technical efficiency and DEA is presented in the subsequent sections.

3.2.6 DATA ENVELOPMENT ANALYSIS (DEA)

DEA is a non-parametric performance assessment methodology initially designed by Charnes, Cooper and Rhodes (1978) to determine the relative efficiencies of organizational or decision making units (DMUs). The DEA method applies linear programming techniques to observe inputs used and outputs produced by decision-making units and constructs an efficient production frontier founded on best practices. Each DMU's efficiency is then determined relative to this frontier. In other words, DEA measures the efficiency of each DMU relative to all the DMUs in the sample, including itself. This relative efficiency is computed by obtaining the ratio of the weighted sum of all outputs and the weighted sum of all inputs. The weights are selected in order to achieve Pareto optimality for each DMU. The DEA methodology is concerned with technical efficiency i.e., the physical quantity of outputs produced and inputs used as compared to allocative efficiency i.e., the optimal input mix given input prices, and price efficiency i.e., the optimal output mix given output prices (Lewin and Morey ,1981). An appealing view of DEA is that it allows analysis of multiple-input multiple-output-production technologies without requiring price or cost data. Also, the different input and output factors need not have the same measurement units i.e., The efficiency may be invariant to scaling, but not the weights . This is important in public sector organizations where financial and cost data is frequently unavailable for all factors. Therefore, even though missing taking into account the random error due to the deterministic nature, the major advantage of DEA method is that DEA can be applied in multi input – multi output conditions. It is a non-parametric approach and constructs the efficient frontier founded on extreme values of the observed data. To measure efficiency, linear programming procedures can be used. Thus, it is redundant to assume earlier any specific functional form or any assumption on distributions of error.

The DEA methodology helps to find inefficient DMUs and the sources and amounts of inefficiency of inputs and / or outputs. The DEA formulation can incorporate both input-reducing and output-augmenting orientations and constant and variable returns to scale. The following discussion states only the input - orientation. The output- orientation is analogous and obtained similarly. However, different results are derived from the two orientations under the variable returns to scale assumption (Fare and Lovell,1978). Since its original development, DEA has expanded significantly. Emrouznejad (2008), has stated more than 55,000 references on the subject. Different applications of DEA to public organizations such as schools, banks, hospitals, armed services, shops, and local authority departments have been published. In this review, the foundations of the DEA framework, and the significant formulations of input-reducing orientation are presented.

3.2.7 INPUT ORIENTATION

Input-oriented technical efficiency states if we fix the output quantities produced, how much input quantities will be proportionally decreased. In a simple model we can measure 2 inputs and 1 output, under the assumption of constant returns to scale, input-oriented efficiency is illustrated in the following figure 3.2.4

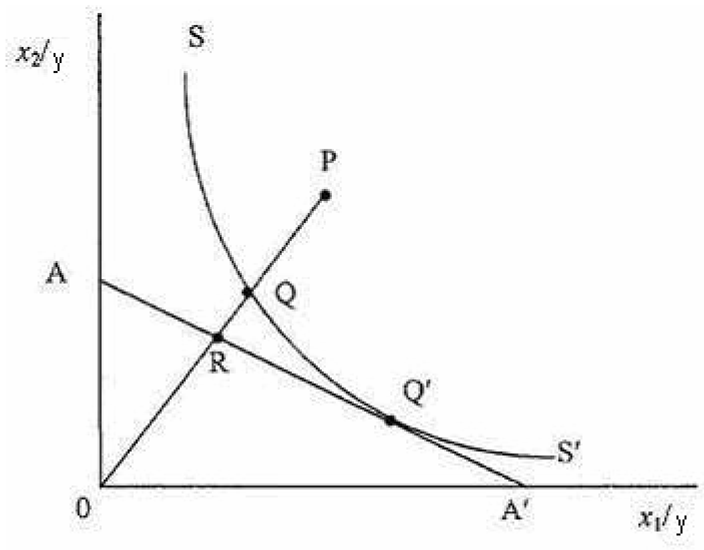


Figure 3.2.3 Technical and allocative efficiency

This figure, the technically efficient firms are those that present the curve SS'. Hence, Q and Q' are technically efficient points. Meanwhile, P shows technically inefficient point and the inefficiency of that firm could be explained by the distance OQ/OP when it is less than one. It means that the firm could reduce the use of both inputs from P to Q without the fall in output. In other words, with the purpose of attaining technically efficient production that firm would have to condense all inputs proportionally by QP/OP and the technical efficiency of a firm is usually measured by the ratio:

$$TE_I = OQ/OP$$

The technical efficiency term will be between zero and one. A firm is completely technically efficient if its technical efficiency score is equal to one, and vice versa. If unit costs of inputs are existing, AA' represents an iso-cost line. Hence, R or Q' have the same total cost. Though, the output at R point production is lower than at Q', which is the intersection between AA' iso-cost and SS' iso-quant (production frontier). Therefore, Q' is said to be technically efficient as well as allocatively efficient. And the cost efficiency can be expected by the ratio:

$$CE_I = OR/OP$$

Then allocative efficiency and technical efficiency can moreover be considered by using the iso-cost line:

$AE_I = OR/OQ$

$TE_I = OQ/OP$

Since those equations, the relation between technical, allocative, and cost efficiency can be expressed by:

$$TE_I \times AE_I = (OQ/OP) \times (OR/OQ) = OR/OP = CE \quad (3.2.4)$$

3.2.8 OUTPUT-ORIENTATION

Output-oriented technical efficiency states if we fixed the input quantities used, how much output quantities would be proportionally increased. When we take the case of producing two outputs from a single input, output-oriented efficiency is explained in figure 3.2.5. Within the figure, the firms, which are on the frontier curve, ZZ' are technically efficient and a lies below the ZZ' curve. Hence, A is an inefficient point. And the distance AB shows technical inefficiency that outputs could be expanded without requiring extra inputs. So, output-oriented technical efficiency is computed by the ratio of OA and OB

$TE_O = OA/OB$

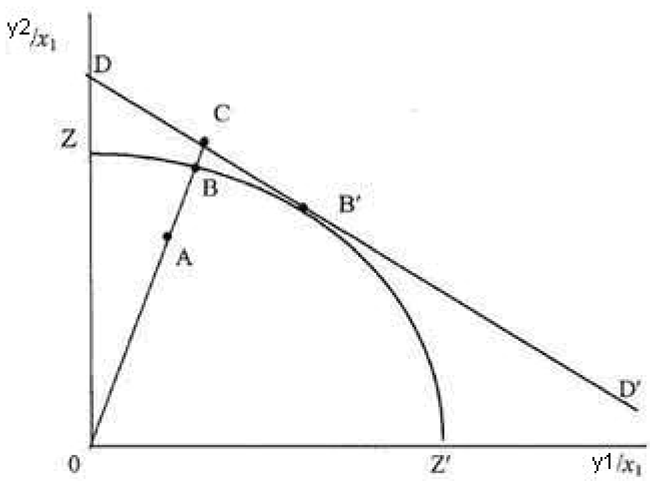


Figure 3.2.4 Technical efficiency and allocative efficiency

Similar to the input-oriented situation, if the unit prices are attainable, DD' shows the iso-revenue line. Hence, the intersection between the ZZ' technical efficient curve and DD' iso-revenue line, B' is called to be revenue efficient. And the revenue efficiency can be descrived by the ratio:

$$RE_O = OA/OC$$

Then allocative efficiency and technical efficiency can also be computed by the ratio:

$$AE_O = OB/OC$$

$$TE_O = OA/OB$$

The relation between technical, allocative, and cost efficiency, can be descrived by:

$$TE_O \times AE_O = (OA/OB) \times (OB/OC) = OA/OC = RE \qquad (3.2.5)$$

In assessment, the level of technical efficiency of a firm can be described by the relationship between observed productions with the best practice production. A firm is technically efficient if its production point is by the boundary. In compare, it is technically inefficient if the production point of that firm lies lower the boundary.

3.2.9 MEASURING EFFICIENCY OF DEA METHOD

The industrial trawl fisheries of Bay of Bengal contain a multiplicity of species. They are fished using a variety of fishing gear such as fish trawler, shrimp trawler, mid water trawler, modern fish trawler, demersal trawler. Though SRF is econometric and more generalized method, for any specific case study where multiple outputs are considered, DEA is more appropriate to determine efficiency of gear wise industrial trawlers of Bay of Bengal. Efficiency of DMU's could be defined, as the ratio of the weight can be market prices. Then the efficiency measure will be a revenue index. In this study, randomly selected 80 trawlers data are available for 2006 to 2010 where two outputs for each trawler such as revenue of target species and by catch is considered. In this study many inputs such as Length of the vessels, crew size, fishing days in the sea are taken into consideration for efficiency analysis. In case of industrial trawl fisheries of Bay of Bengal there are some limitation of resource, for example capital, availability of manpower, skilled staff and workers for investment and especially the restriction of getting license from authority. There is a little possibility to increase their output, but the trawlers can be able to minimize their cost to achieve higher efficiency. So, input-oriented DEA approach is appropriate to describe the production possibility situation. The input-oriented measure is to answer the question what the most efficient combinations are among the limited inputs those industrial trawler situations with the unchanged output. Hence, the reduction of inputs use can be applied to avoid wasting resources, improves vessel's technical efficiency, reduce the production cost or increase the gross margin from industrial trawler. Moreover, due to the existence of imperfect competition, limited finance and socioeconomic limitations prevailing in this study area and almost no vessels are operating at optimal scale. Hence, VRS DEA model seems to be more suitable for analyzing efficiency than CRS DEA in this study.

3.2.10 MALMQUIST INDICES

The Malmquist productivity index, established by (Caves et al., 1982) and extended further by (Färe et al., 1992) relies on distance functions. DEA is an operational method to compute distance functions. Distance functions are very useful in describing the technology in a way that makes it possible to measure efficiency and productivity. The notation of a distance function was introduced independently by Malmquist (1953) in aspecial consumption setting and more generally by Shephard (1953), Distance functions allow one to describe a multi-input, multi-output production technology without the need to specify a behavioural objective. One may specify both input distance functions and output distance functions. An input distance function characterizes the production technology by looking at a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of the output vector , given an input vector.

The input-orientation Malmquist productivity indices are applied in this study. Such orientation is adequate for the sample of industrial trawlers used here, as in the transition conditions. Trawlers owner farmers had more control over the reduction of their inputs than over the expansion of their outputs. The indices are computed with the non-parametric DEA method that applies linear programming to construct a piece-wise frontier that envelops all data points (Charnes et al., 1978). DEA method avoids misspecification errors and permits investigating a multi-output multi-input case simultaneously. The empirical application is to a sample of 80 selected trawlers over 5 years, 2006-2010.

Therefore, input-oriented technical efficiency and in extension, Malmquist indices are measured to determine and compare the efficiency of industrial trawl fisheries in the first stage. Moreover, in order to identify the exogenous factors effecting on vessel technical efficiency and this efficiency scores were used as dependent variables in OLS regression in the second stage.

3.2.11 MODEL SPECIFICATION OF EFFICIENCY

Consider the case of *n* industrial trawlers of Bay of Bengal; Decision Making Units (DMUs), are equal to 80 in this study which are available. Each vessel uses inputs to produce different types of fish species. The inputs are total length of the vessels, crew size, days at sea, which are each household used to fish by industrial trawler in 2010. Outputs are the quantity of target species and by catch of fish per household that were harvested in the same year. The following envelopment form can express the input-oriented VRS DEA model:

Consider a production technology that transforms

inputs $X = (x_1, x_2, \ldots, x_m)$ into

outputs $Y = (y_1, y_2, \ldots, y_s)$ and

let λ_i ($i = 1,2,\ldots, m$) be scalar weights associated with inputs x_i.

Then Fare and Lovell, 1978 define the measure of input efficiency as:

$$R(x, y) = \text{Min}\ \{\Sigma\lambda_i/m: \lambda_i x_i \in L(y), \lambda_i \in (0,1]\ \forall i\} \quad (3.2.6)$$

where L(y) is defined as in section 3.2.1.

The scalar weight λi is the contraction in each input i. The efficiency assess minimizes the average contraction over all the inputs. The point of projection on the efficient subset is taken reducing each input by different proportions or by λ_i

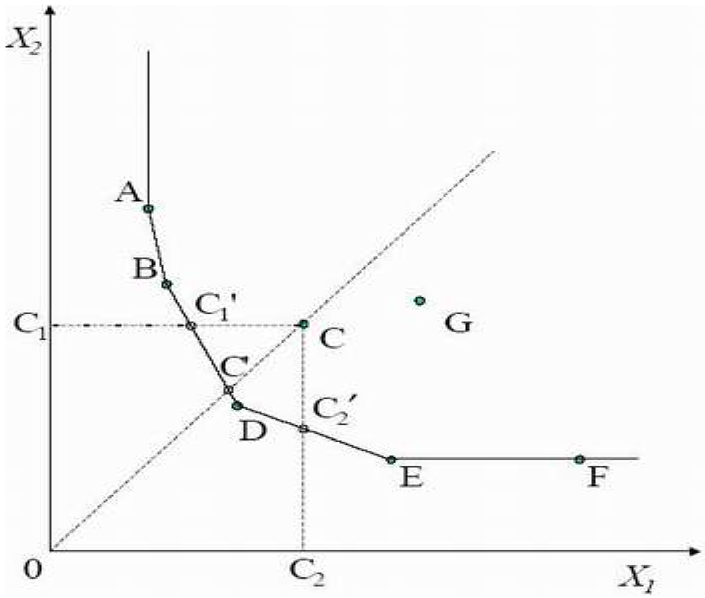


Figure 3.2.5 Input -oriented Technical Efficiency Measure

Figure 3.2.6 illustrates DMUs A, B, C, D, E, F, and G using inputs X_1 and X_2 to give a certain output *Y*. C is an inefficient unit. The Farrell, (1957) would project C onto unit C′. The efficiency measure (3.2.6) would project C onto D reducing the inputs **i**n varying proportions to attain the efficient subset. However, the minimization of the average decline in inputs would select D depending on the numerical outcome of equation (3.2.6) above. The input-oriented VRS DEA model can be expressed by the following envelopment form:

Assuming that there are *n* farms as DMUs *(* $DMU_j = 1,2,3,\ldots, n$*)* to be evaluated, each DMU produces s outputs y_j $(y_{1j}, y_{2j},\ldots y_{sj})$ by using m inputs x_j $(x_{1j}, x_{2j},\ldots x_{mj})$. An input-oriented model developed by Charnes, Cooper and Rhodes (CCR-1978) can be written as:

$$Min\theta_0$$

Subject to

$$\theta_0 x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \quad i = 1,\ldots\ldots,m \qquad (3.2.7)$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - y_{r0} \geq 0 \quad r= 1,\ldots\ldots s$$

$$\lambda_j \geq 0 \quad j= 1,\ldots\ldots,n$$

Where, x_{io} and y_{ro} are the i^{th} input and r^{th} output, respectively for a DMU_o under evaluation. A scalar factor of θ_0 represents the efficiency measure of DMU_o under evaluation, while λ_j is considered as an intensity variable which defines the linear combination of the peers of the j^{th} DMU that the DMU_o is compared with. The magnitude of θ_0 is greater or equal to zero and less than or equal to unity. If θ_0 equal to unity, then the current input levels cannot be reduced proportionally, indicating that DMU_o is on the frontier and can be regarded as full efficient DMU. Otherwise, if θ_0 is less than unity, then DMU_o is dominated by the frontier and can be seen as inefficient DMU. According to Coelli et al. (2005), the CRS DEA model is only appropriate when the farm is operating at an optimal scale. Factors such as imperfect competition, constraints on finance, etc. may cause the farm to not operate at an optimal level in practice. Since CCR (1978) model stands for constant returns-to-scale (CRS) technology. This means that all farms are operating at optimal scale or if all inputs are increased proportionally by a certain amount then the outputs will also increase proportionally by the same. The results of technical efficiency measurement by solving CCR model does not account into effect of scale thus this may be inappropriate for all of the farms in the sample. Therefore, the BCC model, developed by Banker, Charnes and Cooper (1984) and called the input-oriented BCC model, allows for variations in the returns to scale is considered. This model based on input orientation under variable return to scale (VRS) and developed basing on CCR model by adding a convexity constraint $\sum_{1}^{n} \lambda_j = 1$ in to CCR model (3.2.7) and then it can be written as:

$$Min\theta$$

Subject to:

$$\theta_0 x_{io} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \quad \text{i= 1,……..m} \qquad (3.2.8)$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - y_{r0} \geq 0 \qquad \text{r= 1, ……….n}$$

$$\sum_{1}^{n} \lambda_j = 1 \qquad \text{j=1,…….,n}$$

The scores estimated from BCC model after imposing the restriction are therefore pure technical efficiency for the selected vessels.

3.2.12 INPUT ORIENTED MALMQUIST PRODUCTIVITY INDEX

The input-orientation Malmquist productivity index is described as follows (Färe et al., 1992):

$$y_t = \left[\frac{d^t(x_{t+1}, y_{t+1}) d^{t+1}(x_{t+1}, y_{t+1})}{d^t(x_t, y_t) d^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \qquad (3.2.9)$$

where (X_t, Y_t) is the firm input-output vector in the t-th period; Generally, disregard the time subscripts, we define an input oriented distance function as;

$\mathrm{d}^t(\mathrm{x}\ ,\mathrm{y}) = \max\{\delta : (\mathrm{x}/\delta) \in L(y)\}$. Compared to the CRR CRS efficiency, we see that $\delta = \frac{1}{\theta}$ where θ is taken from model (3.2.7). Thus although the Malmquist inputoriented productivity index is defined in termes of distance functions like in (3.2.9), it is in normal circumstances computed by solving four DEA models of type (3.2.7). Distance funtions of type $d^s(x_1, x_2)$ (s may be equal to t or different) are then computed by finding $\theta_0^{s,t}$ meaning finding the effeiciency by a DEA model with technology from time s and observations from time t.

4. DATA

4.1 SOURCES AND CRITERIA OF DATA

Data for this study were collected from the Bangladeshi department of fisheries (DOF) and cover the period from1985 to 2010. The data available for this study are reliable and valid because they are collected by inspectors of the marine department of fisheries, government of Bangladesh. To parameterise the bioeconomic model only data from 2001 to 2010 were used. In the following, catch, effort and economic data of different species and gear categories of the last five years were obtained from DOF. The industrial trawlers are separated into groups based on type of fishing gears and engine horse power. The average price of harvest, revenue, as well as technical and operational characteristics of fishing vessels in the Bay of Bengal was collected to identify optimum level of the fisheries and efficiency analysis.

4.2 YIELD, EFFORT AND CPUE OF DIFFERENT TRAWLERS

The industrial trawl fisheries of Bangladesh now include 165 fish and shrimp trawlers. But only one decade before there were only 21 fish trawlers and 41 shrimp trawlers. After that, fish trawlers have increased significantly. The period starting 2001 is measured more consistently data compared with earlier years by including a more homogenous fleet with a more homogenous catch structure. The major concerns have stimulated the carry out the shorter time series; adjust in accuracy of statistics; catch structure has been varied (i.e additional predators early years), relating rise in catch while adding more prey species; variety in size composition (i.e reducing mesh size or similar) and vary in operational design (i.e dealing with other areas, longer days). All these factors are regarded to have a significant turnaround the year 2001, though all corresponding to smooth changes over longer periods of time. For this reason the data of 2001 to 2010 were selected for this study to draw the bioeconomic model and get optimum economic and sustainable level for fish and shrimp trawlers. Moreover the big changes in the fleet have significantly changed the concept of one fishing hour which means, one fishing hour in the 1980s is very different from one fishing hour in the 2000s. Catch and effort data is shown in tables 2.3 and 2.4

Table 4.1 CPUE of target species of fish and shrimp trawlers

Year	Fish trawlers CPUE	Shrimp trawlers CPUE
2001	0.173	0.018
2002	0.143	0.019
2003	0.150	0.014
2004	0.154	0.017
2005	0.126	0.017
2006	0.098	0.019
2007	0.107	0.015
2008	0.091	0.018
2009	0.100	0.020
2010	0.114	0.022

4.3 TARGET SPECIES AND BYCATCH OF FISH TRAWLERS FOR 2006-2010

Total catch of jew, cat fish, eel, ailla have decreased in these five years. But the catch of bombay duck, mackerel and bycatch have increased and the catch of other species remains constant. The volume of by catch is increasing for fish trawlers due to market value and lack of proper management.

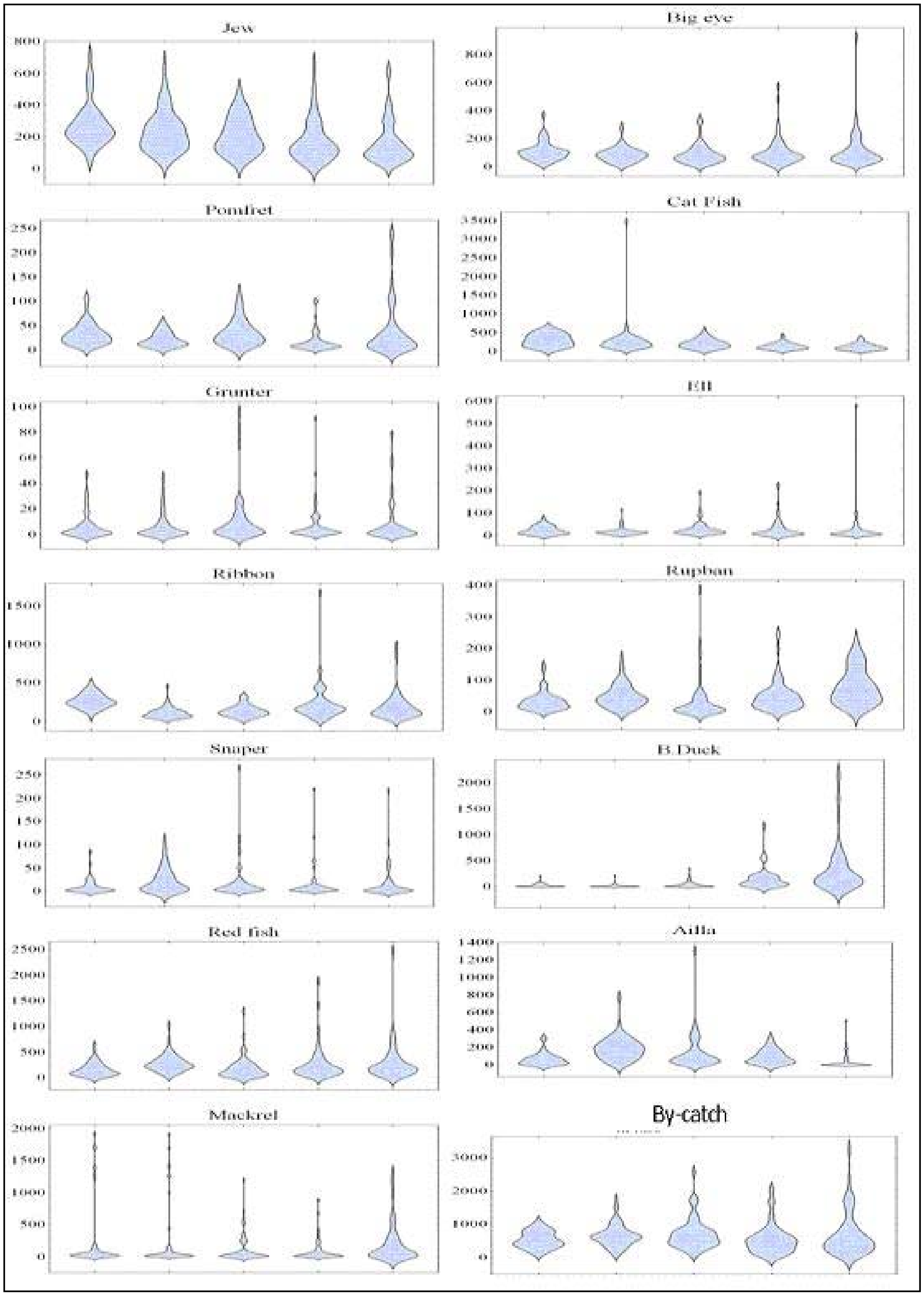


Figure 4.1 Total targeted different species and bycatch of fish trawlers, 2010

Source: DOF

4.4 CPUE OF TARGET SPECIES AND BYCATCH OF DIFFERENT GEAR

The figure 4.2 and 4.3 shows the CPUE of target species and bycatch of different fish and shrimp trawlers between 2006 and 2010.

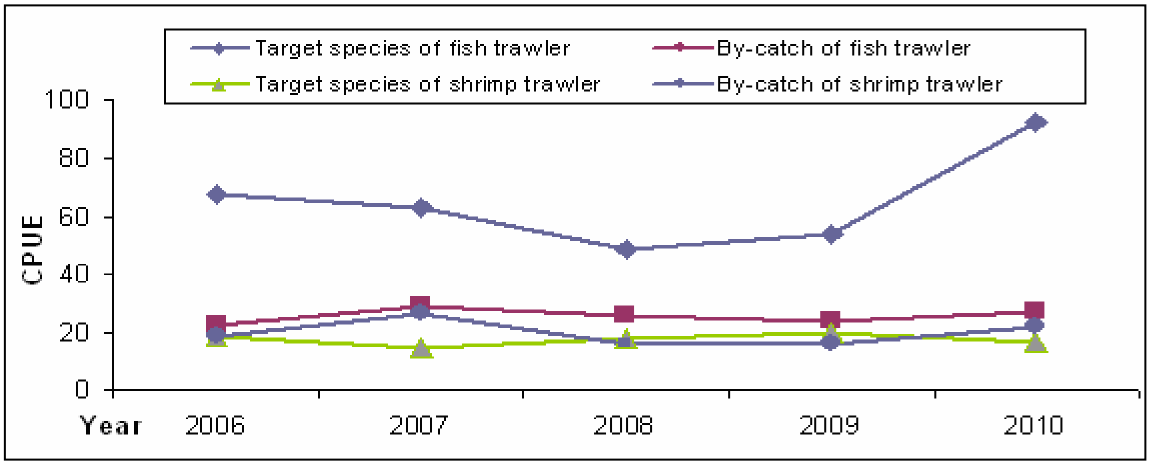


Figure 4.2 CPUE of fish and shrimp trawlers

From the figure 4.2 the CPUE of fish trawlers for target species has increased whereas the CPUE of shrimp trawlers for its target species has decreased and the bycatch of both is almost stable for these years. Bycatch of shrimp trawler is some times bigger than its target species.

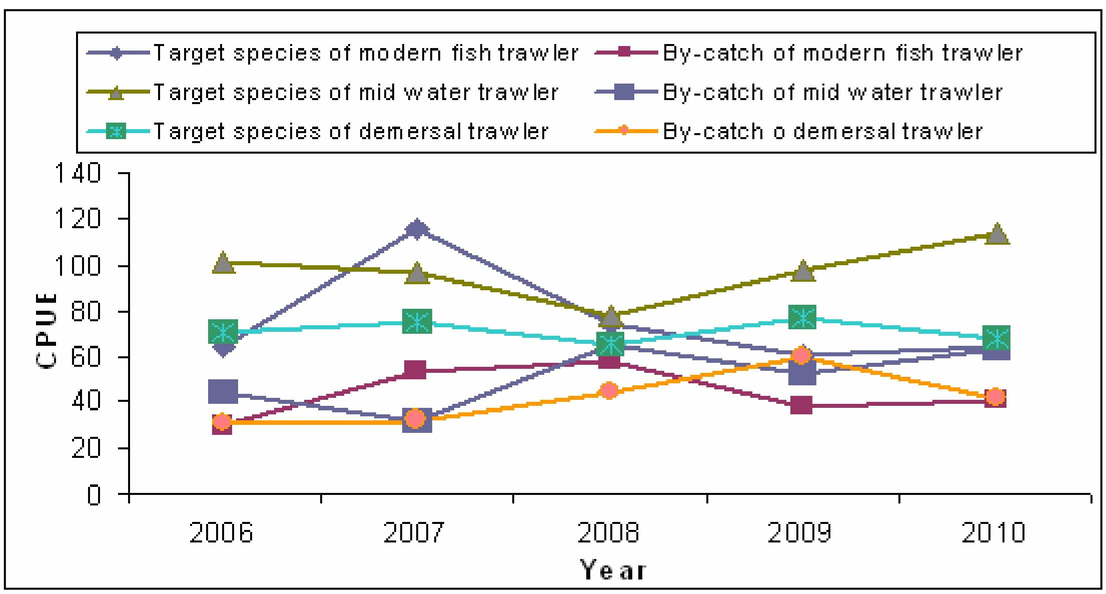


Figure 4.3 CPUE of Modern fish, mid water and demersal trawlers

As is presented in the figure 4.3, the CPUE of modern fish trawler (MFT) have a rapid increase until 2007 at which point it showed a decreasing trend. In contrast, CPUE of mid water trawlers (MT) decreased till 2008 at which point it observed a gradual increase. On comparison the CPUE of demersal trawlers (DT) has been almost stable for these five years. Bycatch of these trawlers group has an upward fluctuation.

4.5 CPUE OF DIFFERENT FISH SPECIES

The following analysis presented makes use of the CPUE over the five years (2006-2010) for each species based on all the individual trawler data which is represented by the more well-known box-whisker plots. The different species are showed by distribution charts where the thickness of the body indicates the frequency or occurrence of the catch volume (vertical axes) per trawler each year.

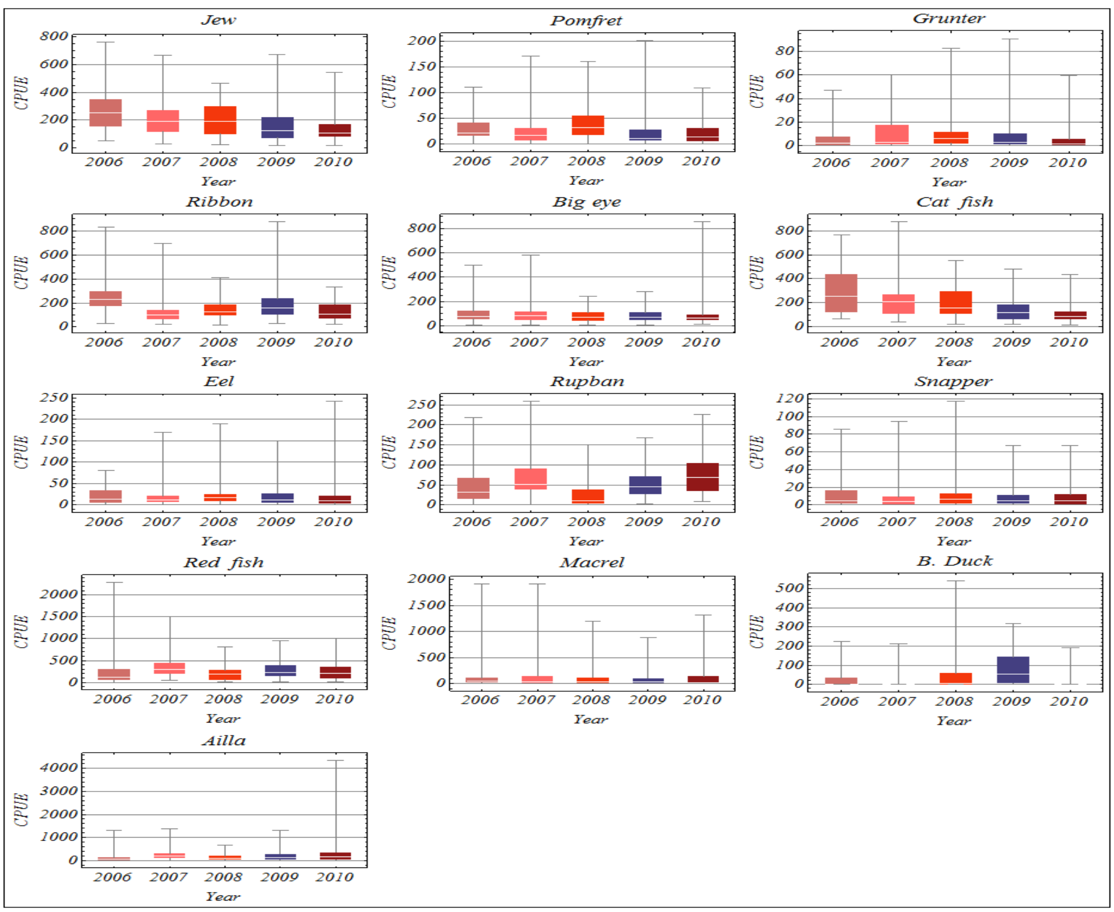


Figure 4.4 Box – whisker CPUE plots for fish trawlers (2006-10)

Source: DOF

The simple CPUE mean values indicate a decline in cat fish and jewfish (Johnius argentatus, Lambu, Kaladatina etc.), while aiila, Bombay Duck (Harpondon nehereus), red fish and rupban CPUEs are increasing. Most CPUEs are however rather stable.

4.6 CPUE OF SELECTED TRAWLER

From the total of 124 industrial trawlers of 2006, 80 trawlers were selected on the basis of available data which have catch and technical data for all five years till 2010. They are hardly selected since they are the only trawlers which could be included. It is a sample restricted as a consequence of unavailable data for some operators one or more years .In this study, a number of single trawlers identified according to their gear category, such as, old fish trawlers, mid water trawlers, modern fish trawlers, modern demersal trawlers, shrimp trawlers, (DOF , 2006). Total catch of the selected industrial trawlers are taken for the five years. Beside this, all the trawlers are divided into three groups, according to their engine power. Such as lower than 400 kilo watt hours (kWh), 400 kWh to 700 kWh and over 700 kWh for comparing the efficiency of these vessels.

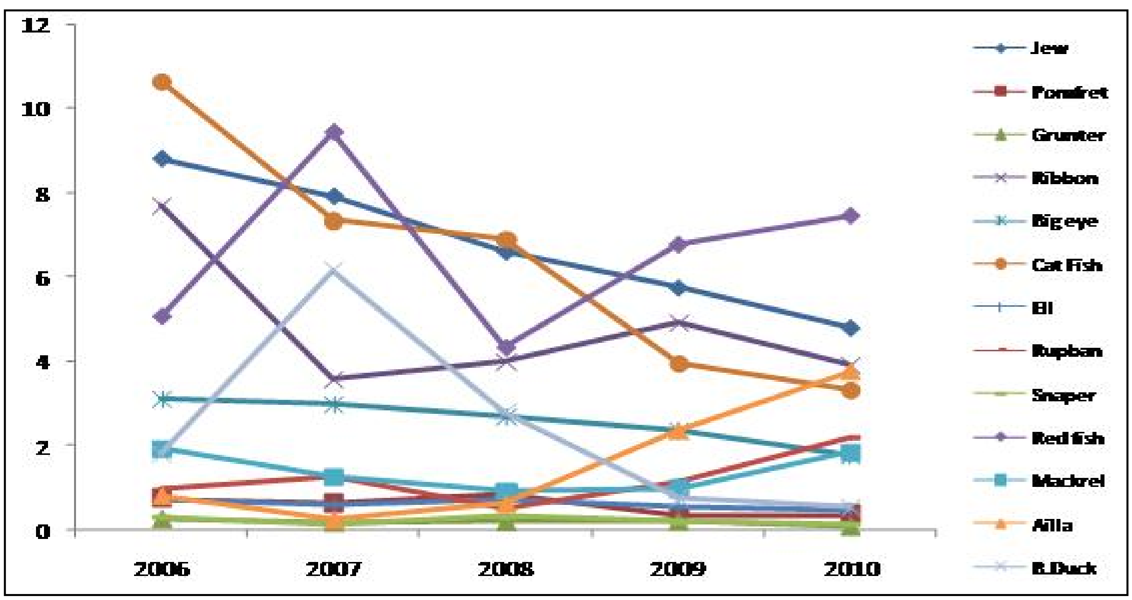


Figure 4.5 CPUE of less than 400 kWh trawlers

The CPUE of different species for less than 400 kWh trawlers showed in figure 4.4 where only red fish, rupban, mackrel and ailla increased from 2008 to 2010 but all other species have a decreasing trend.

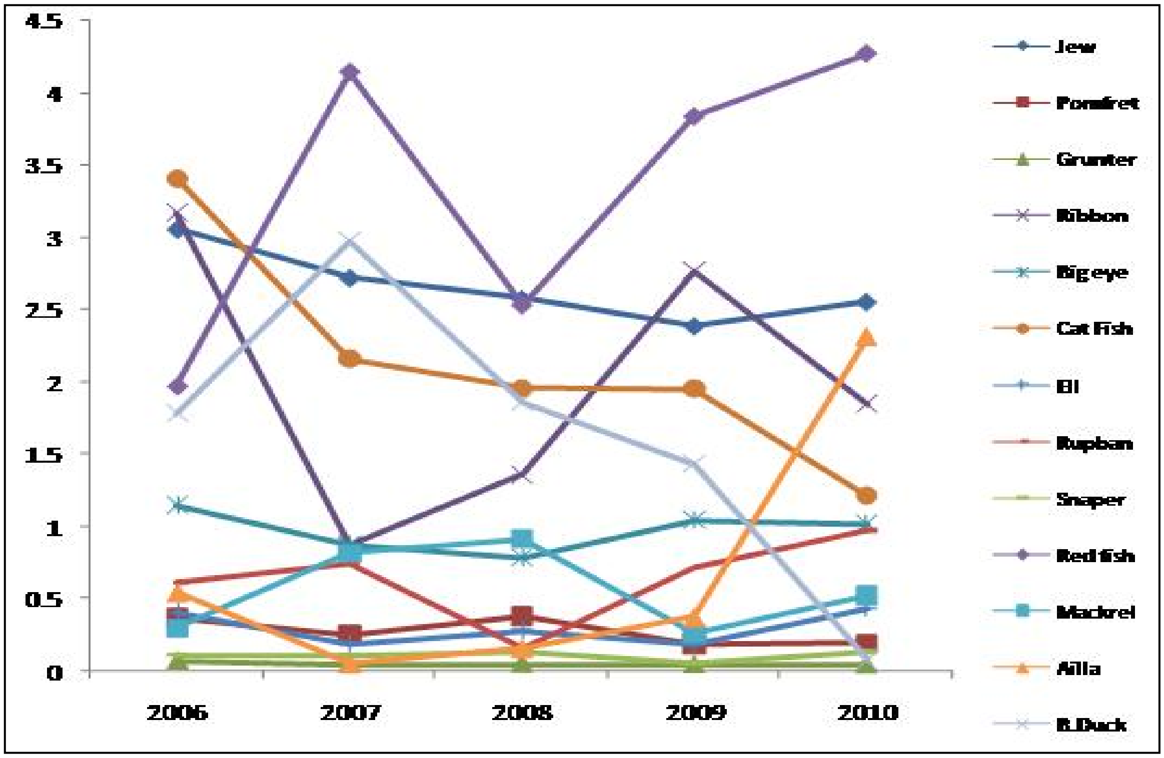


Figure 4.6 CPUE of 400 KWH to 700 kWh trawlers

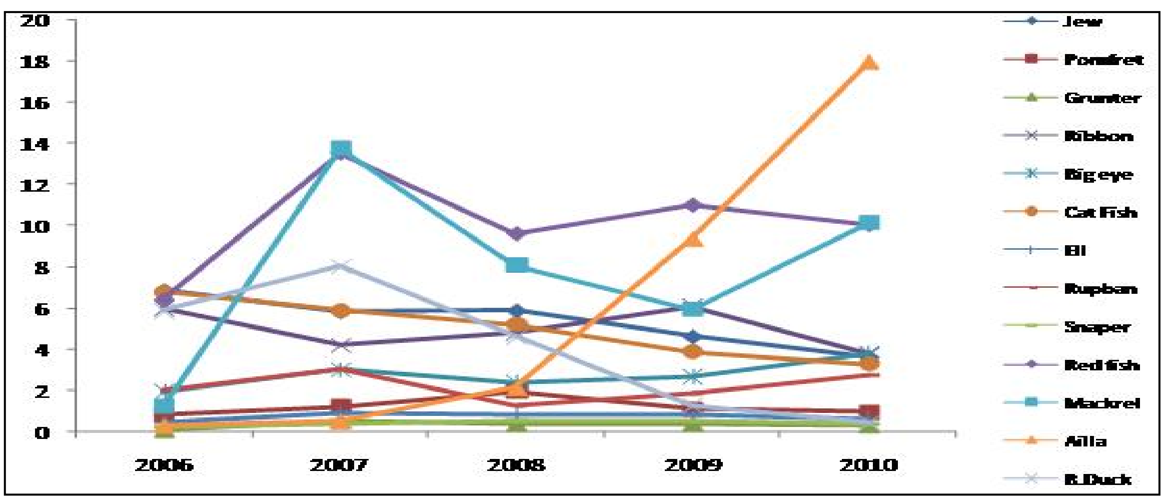


Figure 4.7 CPUE of over 700 kWh trawlers

4.6.1 FISH, SHRIMP AND BYCATCH OF LESS THAN 400 KWH TRAWLERS

According to figure 4.7 engine power of the trawlers which have less than 400 kWh, showed a downward tendency for CPUE of fish and by- catch . By comparison overall the CPUE of shrimp of this trawler group showed a slow increase.

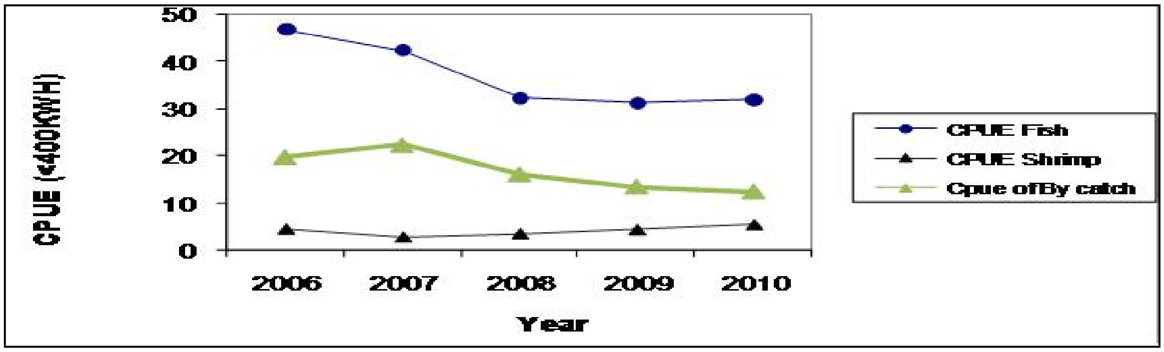
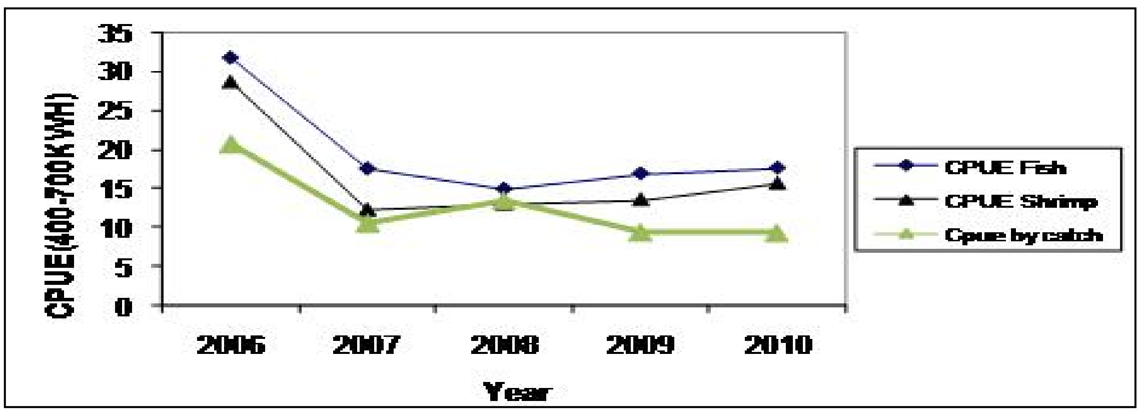


Figure 4.8 CPUE of less than 400 kWh trawlers

4.6.2 FISH, SHRIMP AND BYCATCH OF 400 KWH TO 700 KWH TRAWLERS

The following figure 4.9 shows the trawlers engine power which have 400 to 700 kWh, the CPUE of fish , shrimp and bycatch observed a dramatic decrease up to 2007 then there is a slight upward tendency for CPUE of fish, and shrimp, but the bycatch



decreased.

Figure 4. 9 CPUE of 400 to 700 kWh trawlers

4.6.3 FISH AND SHRIMP CATCH OF GREATER THAN 700 kWh TRAWLERS

The trawlers engine power which has greater than 700 kWh, in general there was a gradual increase for CPUE of fish and by- catch; but overall the CPUE of shrimp remains constant.

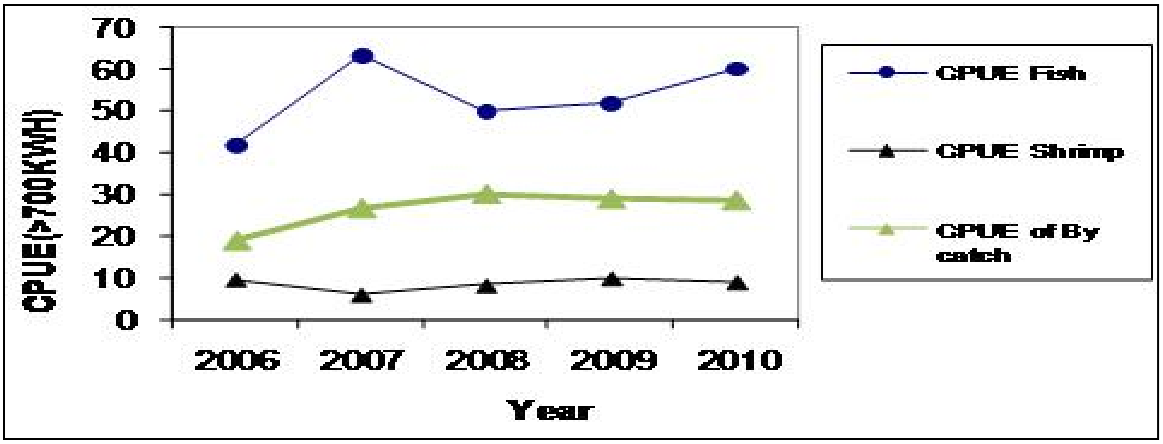


Figure 4. 10 Horse power of 400 to 700 kWh trawlers

Table 4.2 Gear wise category of CPUE

Trawler	Year	< 400 HP Target species	Bycatch	(400-700)HP Target species	By-catch	>700 HP Target species	Bycatch
		N=19		N=8		N=9	
	2006	58.85	21.79	54.35	15.68	54.35	15.68
Old Fish	2007	53.91	28.07	51.82	23.73	87.30	28.74
	2008	42.12	20.41	32.16	19.25	62.81	31.41
	2009	40.84	16.87	44.50	17.54	53.46	28.56
	2010	43.00	15.72	38.85	12.75	75.23	25.61
		N=6		N=14		N=10	
Shrimp	2006	16.05	14.10	40.41	20.96	20.74	5.98
	2007	11.30	2.54	16.90	2.25	17.28	5.68
	2008	13.18	3.01	19.47	2.74	24.63	7.16
	2009	16.49	3.36	20.33	2.54	29.48	7.37
	2010	18.78	3.85	25.02	3.33	24.37	6.25
						N=7	
Mid-water	2006					96.54	45.52
	2007					111.50	62.43
	2008					85.72	60.16
	2009					107.16	58.36
	2010					125.38	70.81
				N=1		N=2	
Modern fish	2006			74.26	40.59	39.93	17.96
	2007			82.87	68.82	94.93	15.58
	2008			73.32	107.76	65.55	40.53
	2009			53.44	48.54	52.41	14.94
	2010			56.82	54.04	41.52	22.08
						N=4	
Demersal	2006					68.12	28.35
	2007					69.18	22.01
	2008					62.61	30.70
	2009					68.87	40.11
	2010					69.57	28.47

(HP- is Horse power, N- Number of trawlers)

The table 4.2 provides information related to show the engine power in five different gear wise categories of the industrial trawler from 2006 to 2010. As is observed, CPUE of the entire trawler over 700 KWH increased but CPUE of other two categories decreased.

4.7 DESCRIPTIVE DATA SET OF TECHNICAL EFFICIENCY ANALYSIS

The data set of costs and earnings, information on vessel and skipper characteristics was collected from DOF, Chittagong. A summary of descriptive statistics for key variables used in DEA and OLS model is given in Table 4.3.

Table 4.3 Descriptive statistics of industrial trawlers (N=80) variables 2010

Name	Mean	Standard deviation	Minimum	Maximum
Revenue Target(Taka)	39,568,268.4	29,680,685.3	2,296,694.4	156,779,480.0
Revenue Bycatch(Taka)	10,774,517.5	11,323,019.4	246331.8	60,530,235.5
Length (m)	29.7	7.0	16.9	43.1
Engine power (HP)	573.9	204.2	317.0	1118.8
Crew size (persons)	27.0	5.6	19.0	39.0
Days at sea (days)	126.3	41.3	50.0	200.0
Age of vessel (years)	21.9	6.9	6.0	32.0
Fishing experience (years)	18.2	8.5	8.0	41.0
Household size (persons)	32.3	6.5	24.0	46.0

(Taka- is the Bangladeshi currency. The money value is 1USD = 73.12 BDT, browsing date 11.5.2011, http://www.xe.com/ucc/full/)

The revenue of target species and bycatch were measured for the year 2010 by average weighted value of the wholesale market. The target species ranged from 2,296,694.4 BDT to 156,779,480 BDT per year and the by catch ranged from 246,331.8 BDT to 60,530,235.5 BDT per year, with the mean equal to 39,568,268.4 BDT and 10,774,517.5 BDT. The vessel length ranged from 16.9 to 43.1 m, with an average length of 29.7 m. Similarly, the engine power, measured in horsepower (HP), ranged from 317.0 to 1118.8 kWh, with the mean being 573.9 kWh. Because of this, the trawlers can fish only in waters beyond the 40 meters depth. The age of vessel varied from 6 to 32 years with a sample mean of 21.9 years. Crew size averaged 27.0 persons with a range of 19–39. The annual average number of days at sea, including both travelling and fishing time, is 126.3 and ranged from 50 to 200 days. The fishing experience was measured by the number of years the fishermen had been involved in fishing activity. Clearly, the skippers were highly experienced, with an average 18.2 years of fishing experience. Household size was relatively high; on average, there were 32.3 persons per household.

5.1 RESULTS OF STEP 1

5.1.1 PARAMETERS

Catch and effort data for the industrial trawlers of the Bay of Bengal have been used to estimate the parameters a, b from equation (3.1.5). Table 5.1.1 shows the results of a linear regression based on catch and effort data (table 4.1), assuming equation (3.1.5) for the years 2001 to 2010. The results confirm an expected negative relationship between CPUE and effort for both fish trawlers and shrimp trawlers. The R^2 values indicate that the Gordon-Schaefer Model explains about 93.57% and 16.63% of CPUE variations, for fish and shrimp trawlers respectively.

Table 5.1.1 Regression analysis based on data from 2001-2010

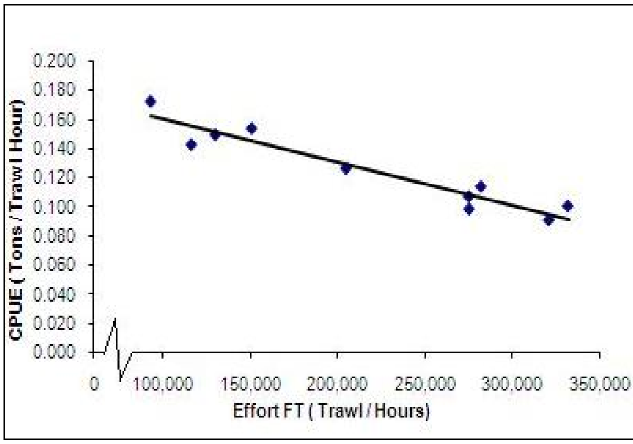
	Fish Trawler			Shrimp Trawler		
	Estimated coefficient	t-value	P- Value	Estimated coefficient	t-value	P- Value
a	0.192364	30.119**	0.00001	0.02560	5.5314*	0.0005
b	-0.00000314	-11.49**	0.00002	-0.0000477	-1.861**	0.136
df	8			8		
R^2	0.93572			0.1663		
F	132.029*			2.756		

* Significant at 5% level

** Significant at 10% level

5.1.2 RESULTS FROM MODELS

The graph of regression line (RL) of fish trawler (FT) and shrimp trawler (ST) derived from the model against effort using data from table 4.1 are shown below in figure 5.1.1a and 5.1.1b



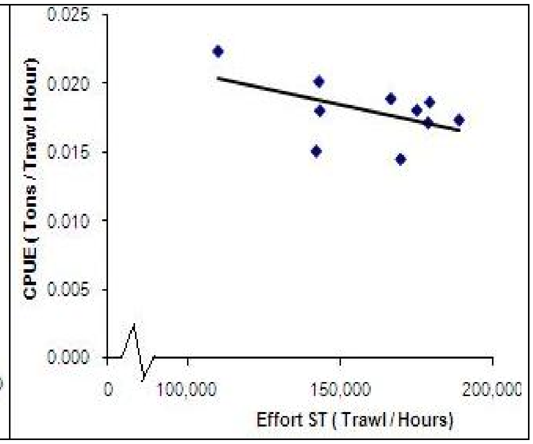


Figure 5.1.1a RL of fish trawlers **Figure 5.1.1b** RL of shrimp trawlers

Source: DOF

The point at which resource utilization exceeds the maximum economic yield is equivalent to the maximum rent obtainable from the fishery, calculated as the largest positive difference of total cost and total revenues but it is noted that the effort level corresponding to MEY is lower than the effort level related to maximum sustainable yield. Though, entry of new participants fascinated by the increased profits ensuing a new equilibrium where no rent is yielded from the fishery and following fishing effort is increased up to a level which is more than the economic yields. Again the long-run effects of better revenue and cost reducing factors in an open-access fishery, are responsible for decreasing stock levels and increasing the size of the harvesting industry. The long run equilibrium harvest may decrease or increase, depending on the size of the stock. In order to evaluate the optimal steady state solutions and economic equilibrium of a Bangladeshi trawl fishery, the average price of the fish and shrimp for Bangladesh used in our study is 50.25 taka/kg and 170 taka / kg respectively. The price of the bycatch of a fish trawler is 30 taka / kg and it is 50.25 for a shrimp trawler (personal interview). The unit cost of fishing incorporates the value of labour, capital, materials and energy inputs used in a Bangladeshi trawl fishery but it is not easy to collect that data. Therefore we take the harvesting cost 3125 tk / hour (DOF). The price of fish, shrimp and unit cost of effort are assumed to be constant over the years.

Predicted catch ability (q), intrinsic growth rate (r) and the carrying capacity (k) is taken from the paper of Habib, A. (2010), Ray and khan (2003), for fish trawlers and for shrimp trawlers respectively. The values for effort, harvest, and stock at MSY, MEY and OAY have been calculated using equations 3.1.8, 3.1.9, 3.1.10 and 3.1.11 from chapter three, effort measured by trawl hour and stock, harvest, yield measured by kg showed in the following table 5.1.2

Table 5.1.2 Steady state solutions of different trawlers

	Fish Trawler	Shrimp Trawler
E_{OA}	540000.00	350000.00
E_{MEY}	270000.00	175000.00
E_{MSY}	321808.97	268572.07
X_{OA}	636533.99	188087.09
X_{MEY}	338596.99	99743.54
X_{MSY}	20330.00	5700.00
H_{OA}	33593672.03	6433823.53
H_{MEY}	8934885.18	1705944.75
H_{MSY}	639407.38	149615.92
OA	16508.00	3123.00
MSY	30553.79	3438.78
MEY	29762.00	3020.50
k	40660	11400
r	3.228	1.330818
q	9.77332E-05	9.77332E-05

The following figure 5.1.1a and 5.1.2b based on catch and effort data of industrial fish trawlers (FT) and industrial shrimp trawlers (ST) describing open access and economic equilibrium as follows:

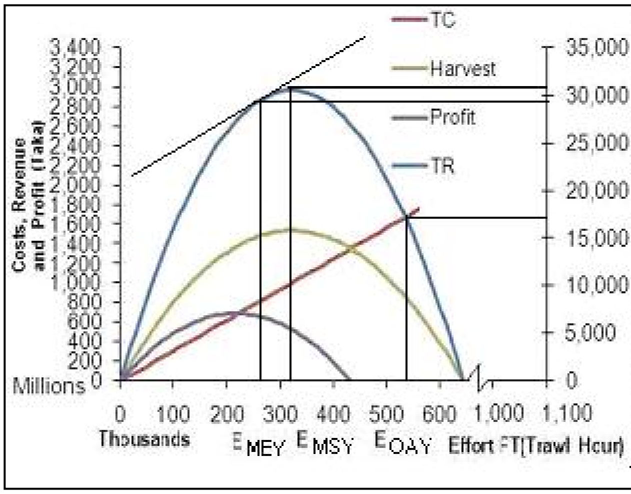


Figure: 5.1.2a Steady state solution of FT

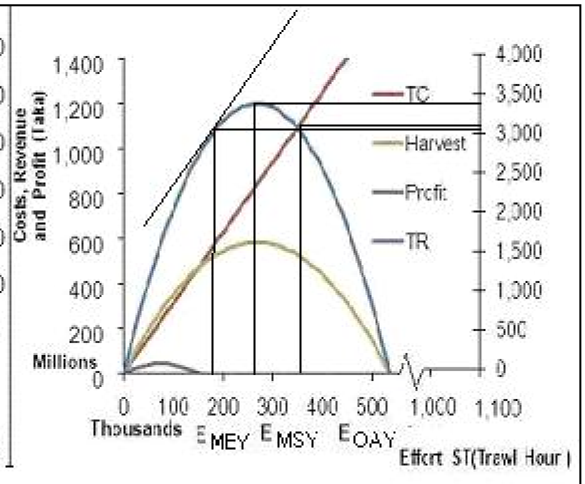


Figure: 5.1.2b Steady state solution of ST

It is observed from tables 5.1.2 and 5.1.3 that the values of H_{MEY} and fishing effort used to achieve MEY for Bangladesh trawl fishery are formulated using dynamic model by equation 3.1.12 with zero discounting rates are equal to the values of H_{MEY} and fishing effort utilized to achieve MEY is found by means of the static model for the same fishery. Again it is observed that the values of H_{OAE} and fishing effort used to achieve OAE for Bangladesh trawl fishery are achieved using dynamic model with infinite discounting rate are equal to the values of fishing effort applied to achieve OAE is obtained by means of the static model for the same fishery.

Table 5.1.3 Long run optimum stock, harvest and effort level

	%	X*	H*	E*
Fish Trawler	$\delta = 0$	338597	1083889	32753.6
	$\delta = .01$	338543	1083717	32753.7
	$\delta = .05$	338764	1084419	32753.5
	$\delta = 0.1$	339040	1085294	32753.3
	$\delta = r$	354635	1134777	32740.6
	$\delta = \infty$	636534	2022565	32511.6
Shrimp Trawler	$\delta = 0$	99743.5	131579	13497.7
	$\delta = .01$	99781.5	131629	13497.7
	$\delta = .05$	99932.5	131826	13497.5
	$\delta = 0.1$	100120.0	132071	13497.3
	$\delta = r$	104320.5	137561	13492.2
	$\delta = \infty$	188087.0	246180	13392.2

5. 2 RESULTS OF STEP 2

Data Envelopment Analysis (DEA) is used to calculate efficiencies. This part will first describe about the statistics of input and output variables. Then the distribution of trawlers technical efficiency and Malmquist efficiency scores from the DEA results are measured for selected industrial trawlers of the Bay of Bengal. After computing the technical efficiencies, characteristics of efficiency scores by variables in different criteria and by factors, using the OLS method are presented systematically in different tables. The results and graphs of the regressions are reported in the following tables and graphs in the following step.

5.2.1 DESCRIPTIVE STATISTICS OF INPUT AND OUTPUT VARIABLES

In 2010, there were 165 industrial trawlers operating in the Bay of Bengal of which 80 trawlers have been selected for efficiency analysis. Table 5.2.1 presents a summary of descriptive statistics of used input and output for these trawlers. To estimate a trawler's technical efficiency, data of selected trawlers were aggregate to obtain three inputs and two outputs. Outputs are revenue of Target species and by catch.

$$\text{Ln } R_T \text{ or } \ln R_B = \alpha_0 + \alpha_L \ln L + \alpha_C \ln C + \alpha_D \ln D + e \qquad (5.2.1)$$

Where R_T , R_B denote annual revenue of Target species and bycatch in taka; L is length of the vessels in meters. *C* is the total number of crew employed per vessel, D denotes the days at sea in the year and e is a random error term**.**

Table 5.2.1 The regression co-efficient of inputs and output variables

	Target species			Bycatch		
	Estimated coefficient	t-value 76 df	P –value	Estimated coefficient	t-value 76 df	P –value
α_L	14712	0.3379	0.736*	87988	1.695**	0.199
α_C	-115200	-2.457*	0.016	-14098	-1.69**	0.095
α_D	11290	1.949**	0.126	26161	2.242*	0.028
α_0	3021700	2.497*	0.015	136700	0.7571	0.551*
R^2	0.426			0.467		
F_{76df}	11.118*			15.759*		

*Statistically significant at the level of 5%

** Statistically significant at the level of 10%.

The results of an ordinary least square (OLS) estimation is presented in table 5.2.1 the econometric package Shazam was used (SHAZAM, version 10.0). Parameter estimates of the equation (* and **) by themselves convey little meaning unless tested for significance. First, t-statistics that the interactive terms have individual significant effects is tested. The F-test statistics, 11.118 and 15.759 for Target species and by catch with 76 degrees of freedom, suggest that the model has overall significant effects. The merit of this approach is that the meaning of estimated parameters can be measured easily. The overall explanatory power is 0.426 and 0.467 respectively. Overall, this indicates that for industrial trawl fisheries, technical and operational characteristics have statistically significant effects on annual revenue.

5.2.2 EFFICIENCY SCORES

Industrial trawler's technical efficiency (TE) scores under the assumptions of VRS were estimated using a DEA input oriented model. In addition a Malmquist efficiency is used to compare the efficiency for five years of these DMUs. The distributions of technical efficiency scores of industrial trawlers are reported in figure5.2.1a and 5.2.1b

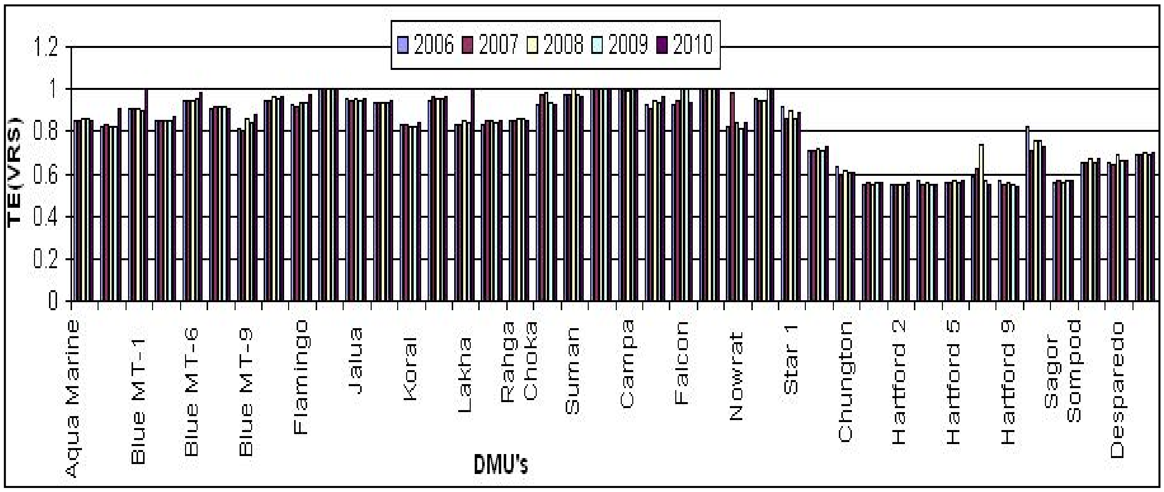


Figure 5.2.1a TE (VRS) scores of industrial trawlers

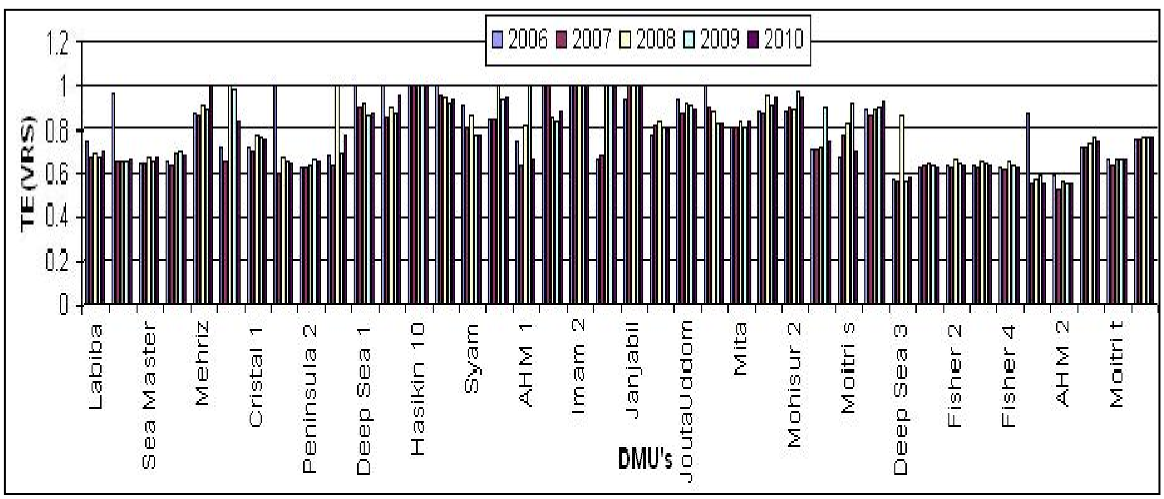


Figure 5.2.1b TE (VRS) scores of industrial trawlers

According to ZHU,2003 in case of Malmquist TFP index, M measures the productivity change between periods t and t+1. Productivity declines if M>1, remains unchanged if M=1 and improves if M <1.

Table 5.2.2 The year wise Malmquist productivity change

Year	Number of Trawlers M>1	M=1	M<1
2006-2007	39	1	40
2007-2008	27	0	53
2008-2009	31	2	47
2009-2010	35	0	45
2006-2008	28	1	51
2008-2010	28	0	52
2006-2010	25	0	55

Following table 5.2.3 shows the change of malmquist productivity and efficiency for different years. Here, Malmquist productivity index represents the total, and the decomposition into catching up and technical change represent by MPI Efficiency and MPI Technical.

Table 5.2.3 Malmquist productivity and efficiency index

Year	MPI Efficiency	MPI technical	Malmquist MPI
2006-2007	1.064767413	1.299716842	1.298809350
2007-2008	1.705073981	0.831653223	1.431593764
2008-2009	1.089269314	1.047264175	1.111246889
2009-2010	0.929609807	1.299946508	1.199005338
Average	1.197180128	1.119645187	1.260163835
2006-2008	1.144773320	1.071012000	1.153156747
2008-2010	0.859189811	1.354001177	1.114631060
2006-2010	0.843904579	1.397843142	1.187236264

From the RTS report, we can say that the number of efficient trawlers (i.e., trawlers operating on the production frontier) were 95% increasing returns to scale, 5% constant returns to scale and there are no trawlers which have decreasing returns to scale.

5.2.3 FACTOR AFFECTING VARIABLES

A number of variables are used to investigate the determinants of technical efficiency of trawlers for the 2nd stage. The selection of variables depends on data availability and on the statistical significance of parameter β . The key inputs used in this chapter are engine power measured in HP, age of the vessel in years (the ownership of the vessel by the present owner), representing vessel characteristics, fishing experience in years, representing skipper characteristics and the household size in persons, representing socio-demography.

The model of ordinary least squares (OLS) estimates of the parameters are shown in table 5.2.2 with the R^2 value of 0.2699, the independent variables used in the model were able to explain 27% of the variation in the technical efficiency scores, t- statistics are calculated, with the null hypothesis that a parameter is zero, which means that the estimated variable has no effect on the dependent variable given that the other variables are in the model.

$$\text{Ln}\, TE = \beta_0 + \beta_{HP} \ln(HP) + \beta_{House\ hold} \ln(\text{House hold}) + \beta_{Vessel\ Age} \ln(\text{Vessel Age}) + \beta_{Fishing\ Exp} \ln(\text{Fishing Exp}) + e \quad (5.2.6)$$

Table 5.2.2 Descriptive statistics of factor affecting variables of industrial trawlers, 2010

Variables	Mean	St.Dev	Min	Max	Estimated coefficient	t-value 75 df	P value
TE	0.80701	0.1546	0.54267	1.000			
HP	573.920	204.19	317	1118.8	-0.07891	-1.692**	0.2790
House hold	32.300	6.5108	24	46	-0.00304	-0.79090	0.937*
Vessel Age	21.887	6.8934	6	32	0.01803	0.71600	0.576*
Fishing Exp	18.225	8.5447	8	41	0.05881	4.8100*	0.0040
Constant					0.81507	6.4970*	0
R^2	0.2699						
F	49.334*						

*Statistically significant at the level of 5%.

**Statistically significant at the level of 10%.

Result indicates that the effect of factor horse power (HP) for industrial trawl fisheries is significant at the 10% level and negatively related to efficiency. Fishing experience is positively related to efficiency and significant at the 5% level. Overall, all of the factors have a significant effect on technical efficiency of industrial trawl fisheries.

6.1 DISCUSSIONS

Marine fisheries of the Bay of Bengal are tropical multi-species and multi-gear fishery. A number of different species are caught by any single fishing operation. Conversely, individuals of single population of one species belonging to a single stock are exploited by different fishing gears (Islam 2003). There were only 21 fish trawlers and 44 shrimp trawlers in 2000. The number of fish trawlers has increased dramatically and in 2010 there were 120 fish trawlers. Fish prices have been increasing with the declining market supplies relative to the increased human population and this might suggest that the stock is becoming scarce. The Bangladeshi trawl fisheries have regulations that prohibit commercial trawlers in waters less than 40m deep. But (Rahman, 2001) notes that the trawl fisheries do not follow this regulation and even operate in waters of as shallow as 10m depth. This creates habitat and resource destruction and also lowering overall catches.

6.2 THE TREND OF CPUE FOR DIFFERENT TRAWLER GROUPS

Less than 400 horse power (HP) and 400-700 HP trawlers showed a decreasing trend of CPUE (see table 4.2) except less than 400 HP shrimp trawlers and there is an increasing trend of CPUE of greater than 700 HP trawlers. On the other hand, bycatch of less than 400 HP and 400-700 HP trawlers has decreased except 400-700 HP modern fish trawlers but CPUE for all greater than 700 HP trawlers has increased. The mid water trawlers has shown a significant rise of CPUE among all trawlers due to the high capacity of the vessels.

6.3 THE BIOECONOMIC MODEL

The relevant results from figure 5.2a and 5.2b indicated that the fishery was in a situation of over-exploitation both biologically and economically. The fish and shrimp stock being overexploited means that the fish and shrimp biomass was below the biomass level of MSY. The Gordon-Schaefer model suggested the current multi species fish and shrimp biomass to be closer to the MSY level. The MSY of the fishery of the Bay of Bengal has been computed. It occurs when the hours of fishing on the Bay of Bengal is about 321808.97 and 268572.07 as shown in table 4.1 for fish and shrimp trawlers respectively. The model resulted in this study is a mixed species equilibrium model which assumes an open access. However, the fishery stock depends on several ecological conditions like food supply, water temperature, disease, pollution, luck, currents and so on. GS harvest curve and yield-effort level are depicted in Figures 5.2a and 5.2b and table 4.1 respectively. Harvests were originally very close to the MSY level, but steadily declined in catch per unit effort. The MSY was calculated as 639407.38 kg and 149615.92 kg for fish and shrimp trawlers respectively and the MEY were calculated as 8934885.18 and 1705944.75 kg and its corresponding effort levels were 270000.00 and 175000.00 fishing hours respectively.

The tables 5.1.2 and 5.1.3 shows that the values of H_{OAE} and fishing effort used to achieve OAE for Bangladesh trawl fishery are achieved using dynamic model with infinite discounting rate are equal to the values of fishing effort applied to achieve OAE is obtained by means of the static model for the same fishery. It is observed from table 5.1.3 that when rate of discounting is gradually increased up to $\delta = 0.1$, corresponding harvesting of the resource increases and the ensuing the stock of the resource is simultaneously increased. Fishing effort gradually decreases as the rate of discounting increases. The fishing effort tends to its maximum level when rate of discounting is considered to be infinite where as for zero discounting rate, the fishing effort is at its maximum value as expected. As a result, even higher level of effort in the recent years does not get adequate quantity of catch. This is obviously demands immediate attention of policy makers and administrations. In order to protect the resource from depletion or any catastrophic collapse, immediate measures must be taken. A scientific approach also must be adopted for managing this resource.

6.4 EFFICIENCY

VRS technical efficiency score ranges from 0.54 to 1 in the year 2006 to 2010 except in 2007 where the lower range is 0.51, with the mean equal to 0.80 in 2006, 2009, 2010 and 0.78, 0.81 in 2007 and 2008 respectively. In the years 2006, 2007, 2008, 2009 , 2010 fully efficient trawlers are 15%, 10%, 15% ,14% , 14% , nearly efficient (efficiency score upper than .8) are 44%, 45%, 48%, 45%, 42% and are more inefficient (efficiency score less than .6) are 11%, 14%, 10%, 13% and 13% respectively . In the year 2010, there are 14% fully efficient shrimp trawlers, 30%, are nearly efficient, 30% are more inefficient. In the year 2009-10, Malmquist productivity result indicates 50%, 66%, 59%, 56% trawlers improvement in the year 2006-07, 2007-08, 2008-09 and 2009-10 respectively and rest of the trawlers shows regress in table 5.2.2 and table 5.2.3.shows the catching up on average of 2009-10 is less than one, but frontier shift is considerable larger than one. The result might be shown for technical efficiency was improved for most of the shrimp trawlers accessed fishing grounds below 40 a meter depth where there is a nursery ground near the shore line, offering more resources for exploitation.

The factors affecting variables could be explained by the algebraic sign and the significance of the estimated coefficients. The coefficients in the 2nd stage OLS model would express the direction of the effects of corresponding factors on technical efficiency. Note that the positive sign will imply a negative effect and a negative sign will imply a positive one. With the exception of the age of vessel variable, house hold size variable for the year 2010, remaining variables in the OLS model are statistically significant. The coefficient for engine power is negative suggests a positive effect of engine power on the vessels' technical efficiency. The coefficients for household size have a negative sign, implying that the household size has a positive impact on technical efficiency.

The 2nd stage OLS model and the frontier model can help us to investigate the factors affecting efficiency and the production process. From the model, the facts that engine power and the household size have a positive impact on efficiency are not surprising. A trawl is a mobile fishing gear, so greater engine power can allow more gear to be worked. Greater engine power also helps the vessels to access the fishing ground more quickly, which then reduces the fishermen's traveling time and fuel cost. The effect of the age of vessels on efficiency was also found not to be statistically significant by t-test but significant by p value. It is probably because vessels are regularly repaired and maintained. Regular maintenance can help to improve the conditions of a vessel and to extend its lifetime. Thus older vessels may still obtain catches similar to the new vessels. However, recall that we have used the time of ownership of a vessel as a proxy for vessel age, since exact data is still not available. The extent to which this is a source of bias, is difficult to determine. In the 1st stage, all coefficients estimated for parameters were significant and showed their impacts on the production process.

6.5 MANAGEMENT

The industrial trawl fisheries of the Bay of Bengal are facing various and wide ranging problems. The fisheries sector has been suffering from a continual lack of well-planned management approaches. The management organizations are practiced on the basis of economic sectors providing major consideration on economic gain from the resources. The complex biophysical mechanisms arising in the ecosystems and their relations with the management are infrequently considered and evaluated. Therefore, persons with adequate knowledge on the scientific basis of fisheries management and development are overlooked from the higher level of policymaking and management bodies. Many of the fisheries development policies cannot be effectively implemented for several reasons. Corruption at different levels of management systems, illegal fishing, and the use of illegal gears are some of the main constraints in successful implementation. Implementation of development policies is hindered to a large extent by lack of manpower for official management, including monitoring, evaluation, supervision, etc. Poor management policies, weak organizat with legal efforts and, especially, the pressure of an increasing population have subjected the coastal areas vulnerable for overexploitation with huge destruction. The need for a fundamental guideline for coastal and marine fisheries resources has been fully identified to overcome the problems of unplanned destruction. Due to the lack of appropriate handling, processing and marketing infrastructure, a big amount fish and other catches are damaged every year. The trawler fleet, while not permitted by rules and ordinance to fish at depths shallower than 40 meter. Since their gear is non-selective, they harvest sizes of fish and shrimp, which fall under the post-juvenile and pre-adult categories, thus restricting adult recruitment of a part of the population. A large increase in industrial trawl fishing pressure considerably lowers the number of fish and shrimp reaching the industrial fishing resulting in lower overall catches in the industrial fleet. For the better production in the trawl fishery mainly depends not on the trawl fishery alone but on the management of artisanal fisheries.

The bycatch of industrial trawl fishery, which destroys large group of other species resulting in reduced standing stock of that species year after year. To decrease the loss as bycatch, an alternate method of collection must be tried, targeting only fish and shrimp. In a country like Bangladesh where there is a shortage of food, the nation cannot afford to discard this low-cost but high value animal protein. The big amount of bycatch should be efficiently utilized as fish meal in fish and poultry feed and can be processed into value-added products. Any development or management activity that relates to the water bodies and resources should be done only in close discussion with the DOF to ensure no harm to the fisheries and aquatic biological resources. Establishment of integrated coastal zone management programs through direct participation of all related bodies would offer a reasonable solution of the problem. Effective measures should be taken by the proper authority to solve these problems.

In 1983, the Government of Bangladesh promulgated the Marine Fisheries Rules, 1983, in accordance with the provisions of the Marine Fisheries Ordinance, 1983. Under the necessities of the ordinance, the marine fisheries wing of the Department of Fisheries (DOF) is authorized to deal with matters relating to marine fisheries exploitation, including licensing and monitoring of fishing vessels.

6.6 CONCLUSIONS

The objective of our study was to estimate the optimal stock, harvest and effort level through the bio economic model with relative changes between different species for recent years and measuring efficiency of trawlers to ensure sustainable fisheries of the Bay of Bengal. It is deemed important to undertake this type of study for the purpose of investigating the efficiency and the models of population growth may be used in the management and regulation of Bangladesh industrial trawl fishery. Harvesting invariably at the maximum sustainable rate would be very dangerous. However, if the population fails to regenerate itself fully for over some time, or if the maximum rate of harvesting is exceeded momentarily, then the population would be driven to extinction. It is obvious from our study that, if the yield falls below the 639407.38 kg and 149615.92 kg for the fish and shrimp resource of Bay of Bengal , then the rate at which the population regenerates itself will fall below the rate of its extraction, and therefore the stocks will head for extinction. The conclusion is that a stable equilibrium can only be reached if the rate of extraction is less than the maximum rate. Another aspect of fisheries management is that of maximizing the economic rent by achieving the economic equilibrium, defined as the maximum economic yield. According to the results found from our study, it is necessary that Bangladesh trawl fishery should be on a concentrated management from the interested fishery managers and stakeholders with strong emphasis in enforcement of the existing regulations. It is also obvious from the calculated results that the fish and shrimp resource of Bangladesh is not sustainably managed to achieve the reference points. Again, for the conservation, restoration and enhancement of fish and shrimp resource, it is necessary to enforce sustainability with respect to the reference points. In this respect, it is noted that our study provides an estimated value of fishing effort to achieve MEY and it should be remembered that at the present scenario maximum economic yield is a globally accepted fishery management tool to manage the resource sustain ably. To maximize the yield and resource rent dynamically, we have applied optimal sustainable yield strategy. The estimated values of optimal stock, effort and yield are presented through considering separate discount rates. It is obvious from the calculated results that the existing fishing effort to harvest fish and shrimp resource should be decreased to achieve MSY, otherwise for a constant period, the population should fail to regenerate itself fully; consequently the resource will collapse as well as the fishery will not be able to fulfill commercial purposes, such that the perceived bioeconomic equilibrium for the fleet will be the optimal stock. It is shown from the calculated results that effort reduction is a primary goal in Bangladesh trawl fishery, the impact of such reduction in terms of equity is important. That is, there should be a strong balance between efficiency and equity objects. An isolated policy to simply lower effort will be possible but is more difficult to apply because fish and shrimp fishing of Bangladesh is largely subsistence in nature as well as a matter of survival for coastal community. Therefore, a retaining and employment program might be necessary. Banning on technically inefficient trawling be a better approach to protect the resource from danger of depletion. A potential option is to pool their resources and organize such programs as promotion of eco-tourism and dispersion of industrial development into Bangladesh's marine trawl fishing areas. Consequently, the obtained results of our study are not only feasible to assess the biological, social and economic impacts of existing fish and shrimp resource of Bangladesh, but also provide appropriate, ensures to maintain long run sustainability of the resource. Due to the limitation of time and ability, this study could not presently show how tax or quota or trawl ban policies are implied and how much slack of the output congestion is applied for analyzing the efficiency of the trawlers. This might be an interesting topic for further study in the future.

7. REFERENCES

Ali Emrouznejada,_, Barnett R. Parkerb, Gabriel Tavaresc,2008. Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA

Banker, R.D., A. Charnes, and W.W. Cooper. 1984. "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis." Management Science 30(9): 1078-1092.

Caves, D., Christensen, L., Diewert, E. 1982. The economic theory of index numbers and the measurement of input, output, and productivity. Econometrica, 50(6): 1393-1414.

Charnes, A., W.W. Cooper, and E. Rhodes. 1978. Measuring the Efficiency of Decision Making Units. European Journal of Operational Research 2(6): 429-444.

DOF 2010. A Brief on Department of Fisheries, Bangladesh, DOF, Bangladesh

DOF, report, 2009. A Report on Department of Fisheries, Bangladesh, DOF, Bangladesh.

DOF, report, 2007. A Report on Department of Fisheries, Bangladesh, DOF, Bangladesh.

Flaaten, O. 2010. Lecture notes on Fisheries Economics and Management. Norwegian College of Fishery Science, University of Tromsø, Norway.

FAO stat, 2009, Food and Agricultural Organization of the United Nations, Rome, Italy

FAO, 2005, Kelleher K.. Report of Discards in the world's marine fisheries ,Food and Agricultural Organization of the United Nations, Rome, Italy

Fare, R., Grosskopf, S., Lindgren, B. and Roos, P. 1994. Productivity Developments in Swedish Hospitals: A Malmquist Output Index Approach. In Data Envelopment Analysis: Theory, Methodology and Applications, A. Charnes, W.W. Cooper, A.Y. Lewin and Seiford, L.M. (Eds.), Boston: Kluwer Academic Publishers: 253–272

Färe, R., Grosskopf, S., Lindgren, B., Roos, P. 1992. Productivity changes in Swedish pharmacies 1980-1989: A non-parametric approach. Journal of Productivity Analysis, 3(1-2):85-101.

Farrell, M.J. 1957. "The Measurement of Productive Efficiency." Journal of the Royal Statistical Society, Series A, General, 120(3): 253-282.

Fare, R. & Lovell, C.A.K., 1978. “Measuring the technical efficiency of production”, Journal of Economic Theory, 19, pp.150-162.

Fare, R., Grosskopf, S. and Lovell, C.A.K. (1985). The Measurement of Efficiency of Production. Boston: Kluwer Academic Publishers.

Gordon, H.S., 1954. The economic theory of a common-property resource: the fishery. Journal of Political Economy, 62:124-42.

Habib, A. 2010. Possible economic impact on coastal fish stock resources in Bangladesh in the case of climate change

Islam, Md. S. 2003. Perspective of the coastal and marine fisheries of the Bay of Bengal, Bangladesh, Ocean & Coastal Management, 46 (8):763-796.

Khan, M.S.U. 2007. Optimal Stock, Harvest and Effort Level of Bangladesh Trawl Shrimp Fishery – A Nonlinear Dynamic Approach. Journal of Agriculture and Rural Development, 5(1&2): 143-149.

Kim Anh, T.N., Flaaten, O., Tuan, N., Dung, T.P., TramAnh, T.N., 2006. A study on costs and earnings of gillnet vessels in Nha Trang, Vietnam. In: IIFET 2006 Proceedings, Portsmouth, England.

Khan, A. A. 2000. “Report on Status of the Demersal Fishery Resources of Bangladesh”, Paper presented at the National Consultative Workshop on Sustainable Development of Coastal Fish Stocks (ADB-RETA 5766 Project) held at Dhaka, Bangladesh during October 3-5, 2000 as Organised by DOF & ICLARM.

Khan, M. S. and Hoque, M. S. 2000a. “Fleet Operational Dynamics: Bangladesh” Paper Presented at the International Seminar in Malaysia

Koopmans, T. C. 1951. An Analysis of Production as an Efficient Combination of Activities. In T.C. Koopmans, (ed.), Activity Analysis of Production and Allocation. Cowles Commission for Research in Economics. Monograph No.13. New York: John Wiley & Sons, Inc

Lovell, C.A.K.1993. Production Frontiers and Productive Efficiency, in H.O. Fried, C. A.K

Lewin, A. Y. and R. C. Morey (1981). "Measuring the relative efficiency and output potential of public sector organizations: an application of data envelopment analysis." International Journal of Policy Analysis and Information Systems 5: 267-285.

Malmquist,S (1953),Index Numbers and Indifference Surfaces,Trabajos de Estatistica,4,209-42

NMFS, 1998. National Marine Fisheries Service a United States federal agency

Parkan C.; Wu M. L. (1997 On the equivalence of operational performance measurement and multiple attribute decision making

Rahman M. , 2001 The impact of shrimp trawl fisheries on living marine resources of Bangladesh. In Tropical Shrimp Fisheries and Their Impacts on Living Marine Resources. FAO Fisheries Circular no. 974, Rome.

Statistics of Marine Fisheries Department, 2010, Chittagong, Bangladesh.

Schaefer, M. 1957. “Some Considerations of Population Dynamics and Economics in Relation to the Management of Commercial Marine Fisheries”, Journal of Fisheries Research, Board of Canada, No. 14, p 669-81.

Shephard ,R.W.1953. Cost and Production Functions,Princeton University Press,Princeton.

Timothy J. Coelli, D.S. Prasada Rao, et al. (2005). An Introduction to Efficiency and Productivity Analysis, Second Edition, Springer: 172.

Wikipedia, 2011. List of countries by Geography. [cited 3 May 2011]. Available from http://en.wikipedia.org/wiki/Geography_of_Bangladesh#Area_and_boundaries

Zhu, Joe, 2003. Quantitative Models for Performance Evaluations and benchmarking, Kluwer Academic Publishers.

8.1 Appendix 1 VRS efficiency score of fish trawlers

DMU	Year				
	2006	2007	2008	2009	2010
Aqua Marine	0.84607	0.850115	0.8564	0.856222	0.847375
Bata	0.821393	0.82685	0.820177	0.821215	0.907753
Blue MT-1	0.909233	0.904962	0.904267	0.900749	1
Blue MT-3	0.848236	0.852949	0.854956	0.85459	0.86463
Blue MT-6	0.941728	0.945094	0.940508	0.950115	0.980976
Blue MT-7	0.908742	0.914441	0.915684	0.912458	0.911442
Blue MT-9	0.807932	0.805844	0.855482	0.836285	0.87432
Dolphin	0.944577	0.944363	0.959816	0.953601	0.964872
Flamingo	0.92526	0.918418	0.936738	0.939138	0.972021
Golda	1	1	1	1	1
Jalua	0.95199	0.948508	0.950431	0.946682	0.951646
Kohinoor-1	0.938085	0.933581	0.934554	0.933813	0.942384
Koral	0.83077	0.829021	0.824191	0.825497	0.836312
Kornofully1	0.947042	0.961702	0.955302	0.952011	0.963955
Lakha	0.83069	0.829697	0.846267	0.836789	1
Minsandhani	0.83217	0.847741	0.847757	0.836712	0.846042
Rahga Choka	0.854212	0.850405	0.862708	0.85632	0.847188
Satelite 3	0.927506	0.974072	0.980505	0.931266	0.928361
Suman	0.969258	0.970398	1	0.97137	0.968237
Bagda	1	1	1	1	1
Campa	1	1	0.990824	1	0.990824
Chandana	0.924939	0.907421	0.945385	0.934399	0.967355
Falcon	0.930582	0.946273	1	1	0.932978
MarineHarvester 2	1	1	1	1	1
Nowrat	0.819266	0.98412	0.844871	0.816846	0.845313
Satelite 1	0.951234	0.949212	0.945235	1	1
Star 1	0.914795	0.862831	0.896042	0.86173	0.890753
Universal 4	0.712877	0.706868	0.717874	0.706879	0.725081
Chungton	0.634622	0.599094	0.617637	0.603309	0.602257
Deep Sea-2	0.549894	0.55508	0.551326	0.560749	0.558549
Hartford 2	0.54617	0.544921	0.546322	0.548747	0.55639
Hartford 4	0.568767	0.550985	0.56067	0.545568	0.544585
Hartford 5	0.55883	0.553663	0.568529	0.55788	0.569048
Hartford 7	0.583959	0.623093	0.733757	0.563273	0.551669
Hartford 9	0.567601	0.548199	0.555712	0.548836	0.542672
Megnah-5	0.818741	0.711102	0.760547	0.752118	0.729645
Sagor Sompod	0.558475	0.562379	0.558953	0.562625	0.567682
Ark	0.647975	0.649888	0.672944	0.656619	0.672115
Desparedo	0.648085	0.640386	0.693565	0.664474	0.662393
F.Karim1	0.692387	0.687536	0.697932	0.690336	0.696268
Labiba	0.750798	0.667051	0.688242	0.671569	0.694504
Peninsula 4	0.965132	0.649993	0.649921	0.650468	0.664578
Sea Master	0.647144	0.640455	0.668251	0.653171	0.669384
Speed 2	0.654911	0.633333	0.691446	0.694867	0.679825
Mehriz	0.866213	0.863636	0.910188	0.892369	1
Chattagram	0.714828	0.651115	1	0.987218	0.833333
Cristal 1	0.722117	0.703704	0.773579	0.761047	0.757804

Dhaka	1	0.595421	0.668966	0.650463	0.644182
Peninsula 2	0.625643	0.6235	0.628503	0.658829	0.653673

8.2 Appendix 2 VRS efficiency score of shrimp trawlers

DMU	Year				
	2006	2007	2008	2009	2010
Speed 1	0.681422	0.633333	1	0.691887	0.775404
Deep Sea 1	1	0.893965	0.918772	0.86388	0.868082
Hart Ford 6	1	0.850658	0.89773	0.868905	0.951929
Hasikin 10	1	1	1	1	1
Salsabil	1	0.958867	0.945541	0.915137	0.930756
Syam	0.90518	0.803589	0.857229	0.770881	0.775175
Nazat	0.845016	0.844736	1	0.935684	0.941937
AHM 1	0.745195	0.635769	0.812137	1	0.660738
Bandhan	1	1	0.847116	0.827872	0.883041
Imam 2	1	1	1	1	1
Imam 3	0.663524	0.684569	1	1	1
Janjabil	0.934185	1	1	1	1
Jouta Jatra	0.778565	0.816965	0.832862	0.798929	0.798305
JoutaUddom	0.939302	0.865044	0.915721	0.907383	0.890124
Minhar 2	1	0.897556	0.875371	0.820614	0.817472
Mita	0.80609	0.807411	0.827695	0.805829	0.835406
Mohisor 1	0.87526	0.873577	0.951323	0.905132	0.948321
Mohisur 2	0.874329	0.901273	0.886071	0.968588	0.946445
Moin	0.706282	0.707022	0.721058	0.898366	0.745057
Moitri s	0.669586	0.773057	0.819528	0.915178	0.697008
Nobi	0.892099	0.863636	0.888006	0.894524	0.922224
Deep Sea 3	0.570705	0.556156	0.862963	0.554928	0.578547
Fisher 1	0.623363	0.62988	0.646237	0.63599	0.627152
Fisher 2	0.63617	0.619094	0.659917	0.638649	0.637245
Fisher 3	0.635272	0.623976	0.652166	0.643469	0.631799
Fisher 4	0.623747	0.616667	0.65187	0.636776	0.62762
Hart Ford 10	0.872945	0.551112	0.563672	0.582189	0.547856
AHM 2	0.585603	0.515236	0.553901	0.544757	0.543519
Minhar 1	0.714929	0.714874	0.734454	0.760836	0.745236
Moitri t	0.661804	0.633333	0.659532	0.660491	0.659145
Rahmat	0.753536	0.756	0.76385	0.763948	0.765237

8.3 Appendix 3 Malmquist efficiency change					
DMU	Year				
	2006-07	2007-08	2008-09	2009-10	2006-10
Aqua Marine	1.018762	1.022327	0.984655	0.952633	0.97695
Bata	2.757125	0.523965	0.688968	0.60032	0.597504
Blue MT-1	0.492452	0.977095	0.573118	0.082466	0.022742
Blue MT-3	1.152741	0.960249	1.02972	0.524184	0.597474
Blue MT-6	0.742146	0.765274	1.608832	0.287233	0.262453
Blue MT-7	0.87823	0.838393	0.783434	0.602377	0.347478
Blue MT-9	0.928421	0.952914	0.607974	0.481639	0.259063
Dolphin	0.88831	1.767022	0.9312	0.656308	0.959306
Flamingo	1.655181	0.382068	1.043783	0.610987	0.403301
Golda	0.59265	1.315439	1.176002	0.612562	0.5616
Jalua	0.418643	1.581423	0.693708	0.538877	0.247491
Kohinoor-1	0.479968	1.221334	0.70118	0.728526	0.299448
Koral	0.638488	1.253705	0.190184	3.194251	0.486284
Kornofully1	1.747819	0.742038	0.68582	0.946014	0.841454
Lakha	0.66699	1.606941	0.918584	0.429803	0.423163
Minsandhani	1.337949	0.682911	1.131834	0.567386	0.586766
Rahga Choka	0.672733	1.066758	1.075433	0.549532	0.424117
Satelite 3	0.762536	0.915101	1.437066	0.762399	0.76452
Suman	0.795137	1.685834	0.547674	1.245793	0.914587
Bagda	0.721416	0.960691	1.432707	0.751955	0.746653
Campa	0.110022	1.457991	2.770999	1.375782	0.611534
Chandana	0.066178	6.080821	1.073385	0.24755	0.106928
Falcon	0.854152	4.287653	1.411455	0.11162	0.576985
Marine Harvester 2	0.581934	0.83208	1.582533	1.743008	1.335646
Nowrat	0.58181	2.028085	0.555909	1.370756	0.899148
Satelite 1	0.780406	3.194154	0.30347	0.170801	0.129206
Star 1	0.215389	14.55755	0.55076	0.346868	0.599016
Universal 4	1.086808	0.538763	0.830194	0.600283	0.291801
Chungton	0.422734	0.399904	1.266146	3.6351	0.778079
Deep Sea-2	0.912711	1.112252	2.187494	0.514965	1.143566
Hartford 2	0.088862	10.15981	0.783253	1.036321	0.732818
Hartford 4	1.776488	0.832923	0.054503	1.797924	0.144996
Hartford 5	1.909708	0.24266	6.792545	0.182993	0.576014
Hartford 7	1.31646	1.632902	0.477659	0.776884	0.797705
Hartford 9	0.221331	1.68176	0.536206	2.511448	0.501259
Megnah-5	0.064505	11.53808	0.96528	0.638114	0.458436
Sagor Sompod	0.559042	1.025239	0.80367	0.411676	0.189628
Ark	2.112952	0.127268	1.474969	0.35545	0.140985
Desparedo	3.779993	0.231219	1.011696	0.420533	0.371847
F.Karim1	0.784358	0.838519	1.061218	0.201393	0.140565
Labiba	0.123632	4.198588	0.685662	0.802326	0.285559
Peninsula 4	0.396808	0.444489	0.642215	1.003931	0.113717
Sea Master	1.161612	0.613215	1.159844	0.98308	0.812199
Speed 2	0.79622	0.212541	2.451491	0.594385	0.24659
Mehriz	0.484587	0.892733	0.56644	7.537134	1.846941
Chattagram	0.350276	2.206456	0.384205	0.568574	0.168832
Cristal 1	0.407794	0.938678	0.27175	0.949801	0.0988

Dhaka	0.297114	0.664031	1.391763	0.462584	0.127019
Peninsula 2	0.797546	0.849035	2.00105	0.306952	0.41592
Speed 1	0.377797	3.359703	0.373215	0.841597	0.398678
Deep Sea 1	0.889196	1.045068	0.568186	0.943758	0.498303
Hart Ford 6	0.48958	1.351205	0.800021	1.784513	0.944422
Hasikin 10	1	0.930503	0.707607	0.749653	0.493595
Salsabil	0.804073	0.748873	0.751489	1.240888	0.561512
Syam	0.868433	0.993963	0.491786	1.037521	0.440432
Nazat	0.45596	5.363849	0.749832	1.066819	1.956402
AHM 1	0.814967	1.171901	1.414535	0.367796	0.49688
Bandhan	1	0.735248	1.004477	1.138255	0.840646
Imam 2	1	0.689363	1.450615	1	1
Imam 3	1.074222	2.206933	1	1	2.370736
Janjabil	1.558905	1	1	1	1.558905
Jouta Jatra	4.059118	1.210796	0.544353	0.8777	2.348172
JoutaUddom	0.908721	1.071599	0.992319	0.878998	0.849381
Minhar 2	0.73972	0.894859	0.660727	1.002844	0.438609
Mita	1.854859	0.814327	0.728461	0.273308	0.300724
Mohisor 1	1.874725	0.748467	0.312325	1.048738	0.459604
Mohisur 2	1.243081	0.651599	1.069821	0.864748	0.749343
Moin	11.48073	1.022671	2.46503	0.5172	14.96876
Moitri s	2.621058	0.959554	0.743215	0.695312	1.299691
Nobi	0.601421	0.542114	1.745955	0.756441	0.430603
Deep Sea 3	1.527415	0.973178	0.84028	2.12562	2.654968
Fisher 1	1.087761	0.937267	1.180857	0.732584	0.881966
Fisher 2	0.429486	2.018377	0.958705	0.851586	0.707725
Fisher 3	0.568788	1.522439	1.048	0.427616	0.388066
Fisher 4	0.504022	2.308	0.927481	0.717571	0.774204
Hart Ford 10	0.32456	0.821956	1.935698	0.531358	0.27439
AHM 2	0.207618	1.83057	1.524057	0.401228	0.232404
Minhar 1	0.706411	0.714017	3.510142	0.777668	1.376847
Moitri t	0.497017	1.392034	0.594656	1.138567	0.468431
Rahmat	1.222622	1.334608	0.758059	0.795411	0.983876

8.4 Appendix 4 Malmquist frontier shift

DMU	Year				
	2006-07	2007-08	2008-09	2009-10	2006-10
Aqua Marine	0.826801	1.154465	0.942704	1.160727	1.210576
Bata	0.898479	1.318218	1.144867	1.44276	1.703429
Blue MT-1	0.910314	1.287175	1.159761	1.383089	1.253318
Blue MT-3	0.904119	1.226497	0.935877	1.224302	1.377724
Blue MT-6	0.865677	1.308898	1.004629	1.313544	1.466966
Blue MT-7	0.909483	1.331896	0.936456	1.20162	1.265116
Blue MT-9	0.886476	1.357095	1.113519	1.494406	1.624154
Dolphin	0.867653	1.166619	0.936002	1.18223	1.302911
Flamingo	0.90402	1.246044	0.910321	1.462599	1.592512
Golda	0.668158	1.213603	1.164656	1.151054	1.195234
Jalua	0.898698	1.353741	0.94324	1.126889	1.297602
Kohinoor-1	0.726365	1.174421	1.313154	1.202206	1.172904
Koral	0.768666	1.259411	1.145352	1.228832	1.509712
Kornofully1	0.891618	1.299269	0.934902	1.224973	1.353035
Lakha	0.856723	1.080863	0.913096	1.427341	1.670196
Minsandhani	0.818578	1.28343	1.120462	1.234547	1.386882
Rahga Choka	0.800097	1.126106	1.175236	1.198993	1.332593
Satelite 3	0.699259	1.582956	1.116812	1.160989	1.249687
Suman	0.835589	1.366902	1.10713	1.166044	1.217159
Bagda	0.824562	1.38806	0.912672	1.654788	1.489735
Campa	0.723792	2.121234	0.911	1.212488	1.513656
Chandana	0.980343	1.383317	0.866632	1.393035	1.569547
Falcon	0.769459	1.293587	0.926547	1.410962	1.221603
MarineHarvester 2	0.913168	1.223909	0.9173	1.141293	1.213522
Nowrat	0.734553	1.776126	0.91055	1.249975	1.522205
Satelite 1	0.849914	1.186452	1.111677	1.724749	1.505847
Star 1	0.851536	1.264018	0.897236	1.295213	1.378655
Universal 4	0.911055	1.334853	0.962471	1.116818	1.272157
Chungton	0.896606	1.169251	1.094316	1.267791	1.403426
Deep Sea-2	0.910709	1.241695	1.139734	1.273128	1.438594
Hartford 2	0.866146	1.135745	1.13357	1.268152	1.25108
Hartford 4	0.905617	1.206738	1.110776	1.262882	1.393619
Hartford 5	0.899884	1.255088	1.02593	1.1489	1.26021
Hartford 7	0.875286	1.407338	0.943348	1.184705	1.340959
Hartford 9	0.900205	1.309045	0.944453	1.179053	1.287638
Megnah-5	0.856044	1.448063	0.92027	1.247719	1.378589
Sagor Sompod	0.908581	1.300799	0.945602	1.193409	1.293223
Ark	0.850268	1.502006	0.874019	1.356204	1.477756
Desparedo	0.856017	1.423055	0.901719	1.354555	1.433526
F.Karim1	0.922391	1.360544	0.95096	1.102767	1.31634
Labiba	0.926266	1.496149	0.915794	1.265355	1.778372
Peninsula 4	0.933861	1.536752	0.906398	1.258442	1.798155
Sea Master	0.937222	1.425219	0.887188	1.245965	1.456374
Speed 2	0.813958	1.531951	0.933213	1.723494	1.766495
Mehriz	0.959851	1.268066	0.876612	1.440541	1.498247
Chattagram	0.64309	2.016518	1.007233	1.701059	2.221895
Cristal 1	0.849555	1.373547	1.128446	1.447801	1.26959

Dhaka	0.683781	2.055104	0.946755	1.816941	2.221895
Peninsula 2	0.868093	1.307023	0.914022	1.378396	1.505826
Speed 1	0.689417	1.401869	1.206444	1.638562	1.636846
Deep Sea 1	0.742998	0.983158	1.438026	1.185691	1.249827
Hart Ford 6	0.751112	0.985444	1.132094	1.305142	1.187643
Hasikin 10	0.557247	1.192215	1.440162	1.150469	1.229301
Salsabil	0.830265	1.025	1.160433	1.229965	1.32083
Syam	0.738401	0.977868	1.387448	1.187352	1.201389
Nazat	0.852617	1.062953	1.003087	1.158242	1.314059
AHM 1	0.663981	0.990839	1.141145	1.393638	1.17458
Bandhan	0.676343	1.379332	1.036164	1.129552	1.181479
Imam 2	0.879059	1.130607	0.970078	1.328387	1.330699
Imam 3	0.909987	1.172362	1.091867	1.435457	1.645491
Janjabil	0.776148	1.3243	1.16096	1.214544	1.435709
Jouta Jatra	0.672222	1.104723	1.478036	1.158118	1.228121
JoutaUddom	0.915841	1.208099	1.079299	1.182858	1.348461
Minhar 2	0.691599	1.223663	1.357915	1.206025	1.28769
Mita	0.786261	1.063965	1.180013	1.264477	1.405812
Mohisor 1	0.657073	1.069752	1.392973	1.416744	1.427639
Mohisur 2	0.863239	1.172359	1.06952	1.565637	1.267095
Moin	0.792417	0.914525	1.114579	1.675987	1.546484
Moitri s	0.759372	1.03109	1.357865	1.432396	1.191926
Nobi	0.839519	1.040444	1.128281	1.224813	1.124812
Deep Sea 3	0.732458	1.433981	0.941767	1.329842	1.542588
Fisher 1	0.920028	1.189117	0.919296	1.135604	1.122938
Fisher 2	0.911184	1.349705	0.944739	1.109507	1.286372
Fisher 3	0.897709	1.341019	0.931666	1.265547	1.348175
Fisher 4	0.84861	1.422457	0.9568	1.12262	1.213528
Hart Ford 10	0.854862	1.352373	0.907707	1.212566	1.361252
AHM 2	0.848933	1.422043	0.886863	1.514425	1.659785
Minhar 1	0.950238	1.320634	0.934283	1.094923	1.188895
Moitri t	0.881688	1.416134	1.16273	1.204596	1.351972
Rahmat	0.882845	1.396453	0.934276	1.218309	1.35561

8.5 Appendix 5 Malmquist Index

DMU	Year				
	2006-07	2007-08	2008-09	2009-10	2006-10
Aqua Marine	1.176126	0.845261	0.928238	1.105747	1.182673
Bata	3.634494	0.470771	0.788777	0.866118	1.017806
Blue MT-1	0.633873	0.889463	0.664681	0.114058	0.028503
Blue MT-3	1.413834	0.86818	0.963691	0.64176	0.823154
Blue MT-6	0.971393	0.66248	1.616278	0.377293	0.385009
Blue MT-7	1.169711	0.762505	0.733651	0.723829	0.4396
Blue MT-9	1.259956	0.844736	0.676991	0.719764	0.420758
Dolphin	1.03632	1.533162	0.871605	0.775907	1.24989
Flamingo	2.062429	0.345397	0.950178	0.893629	0.642261
Golda	0.719241	0.87892	1.369638	0.705092	0.671243
Jalua	0.566735	1.421222	0.654333	0.607255	0.321144
Kohinoor-1	0.563685	0.887135	0.920757	0.875839	0.351224
Koral	0.804119	0.96368	0.217827	3.925198	0.734149
Kornofully1	2.270886	0.661614	0.641175	1.158842	1.138516
Lakha	0.720925	1.376703	0.838755	0.613476	0.706765
Minsandhani	1.717164	0.559016	1.268176	0.700464	0.813775
Rahga Choka	0.757569	0.85351	1.263888	0.658885	0.565175
Satelite 3	1.20706	0.639892	1.604932	0.885137	0.95541
Suman	1.086874	1.408664	0.606346	1.45265	1.113197
Bagda	1.001369	0.792149	1.307592	1.244327	1.112315
Campa	0.233383	1.055283	2.52438	1.66812	0.925653
Chandana	0.091545	5.961292	0.930229	0.344845	0.167828
Falcon	1.10492	3.299174	1.307779	0.157492	0.704847
MarineHarvester 2	0.712235	0.759829	1.451659	1.989284	1.620836
Nowrat	1.033368	1.489736	0.506183	1.71341	1.368687
Satelite 1	0.925914	2.714756	0.33736	0.294588	0.194564
Star 1	0.272255	12.39628	0.494162	0.449268	0.825836
Universal 4	1.450728	0.490843	0.799037	0.670407	0.371216
Chungton	0.494282	0.358557	1.385564	4.608547	1.091977
Deep Sea-2	1.133309	1.012939	2.493162	0.655616	1.645127
Hartford 2	0.100924	8.799874	0.887873	1.314213	0.916814
Hartford 4	2.143757	0.754309	0.06054	2.270567	0.202069
Hartford 5	2.396853	0.218366	6.968676	0.210241	0.725899
Hartford 7	1.852704	1.429256	0.450599	0.920378	1.069689
Hartford 9	0.289732	1.513928	0.506421	2.96113	0.64544
Megnah-5	0.093407	9.877095	0.888319	0.796187	0.631996
Sagor Sompod	0.727201	0.931512	0.759952	0.491298	0.245232
Ark	3.173666	0.108212	1.289151	0.482062	0.208341
Desparedo	5.379137	0.197927	0.912266	0.569635	0.533052
F.Karim1	1.067153	0.773442	1.009176	0.222089	0.185031
Labiba	0.184972	3.88901	0.627926	1.015227	0.50783
Peninsula 4	0.609795	0.415091	0.582103	1.263389	0.204481
Sea Master	1.655551	0.574719	1.028999	1.224884	1.182865
Speed 2	1.21977	0.173	2.287763	1.024419	0.435599
Mehriz	0.614488	0.85689	0.496548	10.85755	2.767174
Chattagram	0.706337	1.41895	0.386984	0.967178	0.375127
Cristal 1	0.560124	0.797458	0.306655	1.375123	0.125436

Dhaka	0.610599	0.454052	1.317659	0.840488	0.282222
Peninsula 2	1.042411	0.737042	1.829004	0.423101	0.626303
Speed 1	0.529622	2.316238	0.450263	1.379009	0.652575
Deep Sea 1	0.87422	0.776483	0.817066	1.119005	0.622792
Hart Ford 6	0.482453	1.014906	0.905699	2.329043	1.121636
Hasikin 10	1.192215	0.51852	1.019069	0.862453	0.606777
Salsabil	0.824175	0.621763	0.872053	1.526248	0.741662
Syam	0.849213	0.733943	0.682327	1.231903	0.529131
Nazat	0.484664	4.573309	0.752147	1.235635	2.570828
AHM 1	0.807501	0.77812	1.614189	0.512574	0.583625
Bandhan	1.379332	0.49728	1.040803	1.285718	0.993206
Imam 2	1.130607	0.605991	1.407209	1.328387	1.330699
Imam 3	1.259377	2.008281	1.091867	1.435457	3.901025
Janjabil	2.064458	0.776148	1.16096	1.214544	2.238133
Jouta Jatra	4.484202	0.813924	0.804574	1.016481	2.88384
JoutaUddom	1.097826	0.981414	1.071009	1.03973	1.145356
Minhar 2	0.905168	0.618884	0.897211	1.209455	0.564792
Mita	1.973506	0.640274	0.859594	0.345591	0.422761
Mohisor 1	2.005489	0.491797	0.43506	1.485793	0.656148
Mohisur 2	1.457338	0.562485	1.144195	1.353882	0.949489
Moin	10.49941	0.810382	2.747471	0.86682	23.14896
Moitri s	2.702547	0.728658	1.009185	0.995962	1.549135
Nobi	0.625745	0.455115	1.969929	0.926499	0.484348
Deep Sea 3	2.190284	0.712812	0.791348	2.826738	4.095522
Fisher 1	1.293475	0.862312	1.085557	0.831926	0.990393
Fisher 2	0.579679	1.839112	0.905726	0.944841	0.910398
Fisher 3	0.762756	1.366707	0.976386	0.541168	0.523181
Fisher 4	0.71695	1.958591	0.887414	0.80556	0.939519
Hart Ford 10	0.438926	0.702659	1.757047	0.644307	0.373514
AHM 2	0.295241	1.554031	1.351629	0.60763	0.38574
Minhar 1	0.932911	0.678486	3.279467	0.851487	1.636926
Moitri t	0.703843	1.22734	0.691424	1.371513	0.633305
Rahmat	1.707334	1.178252	0.708237	0.969056	1.333752