TOWARDS AND APPROPRIATE ECONOMIC MANAGEMENT REGIME OF TUNA FISHERIES IN GHANA

BY

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A thesis submitted to University of Tromsø in partial fulfilment of the requirements for the degree of Master of Science in International Fisheries Management.

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NORWAY

MAY 2003

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DECLARATION

I declare that I have personally under supervision undertaken the study herein submitted.

Date-- ----------------------------

Obeng Victor

(*Student)*

I declared that I have supervised the student in undertaken the study submitted herein and I confirm that the student has my permission to present it for assessment.

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ABSTRACT

The Ghanaian tuna fishery is a baitboat and purse seine fishery. Three main species of tuna are caught namely, Skipjack, Bigeye and Yellowfin. A detailed and comprehensive set of catch and effort data for the tuna fisheries has been obtained for the period 1980-2001.

Harvest functions have been designed and estimated. By maximising the log-likelihood function by numerical methods, parameter estimates and performance indicators of the different models were obtained. The best result was obtained for a harvest model allowing inclusion of a time trend parameter. For this model the stock-output elasticity is assumed to be 1, the effort-output elasticity is estimated at 0.849, and the technological change at about 3.6% annual increase in productivity.

Technical – Economic interactions among the species have been analysed. Different periods where chosen for each period, cross – elasticity of supply calculated between the species. The result indicated a mixed significance, which gives room for the existence of technical – economic interactions among the species over the years, considered. This suggests that single species management may be inappropriate for the tuna fishery.

ACKNOWLEDGEMENTS

Thesis of this nature evidently cannot be the single effort of any individual. However, to the man above there are no words to express how much I THANK YOU for blessings I have received.

I would especially like to thank professor Ola Flåten for his patience with many false starts before the final thesis proposal was chosen and then for guiding me through the writing process, always finding something encouraging to say. Without his continuous encouragement and support, I would not have persevered to the completion of this thesis. I Thank Frode Skjold of Department of Pharmacy for his technical expertise and rigor and, in some ways more importantly, for his enthusiasm, which always managed to revive my own when, it had lagged.

To my father, Mr. Kwaku Obeng, thank you for your infinite wisdom, knowledge, total faith and undying support towards my upbringing. I am also very grateful to my mother, Madam Adwoa Fremah for her love and endless understanding.

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1. INTRODUCTION

1.1. Statement of the problem

The fisheries sub-sector of the Ghanaian economy accounts for about 3% of the GDP. Fish is the major source of animal protein for Ghanaians. Per capita consumption of fish is about 26kg,which represents 60% of all animal protein. In 1996,fish and fish products, including shrimps, tuna loins and canned tuna contributed US $56 million which is about 21% of the total non-traditional exports of Ghana.

The tuna fishery contributes significantly to the total landings in Ghana. For instance, in 1997,out of total landings of 446,883MT, estimated tuna landings was 36,044 MT. The tuna fishery falls under the east Atlantic tuna fishery. In Ghana, it is a two fleet vessel namely the bait-boat (artisanal), which is mainly a coastal operated fishery and the purse seine fleet (industrial) that are high sea oriented.

All tuna vessels are operated on joint venture basis with Ghanaians owing at least 25% of the shares as decreed in the fisheries law, PNDC Law 256 of 1991.The main species caught are Skipjack, Yellowfin and Bigeye. About 67% of the landed tuna is processed into loins or canned and exported; the rest is sold at the local market. Though the bait-boat fleet of Ghana makes significance contributions to the total catch in Ghana, it catches only small fish (about 1.9kg) as against the recommended minimum of 3.3kg by the International Commission for the Conservation of Atlantic Tuna (ICCAT).

A look at the 1997 total landings in Ghana showed that tuna contributed about 8.1% of the total landings. Since the adoption of 200 nautical mile Exclusive Economic Zones, and particularly since the late 1970s, a number of major developments have taken place in the tuna industry. Global demand for tuna commodities increased steadily throughout the 1980s (Hassan, 1997). It seems clearly that tuna, which has a high value in the world market, could contribute more than this. The Ghanaian economy could earn more from the tuna fishery if it is economically manage well. An appropriate harvest function is needed to help exploit the resource in a more or less sustainable way to avoid any depletion. Based on the 1990 production, Ghana ranks 4th out of the 36 major fishing countries exploiting fish out of the Atlantic Ocean. The maximum sustainble catch of the eastern Atlantic is estimated at 200,000 mt out of which about 40% are in Ghanaian waters (ICCAT). This means that Ghana could get a better position in terms of the rankings which is base on production if the 40% share of the maximum sustainable catch will be manage in an economically efficicient way. However, the fishery could be managed by either adopting the Schaefer model, Bell's technique of the Lobster fishery harvest function, the simple linear relationship between fishing mortality and harvest or the more general Cobb-Douglas model. What is appropriate for the Lobster fishery may not be appropriate for the Ghanaian tuna fishery. In much the same way the Schaefer model may not be appropriate for the tuna fishery. The problem of the tuna fishery is that a more appropriate harvest function is needed to manage the fishery so as not to cause any overexploitation.

Moreover, there are three species of tuna exploited in Ghana, namely, Skipjack, Yellowfin and Bigeye. As a result, management and regulation of the species may be frequently complicated by unknown technical and economic interactions among the species. Hence, single species management by means of harvest restrictions without adequately understanding the nature of interactions among the species may result externalities due to substitution possibilities.

As international demand remains high for tuna, intensive fishing raises concerns for the long-term sustainability of this resource. Given the large potential profits and many competing users in the tuna fishery, conservation efforts have sparked heated international debates. It is under these conditions that fishery managers seek to manage east Atlantic tuna, integrating biology with the demands imposed by global economics and politics.

These and a lot more are the challenges of this research.

1.2. Objectives of the study

This study has two broad objectives: specific objectives and general objectives.

The general objective seeks to find out the following:

(i) An appropriate harvest model for the Ghanaian tuna fisheries in the eastern Atlantic. The aim of this model will be to study to what extent catch of tuna varies with fishing effort, stock size, temperature and time trend.

(ii) The maximum economic yield (MEY) of the fishery when other countries where the stock migrates to together with Ghana are in Nash Co-operative Equilibrium.

(iii) Analyse the nature of technical and economic interrelationships by examining the substitution and complementary production relationships among the tuna species.

A more specific objective of this study propose a policy to manage the fishery sustainably to prevent both economic and biological overfishing, in the light of the general policy issues outlined above.

1.3. Data, Scope and Methodology

Secondary sources of data are used. This data is from the fisheries department and some selected companies in Ghana. Historical data on harvest and effort as well as the cost of fishing and prices of fish has been used. Average sea surface temperature is also used here.

A harvest function for the fishery has been estimated. Because different harvest functions could fit the tuna fishery with varying results in terms of the most appropriate and significant model, different models has been tested to see which one would be more appropriate for the tuna fishery. Hence harvest functions ranging from the simplest one as $h=qE$ to a more complex one involving different more parameters such as the Cobb-Douglas harvest function, $h=qE^{a}X^{b}$ has been employed. Tuna is a highly migratory species. Seasonal migration patterns of tuna appear to vary depending on age class and fish size. Movements are presumed to reflect the species search for optimal conditions relating to food, spawning conditions, mean sea surface temperature and other ecological factors These movements are expected to decrease the stock available for harvest in Ghanaian waters. Data on all these variables causing the migration is not available so temperature, the only variable with available data is taken care of in this work. The model has then been extended to include temperature to see if there could be improvement in fit. The model then look like this $h=qE^{a}X^{b}T^{f}$. Where q, α, β and ϕ are parameters to be estimated, E is effort, X is biomass level and T is temperature. A time trend parameter, γ has been introduce to see the rate of annual technological progress and its general contribution to the fit of the model. The model is then formulated as, $h=qE^aX^bT^fe^{gw}$, where w is year. A Durbin-Watson test (DW test) has been conducted to check if the parameter estimates of the production function are free from serial autocorrelation while the F-test is conducted to ascertain the overall significance of the model. An idea of cross – elasticity of supply has been employed to analyse the technical – economic interrelationships among the species. This has been done to determine any complementary or substitute relationship. Finally, I have tried to calculate the maximum economic yield of the fishery.

1.4. Model assumptions

In the study the following assumptions have been made.

(i) Tuna is a highly migratory species. In the eastern Atlantic the species migrate along the waters of almost all the countries with favourable sea temperatures for the stock although the greater percentage of the MSY is found in Ghanaian waters (ICCAT homepage). The study hence assumes that all countries are cooperating and exploiting the stock in a sustainable way

(ii) The industry’s total cost (TC) curve has been assumed to be a linear function of effort.

(iii) Since the Ghanaian tuna fishery is part of the East Atlantic tuna fishery, some biological parameters have been assumed to be similar to that found in the entire east Atlantic.

1.5. Prior expectations

Based upon the objectives of the study and the statement of the problem, the study is expected to reveal the following.

(i) The result is expected to show that an assumption of linearity between fishing mortality and fishing effort has to be modified.

(ii) The appropriate harvest model is expected to reveal if over the years there has been technological improvement.

(iii) The null hypothesis that the Schaefer harvest function is appropriate and the null hypothesis that the biomass and effort Cobb – Douglas function is appropriate are both expected to be rejected on statistical grounds.

(iv) The study is expected to reveal that the tuna fishery in Ghana is engulfed with Technical – Economic interactions among the species of tuna.

1.6. Limitations of the study

This study is limited by the fact that measurement errors may exist in the catch information. These errors are statistical discrepancies emanating from punching errors to incorrect reporting.

1.7. Organization of work

In all the study consist of six chapters.

Chapter one constitutes the introduction. The chapter covers the objectives of the study, model assumptions and statement of the problem. The chapter also includes the scope, data and methodology of the work as well as the expectations of the study.

Chapter two is captioned the literature review. The pertinent literature on tuna species including the biological characteristics is reviewed. Historical trends of tuna catches as well as management of the species in Ghana are also recounted in this chapter.

Chapter three has been captioned Bioeconomic models and deals with the summary of the models from fisheries economics and biology used in analysing the data.

Chapter four is the empirical modelling and data. This chapter deals with the general objectives; analyses of the data collected as well as the functional relationships are all taken care of.

In chapter five titled discussions and policy implications, the results and all the functional relationships are discussed. Here, recommendations have been made and the possible implications of the recommendations are recounted.

Chapter six is the concluding chapter, which deals with summary and conclusion.

2. LITERATURE REVIEW

2.1. Biology and Ecology

2.1.1. Stock Structure

Tuna is a highly migratory and pelagic species. In Ghana, ICCAT[1] identifies three species of tuna *stock* namely, Yellowfin, Bigeye and Skipjack tunas. The definition for stock is a very confusing term. Several definitions of "fish stock" exist within the scientific community, relying in whole or in part on geography, genetics, and politics. While some define a "fish stock" as all individuals of a given fish species residing in a particular geographic area, a more standard scientific definition identifies a stock as a population wholly or partially reproductively isolated and often displaying unique genetic characteristics. Political boundaries are sometimes used as a means of stock differentiation, but scientific validity may be sacrificed if a migratory stock is defined on the basis of geopolitical boundaries alone. Regardless, a fish stock is a management unit representing a technical choice by scientists -- and sometimes also a political choice. The management of tuna stocks in Ghana has been based on a three-stock hypothesis assuming limited mixing among the three stocks.

2.1.2. Yellowfin Tuna

Yellowfin tuna is a cosmopolitan species distributed mainly in the tropical and subtropical waters. In the Tropical Eastern Atlantic, yellowfin is caught by vessels operating in an area roughly bounded by latitudes 30^o North to 30^o South and by longitude 30^o West to the west coast of Africa. The sizes exploited range from 30cm to 170cm. Smaller fish form mixed schools with skipjack and juvenile bigeye and are mainly limited to surface waters, while larger fish are found in surface and sub-surface waters. The main spawning ground is the equatorial zone of the Gulf of Guinea, with spawning occurring from January to April. They are multiple spawners. From the Gulf of Guinea, the juveniles move towards more coastal waters off Africa. When they reach the pre – adult age (60-80cm:fish from age 1.5-2), it is presumed that the majority migrates west towards the American coasts, with the majority of these in turn returning to the East Atlantic fishing grounds for spawning when they reach about 110cm. Natural mortality is assumed to be higher for juveniles than for

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[1] International Commission for the Conservation of Atlantic Tunas

adults (ICCAT home page). Growth patterns are variable with size being relatively slow initially, and increasing at the time the fish leave the nursery grounds. It is an oceanic species occuring above and below the thermoclines. Sensitive to low concentrations of oxygen and therefore is not usually caught below 250m in the tropics. Yellowfin tuna smaller than 15kg often form schools of similar sized fish. Schools may be mono-specific (i.e, consist of only 1 species or include other tunas, such as skipjack tuna). Feed during the day and at night (diurnal and nocturnal).

2.1.3. Bigeye Tuna

Geographically, bigeye tuna covers almost the entire Atlantic Ocean between 50^{o}N and 45^{o}S. In the Tropical Eastern Atlantic, bigeye is caught by vessels operating in an area roughly bounded by latitudes 30^{o} North to 30^{o} South and by longitude 30^{o} West to the west coast of Africa. This species spawns in tropical waters when the environment is favourable. They then tend to migrate from the spawning areas into temperate waters, as they grow larger. Archival tagging and sonic tracking studies conducted on adult fish in other oceans revealed that they exhibit clear diurnal patterns being much deeper in the daytime than at night. Dwelling in deeper water than other species, it indicates extensive vertical movements. In the stomach of the bigeye, various prey organisms such as fish, molluscs and crustaceans are found. Usually, yellowfin and skipjack tunas have a mixture of young bigeye, which has form schools. Seamounts, whale shark and drifting objects are often associated with these schools. They are more tolerant to lower levels of temperatures and lower dissolved oxygen concentration than are other tunas. Adults tend to be solitary.

2.1.4. Skipjack Tuna

Also a cosmopolitan species, skipjack form schools in the tropical and sub-tropical waters of the three oceans. Normally inhibit waters with surface temperatures of 20^{o}C to 30^{o}C. In the Tropical Eastern Atlantic, skipjack is caught by vessels operating in an area roughly bounded by latitudes 30^{o} North to 30^{o} South and by longitude 30^{o} West to the west coast of Africa. However, adults are sometimes present in waters as cold as 15^{o}C. This stock is often associated with floating objects, both natural or diverse fish aggregating devices (FADs) that have been used extensively by purse seiners and baitboats since the early 1990s. The concept of viscosity (low interchange between areas) could be appropriate for the skipjack stock.

A viscose stock can have the following characteristics:

- A local decline of a segment of the stock
- Over-fishing of that component may have little, if any, repercussion on the abundance of the stock in other areas.
- There is a minor proportion of fish that make large-scale migrations.

The size at first maturity is reached at 51cm for males and about 42cm for females in the East Atlantic, while in the west sexual maturity is reached at 51cm for females and at 52cm for males. Skipjack growth is variable and seasonal, and substantial differences in growth rates have been reported between areas. There remain considerable uncertainties about these growth rates and the variability in growth between areas.Aggregations of this species tend to be associated with convergence boundaries between cold and warm water masses, upwelling and other hydrographic discontinuities. Stay near the surface at night. Opportunistic feeders preying on any forage available. The feeding activity peaks in the early morning and in the late afternoon. Skipjack tuna also needs dissolved oxygen level of 2.5ml per litre of seawater to maintain a minimum swimming speed and require higher levels when active. This requirement generally restricts skipjack tuna to water above the thermocline and in some areas, such as the eastern Pacific, may exclude them from surface waters.

2.2. Production and trend

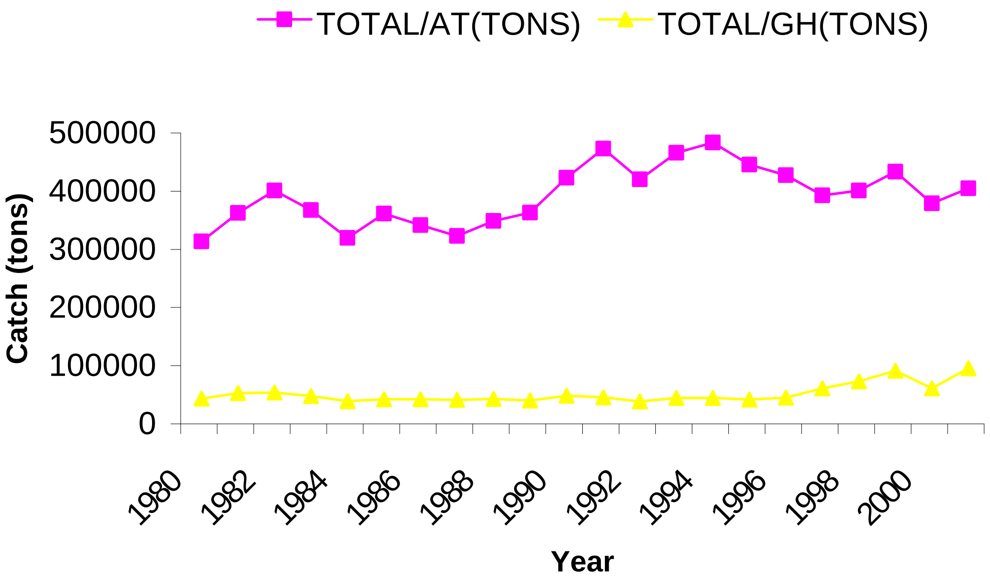
Tuna accounts for between four and seven percent of world marine catch by volume, and its contribution on average amounts to 7.8% of world total fish exports and 8.5% of world total imports by value. The volume of tunas has increased steadily, from around 2.6 million MT in 1977 to more than 4 million MT by 1993, at a rate of about 157,165MT per year. During 1977 – 1985 the landings increased at a rate of approximately 102,842 MT per year while the growth rate during 1986 – 1993 period rose to 179,950MT per year. The overall share of tunas as a percentage of the total landings of marine fishes has varied between four and seven percent over this same period, with trends favouring an increasing proportion of total landings. Approximately 13% to 16% of the world landings of tuna come from the Atlantic Ocean (Hassan, 1997). Based on the 1990 production, Ghana ranks 4th out of the 36 major fishing countries exploiting fish out of the Atlantic Ocean. The maximum sustainable catch of the Tropical Eastern Atlantic is estimated at 200,000 MT. Out of that about 40% are in Ghanaian waters (ICCAT home page). Catch of tuna has increased steadily in Ghana from 35,856MT to 88,000MT in the period 1980 - 2001.The figure below shows the production of tuna in Ghana as well as that for the entire Atlantic.

Table 2.1 Total catch for Atlantic and total catch for Ghana (all values in metric tons)

YEAR	**TOTAL CATCH (ATLANTIC)**	**TOTAL CATCH (GHANA)**
1980	305915	35856
1981	354632	45173
1982	393403	46247
1983	359795	40029
1984	311818	31266
1985	353475	34407
1986	334103	34720
1987	314970	33465
1988	340977	35434
1989	355510	32294
1990	415452	40803
1991	465353	37795
1992	412522	30777
1993	458079	36856
1994	475963	36972
1995	437754	33905
1996	419880	37255
1997	384811	53625
1998	393171	65568
1999	425941	83553
2000	371414	53255
2001	396968	88000

Source: ICCAT homepage and Ministry of Fisheries (Ghana)

Figure 2.1:Trend of tuna catches for Ghana and the Atlantic (AT is Atlantic and GH is Ghana in the legend).



2.3. Description of the fisheries

Tuna fisheries are composed of various kinds of fisheries from the purse seine fishery with modernized bigger vessels, whose size are larger than 3,000 gross tones, to the artisanal fishery such as hand line fishery with small canoes. These fisheries often target same tuna resources. The fishing grounds of tuna species, which are highly migratory species, are widely distributed and straddled among the high seas and many national economic zones. The economic values of tunas are variable among the countries and among regions even in a same nation. Furthermore, the economic values are also variable with the size of fish even in a region. There is a substantial difference in a sense of values for tuna between commercial and recreational fisheries. It is necessary for the international management of tuna fisheries to consider these variations in the fisheries and the differences in economic value among the fisheries and regions.

2.3.1. Yellowfin fishery

Yellowfin tuna is caught by surface gears (purse seine, baitboat, troll and handline) and with sub-surface gears. Troll and handline, although used in artisanal fisheries, have never been a large component of the yellowfin fisheries, although these gear types can represent a large proportion of the catch by a nation. The baitboat fisheries in equatorial areas have always targeted juveniles in coastal waters, together with skipjack, young bigeye and other small tunas. Baitboat fisheries are still active in waters of Ghana (Tema).

Purse seine fisheries began operating in the East Atlantic in the 1960s and developed rapidly in the 1970s. Beginning in 1975, the fishing area was extended from coastal waters to the high seas, especially at the equator, where large size yellowfin are caught during the spawning season. This gear is very efficient as it catches a wide range of sizes (40 to 160cm); particularly since 1991, the purse seine fleets, which operate in the East Atlantic, have developed a fishery, which targets schools associated with artificial floating objects. This translates into an important increase in catches of skipjack, juvenile bigeye and, to a lesser extent, increases in catches of juvenile yellowfin and by-catch.

Longline fisheries principally catch yellowfin larger than 70cm. However, deep longlines, which began being used in the early 1980s, mainly target bigeye, and therefore the proportion of yellowfin caught by longliners in the Atlantic is becoming less important (in 2000, it amounted to 14% of the total; ICCAT homepage). Coincident to the development of purse seine fisheries during the 1960's and 1970's, longline catches diminished. Yellowfin catches in the Atlantic as a whole reached a historical high in 1990 (192,500MT), but have since declined by 30% to 135,000MT in 2000. However, the relative contributions of the various gear types have remained similar. In the East Atlantic, landings reached a high of around 138,000MT in 1981 and 1982, then declined to a low of 76,000MT in 1984, gradually increasing to a new record of 157,000MT in 1990, and subsequently fluctuating between 126,000MT and 100,000MT, with a generally declining trend.

2.3.2. Bigeye fishery

This stock is exploited by using three major gears (longline, baitboat and purse seine fisheries). The size of fish caught varies among fisheries: medium to large for longline fishery, small to large for the directed baitboat fishery, and small for other baitboat and purse seine fisheries. Longline and baitboat fisheries have a long history that dates back before 1960. Major baitboat fisheries are located in Ghana, Senegal etc. Unlike other oceans, baitboats catch significant amounts of medium and large size bigeye tuna except in Ghana where mainly small fish are caught. While bigeye tuna is a primary target species for most of longline and baitboat fisheries, this species has been of secondary importance for purse seine fisheries.

Since about 1991, the purse seine and Ghanaian baitboat fisheries introduced a fishing technique that utilizes artificial fish aggregating devices (FADs). Similarly, baitboat fleets in Senegal and the Canary Islands have developed a method, which makes use of baitboats as FADs. These new techniques have apparently improved fishing efficiency and contributed to the increase of bigeye catch. The gear efficiency of purse seine with FADs is several times higher than a gear without FADs. Total annual catch exhibited an increase up to the mid-1970s reaching 60,000MT and fluctuating between 45,000 and 84,000MT over the next 15 years. In 1991, it passed 95,000MT and continued to increase, reaching a historic high of about132,000MT in 1994.

2.3.3. Skipjack fishery

Skipjack are caught almost exclusively by surface gears in the entire Atlantic Ocean, although minor amounts of skipjack are taken by longlines as by-catch. *In the East Atlantic, the skipjack fishery underwent important changes in 1991, with the introduction of artificial floating objects (FADs), with the subsequent expansion of the purse seine fishery towards the West, in latitudes close to the Equator, following the drift of the objects, the introduction of FADs in the Ghanaian purse seine and baitboats (1992), and the development of a fishing technique in which the baitboat is used as the aggregating device, fixing the school during the entire fishing season in waters off Senegal, Mauritania and the Canary Islands (1992). These changes have resulted in an increase in the exploitable biomass of the skipjack stock (due to the expansion of the fishing area) and in its catchability. At present, the most important fisheries are the purse seine fisheries, mainly those of EC-Spain, EC-France, Ghana* *and Netherlands Antilles, followed by the baitboat fisheries (Ghana, EC-Spain and EC-France). In 2000, catches in the eastern Atlantic reached 111,283MT, which represented a decrease of 20% as compared to 1999 (138,985MT)(ICCAT Report, 2000 – 2001).*

According to ICCAT, there is no information available on the effective fishing effort exerted on skipjack in the East, particularly after the introduction of fishing with artificial floating objects. Considering the carrying capacity of the vessels as a measure of nominal effort, in the East Atlantic Ocean, the total carrying capacity of the baitboat fleets remained relatively stable between 1972 and 2000. On the other hand, purse seine carrying capacity showed an increase trend until 1983 and a spectacular decline in 1984, due to the shift of a part of the fleet to the Indian Ocean. Since 1991, this carrying capacity of the purse fleet has declined gradually until 1997, and since then it has stabilized at about 32,000MT(ICCAT homepage).

The increase in the efficiency of the fleet due to technological improvements, the development of fishing with floating objects, etc., as described by the Working Group on Abundance Indices in the Tropical Tuna Surface Fisheries (Miami, 1998), have resulted in an increase in the effective effort of the different fleets. Preliminary analyses estimate an average annual increase of 5% in efficiency of all the fleets in the Eastern Atlantic for the period considered (1969 – 1998).

2.4. Management Regimes

The highly migratory nature of the tuna stocks means that there should be international management of the resource in addition to the domestic management regime so as to avoid international conflict on the exploitation of the resource.

2.4.1. Highly Migratory Characteristics

The vessels engaged in tuna fisheries also have highly migratory characteristics, especially for purse seine and longline boats operating in offshore waters. The distributions of these highly migratory vessels are not only influenced by the abundance of fish, but also by the difference in the degree of regulations among different grounds (UNEP Fisheries Workshop, Geneva, 2001). This phenomenon show that the tuna fisheries generally change their fishing ground quickly, depending on the condition of stock and regulations for the fisheries. Consequently, the fishing efforts tend to be concentrated in the region where the fishing vessels can operate more freely without strict regulations. It is therefore desired to manage the tuna fisheries in the global scale, not independently in each region or country. Furthermore, it is recognized that the effort control in the global scale is necessary for the effective management of the tuna fisheries over the world, because the overcapacity of the fishing effort is one of the major factors, which hamper the effective management of the fisheries. Under the current circumstances, it is very difficult to agree on the introduction of the regulatory measures in the tuna fisheries due to the conflict of the interests among nations.

2.4.2. International Management

Increasing capitalization and declining catch-per-unit-effort (CPUE) trends in the Atlantic during the 1960s drew concern by the international scientific community regarding the abundance, health, and reproductive capacity of tuna. Recognizing the need for coordinated international management, the International Convention for the Conservation of Atlantic Tunas was negotiated and signed in Rio de Janeiro in 1966. In 1969, member nations established the International Commission for the Conservation of Atlantic Tunas (ICCAT) to recommend conservation and management measures for tuna and other highly migratory species

ICCAT is currently composed of 22 member nations, including Ghana, Japan, the United States and most major fishing nations on the Atlantic rim. ICCAT's primary responsibilities are to provide internationally coordinated research on the overall condition of highly migratory species in the Atlantic Ocean and Mediterranean Sea and to recommend regulatory and management measures to maintain all highly migratory tunas and billfish at their most productive levels. The Commission conducts annual meetings, usually in November or December, to analyze statistical data and recommend management measures. Although the member nations agreed, in the Convention, to implement ICCAT recommendations domestically within six months, they often may not do so.

ICCAT's primary stated management objective is to maintain Atlantic tuna populations at levels that will permit maximum sustainable yield (MSY). MSY is an estimate of the greatest average catch that can be removed from a fish stock year after year without harming its ability to sustain these maximum catches in subsequent years. In an effort to reach this objective, ICCAT recommends a number of management measures for the Atlantic tuna fishery, including, minimum size limits. With respect to the minimum size limits, Bigeye tuna has 3.2kg and yellowfin has 3.2kg. Notwithstanding this size limit, the contracting states may grant tolerances to boats which have incidentally captured yellowfin and Bigeye weighing less than 3.2kg, with the condition that this incidental catch should not exceed 15% of the number of fish per landing of the total yellowfin and bigeye catch of said boats. (ICCAT, 1972). The effectiveness of implementation and enforcement of these ICCAT recommendations by individual nations has been repeatedly questioned by environmental, fishing industry, and government interests. In addition, environmental groups have faulted ICCAT for weak recommendations that they consider insufficient to assure that ICCAT's MSY objective could be met (Eugene H. Buck, 1995). It should however be stated that it is not possible to force a country to accept more stringent regulations than what it would do voluntarily. In the case of ICCAT, the least productivity country, and thus the one most likely to be hurt by strict regulations, blocks all attempts to pass measures strict enough to conserve the resource.

2.4.3. Problems with the International Management Regime

The allocation of total allowable catch (TAC) has been carried out based on the actual catch by nations in the past. Recently there are big arguments on the criteria for allocation of the TAC. ICCAT has a special working group on allocation criteria, and it is very difficult to get consensus on the allocation criteria among the contracting parties at present. This issue is the most fundamental point in the international management of tuna resources, because the major management tool in the international organizations is catch control through the allocation of TAC among the contracting parties. If there is no consensus on this issue, the most important function of the international fishery organizations will be lost. This problem of the allocation criteria is not only related with TAC allocation, but also will be related with the allocation of the fishing effort in the future, which is closely related with the solution overcapacity in the international waters.

The argument on the allocation criteria is posed by the developing states and argues that allocation criteria should take into account the distribution of stock biomass, state of development of countries, dependency on fishing areas, compliance with conservation and management measures in addition to the historical catch (ICCAT, 1998). In this issue, there is very clear conflict of interest between developed and developing states. There is a possibility that a state intends to use subsidies for increase of the fishing effort, linking with this argument. But it is less probable that the states pose this kind of argument due to the past increase of fishing efforts by the subsidies, which has already happened. The allocation criterion is one of the very fundamental concepts in international management of the fishery.

2.4.4. Domestic Management Regime

Ghana's fishing industry supports up to about 1.5 million people, which is about 10% of the total population. Majority of these employees live along the 528km coastline. In her bid to make sure its citizens employed in the fishing sector gets a secure job, a number of direct and indirect controls are adopted to regulate the fisheries resources. In order to have access to its marine resources, Ghana welcomed the Extended Fisheries Juridiction from 12 Nautical miles to 200 Nautical miles. With a continental shelf of 23,700km^2 and an Exclusive Economic Zone (EEZ) stretching over 218,000km^2 the stage was set for Ghana to manage her marine resources in addition to what measures are taken by international management bodies.

As a key instigator of the Convention, Ghana joined ICCAT seeking to improve tuna management through better international cooperation. To implement Ghana's participation in ICCAT, PNDC[2] Law 256 of 1991 was enacted. Under this law, all tuna vessels are operated on joint-venture basis with Ghanaians owing at least 25% of the shares. And to continue her participation in ICCAT, Ghanaian Scientists participated in a tagging cruise organized by the Bigeye Tuna Year Program (BETYP) off Sao Tome during the months of April to July 2001 (ICCAT Report, 2002-2003). There are no quotas allocated to ICCAT members. Ghana therefore has the right to increase the volume of catch if she so desires (MFRD[3], 1999 & 2000). Fishing gear used in Ghana tuna fishery includes purse seines and baitboat. The domestic management authorities have allowed the use of extensive Fish Aggregating Device

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[2] Provisional National Defence Council: A former military government regime in Ghana.
[3] Marine Fisheries Research Division.

(FADs) in the fishery. Purse Seiners continue to work in association with baitboats often sharing the catch off FADs. This collaboration has led to a mixture of varying sizes of fish often landed by the baitboats, leading to some problems in stratification by gear (ICCAT Report, 2002-2003).

3. BIOECONOMIC MODELS

3.1. Harvest functions

Different harvest functions have been used in some empirical works on fish stocks in the East Atlantic. This range from a simple linear relationship between fishing mortality, F, and fishing effort, E to a more complex non-linear harvest functions like the Cobb-Douglas general harvest function. In this study, statistical analysis is carried out on a number of these harvest functions and the one showing the highest improvement of fit is adopted for the Ghanaian tuna fishery.

The fishing mortality rate, F, normally is assumed to be proportional to the fishing effort, E:

$$F = q \cdot E. \tag{1}$$

The Schaefer harvest equation on the other hand succinctly illustrates how biological factors and economic factors interact to create a stock externality. The model implies that an increase in the stock biomass leads to an increase in the catch at the same rate, keeping the fishing effort unchanged. The underlying assumption is that the fish stock is homogeneously distributed in the ocean and the abundance of fish changes linearly. This Schaefer harvest equation (Schaefer, 1957; Flaaten, 2003) is commonly used in Bioeconomic analysis

$$h\ (E, X) = q \cdot E \cdot X, \tag{2}$$

Which assumes a linear relationship where harvest (h) directly depends on fishing effort (E) and stock biomass (X). The coefficient q is a gear and stock specific constant, commonly referred to as the catchability coefficient. Use of this function is common among biologists (besides Schaefer, see Ricker, 1958 and Schnute, 1977). In one of the first applications of dynamic fisheries models, Patterson and Wilen, 1977 and Wilen, 1976 assumed a Schaefer harvest function in their study of the dynamics of the overexploitation of the North Pacific fur seal. Bell, 1972 assumes Schaefer function in his study of the northern lobster fishery. Because of its simplicity, the Schaefer harvest function has been assumed in much of the applied dynamic work. The Schaefer model remains the pre-eminent pedagogical model of fishery economics. But this position according to Ralph E. Townsend in *A critique of models of the American Lobster Fishery (1984)* is not based upon empirical applications. The Schaefer harvest function, however, is highly restrictive. It is homogeneous of degree one in both E and X. Diminishing productivity does not apply, and production is characterised by increasing returns to scale since the function is homogeneous of degree two in inputs.

Polacheck *et al*., 1993 also gave a harvest function that assumes equilibrium harvest. This function is model as:

$$h = E\,(a - bE)^{1/p} \qquad (3)$$

Where a, b and p are parameters.
This function is quadratic in E, assuming p = 1. For such a function, the Maximum Sustainable Yield (MSY) is the top of the curve where dh/dE = 0 and the optimum effort (EMSY) are directly below the MSY peak of equilibrium catch. However, this model usually overestimates the safe catch levels (Boerema and Gulland, 1973, Larkin, 1977).

This study also tries to use the more general Cobb-Douglas harvest function, which has been used in some empirical works on the Northeast Artic Cod catches production (Flaaten, 2003).

1. $h(E_i\,, X_i) = q\cdot E_i^{\alpha}\cdot X_i^{ß}$ (4)

This equation involves two more parameters than the Schaefer equation. The additional parameters are the effort-output elasticity *(a)* and stock-output elasticity *(b)*. Here a gives the percentage increase in catch when *effort* (E) increases by 1% while b gives the percentage increases of *catch (h)* with an increase of 1% of stock *biomass* (X). The Schaefer equation (1) is restored when $a = b = 1$ in equation (3). The elasticities are expected to be within the ranges

$$\alpha = 0$$
$$0 = \beta = 1$$

This is supported by Flaaten 2003 on Harvests functions of the Norwegian bottom trawl fisheries of cod in the Barents sea when a and b were estimated to be 1.232 and 0.424 respectively.

Given the widespread use of the Schaefer function and this Cobb-Douglas function, it is unfortunate that they had not been more extensively tested. Flaaten, 2003 (Harvests functions: the Norwegian bottom trawl fisheries of Cod. Marine Resource Economics) tried testing this by incorporating more additional inputs.[4] The result was marvellous since the additional inputs considerably improved the overall fit of the model. This study also tries to rectify the deficiency in the Cobb-Douglas and Schaefer models through the estimation of a harvest function for the Ghanaian tuna fishery that considers more inputs.[5]

Over the years, there has been a consistent global warming causing instability in sea surface temperatures. This instability could mean that the tuna species in Ghanaian waters would migrate to more suitable areas where temperatures will be ideal for them. Should this happen, then less tuna will be available for harvest in Ghana. Seasonal migration patterns of tuna appear to vary depending on age class and fish size. Movements are presumed to reflect the species search for optimal conditions relating to food, spawning conditions, mean sea surface temperature and other ecological factors These movements are expected to decrease the stock available for harvest in Ghanaian waters. Data on all these variables causing the migration may not

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[4] See Flaaten, 2003. Harvest functions: The Norwegian bottom trawl fisheries of Cod.

[5] for a further discussion of the restrictive nature of the Schaefer harvest function see Bell.

be available so temperature, the only variable with available data is taken care of in this work. The harvest function is thus also specified to include this climatic effect as;

$$h_i\ (E_i, X_i, T_i) = q \cdot E_i^{\alpha} \cdot X_i^{\beta} \cdot T_i^{\phi} \qquad (5)$$

Here T is temperature and measured in degrees Celsius.

Trend terms of the statistical analysis of Flaaten (2003) were considered to reflect technological improvement of the fisheries during the investigated period. Following this approach, I have included the trend term, $e^{w\gamma}$ in the harvest function. Thus, γ shows annual percentage neutral technological change (Flaaten, 2003). The harvest function then becomes

$$h\ (E_i, X_i, T_i, w_i) = q \cdot E_i^{\alpha} \cdot X_i^{\beta} \cdot T_i^{\phi} \cdot e_i^{w\gamma} \qquad (6)$$

Where w, indicates year.

$$h_i\ (E_i, X_i, w_i) = q \cdot E_i^{\alpha} \cdot X_i^{\beta} \cdot e_i^{w\gamma} \qquad (7)$$

Equations (4), (5), (6) and (7) are non-linear harvest functions involving constant elasticities so statistical analyses are carried out by logarithmic transformation such as:

$$\text{Log}(h^*_i) = \log[q] + \alpha \log(E_i) + \beta \log(X_i) + w\gamma + \mu_i \qquad (8)$$

Here μ_i is the stochastic error term and is expected to follow an autoregressive scheme of order 1 and define by;

$$\log\mu_i = \rho\log(\mu_{i-1}) + V_i \tag{9}$$

With $V_i \sim N(0, \sigma^2)$

Thus the joint distribution of V_i is multivariate normal. ρ is a constant called coefficient of autocorrelation. μ is thus what is causing ups and downs in catch at any given period of time. A reason for autocorrelation in the error term is factors not included in the model, such as fish migration.

3.2. Existence of Technical – Economic Interactions Among The Species

Insights into the substitutes and complementary production relationships among the three different species of tuna can be gained by examining some estimated elasticities:

$$\varepsilon_{ij} = (\Delta H_i/\Delta P_j)^* (P_j/H_i)$$

Where: $\varepsilon_{ij} \equiv$ is the elasticity of transformation that measures how a fleet substitutes fishing one species for fishing another species as the relative price for the two species changes.

$H_i \equiv$ Harvest of Species *i*

$P_j \equiv$ Price of Species *j*

The elasticities are calculated using years 1980, 1995, 1998 and 2000. The intuition behind choosing 1980 is that, it was the time when international management of the resource began and hence it is an ideal year for any comparison. The rest of the years were chosen due to the availability of price data from 1995 – 2000. The same elasticity analysis could be done for the mid 1980s and late 1980s when price data is available.

3.2.1. Complementary Relationship (e_{ij} = +)

- In complementary relationship, an increase in price of species *i* will increase production of species *j*.
- When outputs are complements, management policy that restricts the harvest of species i also restrict the harvest of species j. Then, the most easily regulated output requires regulation to reduce output levels.
- The lack of complementarity across all the species suggests a degree of selective harvesting and incomplete joint production on the part of fishers. It may be partially attributed to the tendency of fishers to retain high priced species during initial part of the fishing trip, subsequentially filling their vessel holds with other species as the time approaches to return to port.

3.2.2. Substitute Relationship (e_{ij} = -)

- An increase in price of species *i* will decrease the production of species *j*.
- When two species are substitutes, effort is allocated among species on the basis of differences in relative prices. If two products are substitutes, management policy that restricts the harvest of one species will lead to increased exploitation of other.
- The existence of substitute relationships highlights the concern that single species management of the tuna fishery may have negative effects on non – regulated species through unanticipated shifts in harvests.

3.2.3. No Relationship (e_{ij} = 0)

- An increase in price of species *i* will have no effect on the production of species *j*.

3.3. Profit function

Ghana shares the tuna fishery in which the stock grows according to a logistic growth curve

$$F(x) = r \cdot x\,(1 - x/k) \qquad (12)$$

Where F (X) is the growth function, which gives the rate of stock growth per unit of time, x is the stock of fish, r is a growth parameter, and k is the carrying capacity of the marine ecosystem. The Schaefer short – run harvest function is given as:

$$h = qEX \qquad (13)$$

Making X the subject and putting in equation (12) gives Schaefer long – run harvest function as:

$$H = rH/qE\ (1 - H/qEK) \qquad (14)$$

In equation (14), if F(X) = H and doing a little bit of arrangements, we have the long run harvest function as:

$$H = H\ (E) = qKE\ (1 - qE/r), \qquad \text{For } H = F(X). \qquad (15)$$

Assuming a constant price, p, per unit of fish harvested, the total revenue will be given by;

$$TR\ (E) = p{\cdot}H = \qquad (16)$$

And assuming a constant cost, c, per unit of effort, the total costs, TC, of fishing is given by;

$$TC\ (E) = cE \qquad (17)$$

If there is a sole owner exploiting the resource, then in equilibrium that manager harvests the growth in biomass so that the Maximum Economic Yield, MEY is given as:

$$MEY = TR - TC = p \cdot qKE\,(1 - qE/r) - cE \tag{18}$$

And to obtain the effort level that will maximise equation (18), the resource manager has to equate the marginal revenue per unit of harvest to the marginal cost of harvest. This represents a social optimum where the marginal revenue from fishing equals the marginal social cost. The marginal revenue is define as:

$$MR(E) = dTR(E)/dE = pqk(1 - 2qE/r) \tag{19}$$

However, tuna is a highly migratory species and that the resource is shared. The idea of a share resource could be likened to a game – theoretic concept in environmental economics by A. W. Tucker. In such a fishery like tuna fisheries, there is high competition for the available stock so there is little incentive for a country to limit how much they catch unless they could be sure that everyone else would do the same. The problem is conventionally seen as one of an absence of, or share rights over, a resource where each country imposes an externality on other countries that share the resource. The fact of the matter is that one country’s action of taking more than what it is suppose to take will impact a negative externality on other countries while if a country tries to conserve, a positive externality will be generated for the other countries. Assume that there is no binding agreement of cooperation between these countries sharing the resource. Because of this lack of cooperation Ghana could choose to manage the resource in an open access way. If this happens then assume further that neighbouring countries do not go fishing. This gives reaction curves of two countries illustrated below.

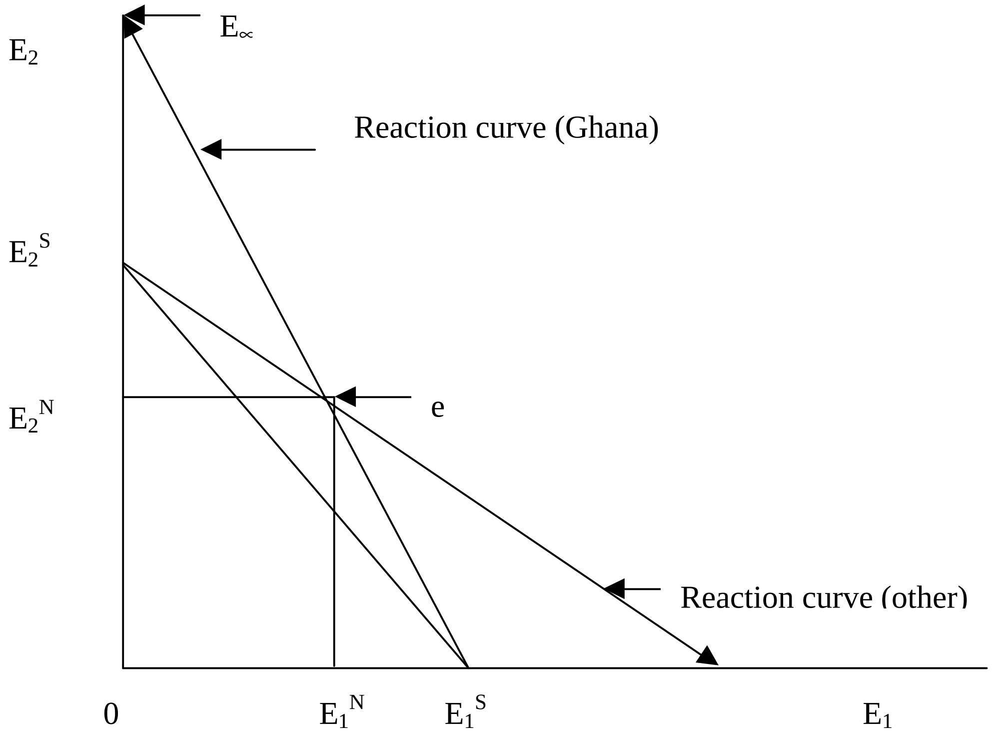

Figure 3.1 Fishery Nash equilibrium

The harvest rates E_1^N and E_2^N are the profit – maximising effort that the firm would choose if they had sole ownership of the resource. The Nash equilibrium fishing effort E_1^N and E_2^N is greater than under sole ownership but the harvest is less: this therefore represents an inefficient outcome. Reaction curves give the Nash response of Ghana to the other countries harvest effort that is they give the profit – maximising harvest effort given the other countries harvest effort. If Ghana chooses an open access regime of E_α in the diagram, then the other country does not go fishing and chooses $E_1 = 0$. Nash equilibrium occurs at *e* with effort of E_1^N and E_2^N. The line E_1^S to E_2^S gives the pareto optimal cooperative solutions. Along this line harvest effort is chosen so that the countries exploiting the tuna species maximize their joint projects. At the point e there is no incentive for the countries to choose another strategy. There are two key results that emerge from this analysis. First, that if the two countries cooperate, then they stand to benefit by increasing their profit. The second point is that the problem of suboptimal exploitation becomes worse as the number of firms increases (the case of tuna fisheries in the eastern Atlantic) until the open – access equilibrium is reached where all countries earn zero profits. This gives a game – theoretic interpretation of Hardin’s (1968) tragedy of the commons.

This lack of binding cooperation also means that Ghana no longer equates its marginal cost of harvest to marginal revenue per unit of harvest but rather marginal cost is equated to average revenue in order to maximize profit. In a share resource like this, what normally happens is that an obvious socially optimal solution is often rejected because of distrust among the countries.

4. DATA, EMPIRICAL MODELLING AND RESULTS

4.1. Data

Data are available for the two types of fleets in Ghana, namely the purse seine and baitboat fleets. The data available are from 1980–2001, a period in which international regulation of the stock started in the Tropical Eastern Atlantic. Regulation commenced in 1969. Prior to the international regulation, each country was therefore faced with the problem of how to allocate their effort among the different common property tuna stock. To see the effect of a climatic element on harvest, temperature data are included in the analysis while time trend data from 1980–2001 is included in the analysis to determine vessel efficiency over the years.

4.1.1. Economic Data

A particularly rich data set on harvest, effort, price and cost is used in this analysis. The Marine Fisheries Research Division (MFRD) collects the data for harvest and effort on an annual basis. Catch data from the ICCAT data base have been rejected and not used in this analysis because of wide differences existing between data from ICCAT database and that from MFRD (Ghana). A look at for example total catch of 8,118MT from the ICCAT database is entirely different from the total catch from Ghana, which recorded 35,855MT for the same year, 1980. Reasons for such a wide difference is not within the scope of this work but a simple reason could be under reporting from Ghana to ICCAT. In the data set, effort are available both as number of vessels for each fleet (purse seine and baitboat) and also as standardised effort in sea days for each fleet. However, the analysis presented in this paper uses only effort in sea days which has been standardised to take care of the different fleet capacities. Thus, the number of days fished by small seiners and baitboats have been converted to large – seiner day equivalents. Analysis presented makes use of the aggregate catch data for all the three species but not each species in isolation. I have done this because I have assumed that the three species are harvested together by each fleet and that there is no selective harvesting. And infact, this is what happens in the Ghanaian tuna fishery. No fleet harvest only one species but the gear catch any species that comes in its way.

Data on stock biomass (X) have not been available both from Ghana and ICCAT database. I have as a result chosen to give the stock – output elasticity parameter (β)

the value of, $\beta = 1$. (See Flaaten, Harvest functions: The Norwegian Bottom Trawl Fisheries of Cod, 2003) for more discussion on the stock – output elasticity parameter.

Table 4.1: Average tuna prices

Year/Species	Bigeye	Skipjack	Yellowfin
1995	$770	$700	$770
1996	$825	$725	$825
1997	$775	$725	$775
1998	$1050	$1000	$1050
1999	$562	$512	$562
2000	$450	$400	$450

Because of the uncertainties of the cost data (for example I had no access to the cost of harvesting from reputable firms exploiting tuna in Ghana. This is because the fear of disclosing a vital information was high since that information could be essential for their competitors not only in Ghana but elsewhere too), I have chosen to adopt the cost data from Marbel, 2002. That writer had all the essential information for her thesis work. She obtained the average price of fishing from Tema Tuna Ventures (TTV), a tuna fishing company that owns a third of the total purse seine fleet in Ghana as well as five baitboats and a carrier vessel. The average variable cost (AVC) per ton was found to be $314 for purse seiners and $370 for baitboats. The total costs per sea day for harvesting all three species is $2,550 for baitboats and $4,183 for a purse seiner. The current social rate of discount in Ghana is 26.8% per annum (p.a). And to ease the job of having to compare prices of tuna across the different companies and markets, average price per ton were obtained from Pioneer Food Cannery (PFC), which exports about 80%[6] of the canned tuna from Ghana. This data is average price per ton for each species from 1995 – 2000.

4.1.2. Biological data

Data on average sea temperature are provided by meteorologists in Ghana and available from 1980 – 2001. Seawater temperature at Tema Fishing Harbour is used since that is where all the tuna caught are landed. The non-availability of stock size data means that the CPUE will be used to determine the trend of the stock size over the period 1980 – 2001. CPUE is at least expected to give an idea of how the population size will look like. However, it should be stated that, for schooling fish, such as tuna, CPUE might lead to an overestimate of population size (Conrad and Adu – Asamoah, 1983).

Table 4.2: Effort in number of vessels, CPUE by vessel type and Standardised effort is in sea days.

	BAITBOAT FLEET				PURSE SEINER FLEET			
Year	**Catch**	**Effort**	**St.Effort**	**CPUE**	**Catch**	**Effort**	**St.Effort**	**CPUE**
1980	33399	41	2,728	12.24	2457	6	570	4.31
1981	38829	41	2,728	14.24	6,344	6	570	11.12
1982	37462	41	2,728	13.73	8,785	6	570	15.41
1983	34263	33	2,195	15.16	5,766	5	475	12.13
1984	23000	30	1,996	11.52	8,266	4	380	21.74
1985	27227	27	1,796	15.16	7,180	6	570	12.59
1986	29063	25	1,663	17.47	5,657	6	570	9.92
1987	31658	20	1,331	23.79	1,808	2	190	9.51
1988	35434	29	1,929	18.37	*	*	*	*
1989	32294	33	2,195	14.71	*	*	*	*
1990	40803	34	2,262	18.04	*	*	*	*
1991	37795	29	1,929	19.59	*	*	*	*
1992	30777	28	1,863	16.52	*	*	*	*
1993	36856	25	1,663	22.16	*	*	*	*
1994	36973	26	1,730	21.38	*	*	*	*
1995	33905	29	1,929	17.57	*	*	*	*
1996	28650	33	2,195	13.05	8,605	2	190	45.27
1997	38338	29	1,929	19.87	15,287	5	475	32.17
1998	55296	24	1,597	34.63	10,271	7	665	15.44
1999	51507	24	1,597	32.26	32,045	8	760	42.15
2000	32364	27	1,796	18.02	20,891	9	855	24.42
2001	56320	26	1,730	32.55	31680	10	950	33.33

Source: Ministry of fisheries, Ghana.

*No purse seining for these years.

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[6] Source: Ministry of Trade

Table 4.3: Annual tuna harvests (MT), Standardized effort (sea days), Temperature (degrees Celsius).

Year	**Temp** *(degree Celcius)*	**Harvest** (*tons*)	**Effort** (days at sea)	**Ln h**	**Ln E**	**Ln T**	**w** *(years)*
1980	25.935	35855.9	3298	10.48726	8.101072	3.255593	1
1981	26.478	45172.7	3298	10.71825	8.101072	3.276314	2
1982	25.747	46247.0	3298	10.74175	8.101072	3.248318	3
1983	25.399	40029.0	2670	10.59736	7.889834	3.234710	4
1984	26.373	31266.0	2376	10.35029	7.773174	3.272341	5
1985	25.836	34406.8	2366	10.44601	7.768956	3.251769	6
1986	25.411	34719.9	2233	10.45507	7.711101	3.235182	7
1987	26.970	33465.1	1521	10.41826	7.327123	3.294725	8
1988	26.525	35433.6	1929	10.47542	7.564757	3.278088	9
1989	26.323	32294.3	2195	10.38265	7.693937	3.270443	10
1990	25.918	40802.9	2262	10.61651	7.724005	3.254938	11
1991	26.176	37794.6	1929	10.53992	7.564757	3.264843	12
1992	26.068	30777.0	1863	10.33452	7.529943	3.260709	13
1993	26.573	36855.6	1663	10.51476	7.416378	3.279896	14
1994	26.332	36973.3	1730	10.51795	7.455877	3.270785	15
1995	26.684	33904.5	1929	10.43130	7.564757	3.284064	16
1996	26.226	37255.0	2385	10.52554	7.776954	3.266751	17
1997	26.334	53624.8	2404	10.88977	7.784889	3.270861	18
1998	25.891	65567.6	2262	11.09084	7.724005	3.253895	19
1999	26.280	83552.5	2357	11.33323	7.765145	3.268808	20
2000	26.088	53255.0	2651	10.88285	7.882692	3.261475	21
2001	26.126	88000.0	2680	11.38509	7.893572	3.262931	22

Ln h = natural log of harvest

Ln T = natural log of temperature

Ln E = natural log of effort, w = Year

Table 4.4: Landings in MT, Standardised Effort in sea days for Skipjack, Bigeye and Yollowfin.

	BIGEYE			**SKIPJACK**			**YELLOWFIN**		
Year	**Catch**	**St.Eff.**	**CPUE**	**Catch**	**St.Eff**	**CPUE**	**Catch**	**St.Eff**	**CPUE**
1980	332	454	0.73	5,812	1,722	3.38	1,974	1,122	1.76
1981	780	454	1.72	7,858	1,722	4.56	5,510	1,122	4.91
1982	791	454	1.74	18,272	1,722	10.61	9,797	1,122	8.73
1983	491	368	1.34	24,376	1,394	17.48	7,689	909	8.46
1984	2,162	327	6.61	20,697	1,240	16.69	9,039	809	11.18
1985	1,887	326	5.79	19,082	1,235	15.45	12,550	805	15.58
1986	1,720	307	5.59	22,268	1,166	19.10	11,821	760	15.55
1987	1,178	209	5.63	24,347	794	30.67	10,830	517	20.93
1988	1,214	266	4.57	26,597	1,007	26.41	8,555	657	13.03
1989	2,158	302	7.14	22,751	1,146	19.85	7,035	747	9.42
1990	5,031	311	16.16	24,251	1,181	20.54	11,988	770	15.57
1991	4,090	266	15.40	25,052	1,007	24.87	9,254	657	14.10
1992	2,866	256	11.18	18,967	972	19.50	9,331	634	14.72
1993	3,577	229	15.62	20,225	868	23.29	13,283	566	23.47
1994	4,738	238	19.90	21,258	903	23.54	9,984	589	16.96
1995	5,517	266	20.77	18,607	1,007	18.47	9,268	657	14.12
1996	5,805	328	17.68	19,602	1,245	15.74	12,160	812	14.98
1997	7,431	331	22.45	27,667	1,255	22.04	16,504	818	20.17
1998	13,252	311	42.56	34,150	1,181	28.92	17,807	770	23.13
1999	11,460	324	35.32	43,460	1,230	35.32	28,328	802	35.32
2000	5,586	365	15.30	29,950	1,384	21.64	17,010	902	18.85

Source: Ministry of fisheries, Ghana.

Biological parameters such as the carrying capacity (K), the growth rate (r) and the catchability coefficient (q) presented in table (4.4) below are adopted from Conrad and Adu – Asamoah since their study covers the same Tropical Eastern Atlantic as mine.

Table 4.5: Estimates of r, q and K for skipjack, yellowfin and bigeye

Species	**q (times 10^{-2})**	**r**	**K (times 10^3MT)**
Yellowfin	1.372	1.2883	351.2244
Skipjack	1.240	1.5686	264.9435
Bigeye	2.110	1.9018	48.6540

Source: (Adopted from Conrad and Adu-Asamoah, 1986)

4.2. Results

4.2.1. Harvest models

In all, the following five models designated M1, M2, M3, M4, M5 and M6 were tested. However, one basic shortcoming of this work has been lack of observations for X, the stock biomass. The following statistical results do not therefore include the effect of the stock biomass. Moreover, the parameters q, α, γ, β and ϕ are different from one model to another. Thus, q in M1is not the same q in M2 and so on.

$$h(E, X) = q \cdot E \cdot X \qquad \text{(M1)}$$

$$h(E^2) = E(a - bE) \qquad \text{(M2)}$$

$$h(E, X) = q \cdot E^{\alpha} \cdot X^{\beta} \qquad \text{(M3)}$$

$$h(E, X, T) = q \cdot E^{\alpha} \cdot X^{\beta} \cdot T^{\phi} \qquad \text{(M4)}$$

$$h(E, X, w) = q \cdot E^{\alpha} \cdot X^{\beta} \cdot e^{w\gamma} \qquad \text{(M5)}$$

$$h(E, X, w, T) = q \cdot E^{\alpha} \cdot X^{\beta} \cdot e^{w\gamma} \cdot T^{\phi} \qquad \text{(M6)}$$

The results of maximising the log-likelihood functions are presented below.

M1 Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson	Akaike Information Criterion
0.941	0.886	0.881	16103.7645	0.702	427.196

ANOVA

	Sum of Squares	**df**	**Mean Square**	**F**	**P-value**
Regression	4.24E+10	1	42445792347	163.674	0.000
Residual	5.45E+09	221	259331230.14		
Total	4.79E+10	22			

Coefficients

	Coefficients	**Std. Error**	**t**	**P-value**	**95% Confidence Interval for coefficients**	
					Lower Bound	*Upper Bound*
Total stan.effort	18.429	1.440	12.794	0.000	15.433	21.425

The estimated coefficient of effort for M1 is just too high, around 18.429. This value is significant while the overall model is also significant because, from statistical table F < 0.05. Though the model has only one predictor, it has high R^2 of 88.6%. This is because of no intercept for the model while it shows low DW – value of 0.702 showing that the model is serially autocorrelated. The model has a high AIC (Akaike Information Criterion) of 427.196.

M2 Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate	Akaike Information Criterion	Durbin-Watson
0.950	0.902	0.892	15333.7261	425.967	0.737

ANOVA

	Sum of Squares	df	Mean Square	F	P-value
Regression	43189285050.784	2	21594642525.392	91.844	0.000
Residual	4702463129.146	20	235123156.457		
Total	47891748179.930	22			

Coefficients

Parameter	Coefficients	Std. Error	t	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
a	30.335	6.835	4.438	0.000	16.078	44.592
b	4.681E-03	0.003	1.778	0.091	-0.010	0.001

Model M2 is also a model with no intercept and so as expected it has a very large R^2 of 90.2%. However, its AIC value is also high and was calculated to be 425.967. While the model has an overall significance, the parameter estimates are also significant. Model M2 has better parameter estimates than M1. M2 has the largest R^2 and the lowest AIC value hence making it the best over M1. M2 is also autocorrelated having a DW value of just 0.737 hence making M2 to lose its prediction power.

M3 summary

R	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Durbin-Watson**	**Akaike Information Criterion**
0.361	0.131	0.087	0.2867	0.642	-53.063

ANOVA

	Sum of Squares	**df**	**Mean Square**	**F**	**P-value**
Regression	0.247	1	0.247	3.004	0.098
Residual	1.644	20	8.221E-02		
Total	1.891	21			

Coefficients

Parameter	**Coefficients**	**Std. Error**	**t**	**P-value**	**95% Confidence Interval**	
					Lower Bound	Upper Bound
(Constant)	6.716	2.266	2.964	0.008	1.989	11.443
α	0.508	0.293	1.733	0.098	-0.103	1.119

For M3, R^2 was just 13.1% while DW – value was only 0.642. The model is therefore autocorrelated. However, all the parameter estimates are significant while the model has overall significance with AIC of –53.063.

M4 Summary

R	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Durbin-Watson**	**Akaike Information Criterion**
0.369	0.136	0.045	0.2932	0.645	-51.206

ANOVA

	Sum of Squares	df	Mean Square	F	P-value
Regression	0.258	2	0.129	1.498	0.249
Residual	1.634	19	8.598E-02		
Total	1.891	21			

Coefficients

Parameter	Coefficients	Std. Error	t	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
(Constant)	0.465	17.902	0.026	0.980	-37.005	37.935
a	0.569	0.346	1.644	0.117	-0.156	1.293
f	1.771	5.028	0.352	0.729	-8.752	12.294

When an additional parameter temperature T^{o}C was added to M3 to give M4 there was no significant changes to parameter estimates even though model specifications vary significantly. R^{2} was only 13.6% compared to 13.1% for M2 while α only increased to 0.569 from 0.508. The model is still autocorrelated even with the inclusion of additional parameter. It only recorded a DW – value of 0.645 while F was reduced to 1.498 though there is overall significance. All parameter estimates α and ϕ are significant while its AIC value was increased to –51.206 as compared to M3.

M5 Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson	Akaike Information Criterion
0.818	0.670	0.635	0.1813	1.859	-72.361

ANOVA

	Sum of Squares	**df**	**Mean Square**	**F**	**P-value**
Regression	1.267	2	0.633	19.270	0.000
Residual	0.624	19	3.287E-02		
Total	1.891	21			

Coefficients

Parameter	**Coefficients**	**Std. Error**	**t**	**P-value**	**95% Confidence Interval for coefficients**	
					Lower Bound	Upper Bound
(Constant)	3.669	1.534	2.392	0.027	0.459	6.879
α	0.849	0.195	4.350	0.000	0.440	1.257
γ	3.574E-02	0.006	5.570	0.000	0.022	0.049

In model 5, a time trend parameter,γ has been introduced while the temperature is removed. The time trend parameter in M4 caused significant changes in estimated parameters. The introduction of γ caused increase in α to 0.849. γ itself was estimated to be 0.03574, which shows annual technological change of approximately 3.6%. Model 5 seem to have best parameter estimates over M1, M2, M3.and M4 With DW – value of 1.859, it is close to 2 and hence the model is free from serial autocorrelation. This time the predictors explained 67% of harvest and the model has overall significance since from statistical table, F < 0.05. Infact, F increased tremendously to 19.270 from 1.498. It has the lowest AIC value of –72.361 over models M3 and M4.

M6 Summary

R	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Durbin-Watson**	**Akaike Information Criterion**
0.818	0.670	0.615	0.1862	1.848	-70.369

ANOVA

	Sum of Squares	**df**	**Mean Square**	**F**	**P-value**
Regression	1.267	3	0.422	12.177	0.000
Residual	0.624	18	3.468E-02		
Total	1.891	21			

Coefficients

Parameter	**Coefficients**	**Std. Error**	**t**	**P-value**	**95% Confidence Interval for coefficients**	
					Lower Bound	Upper Bound
(Constant)	2.728	11.378	0.240	0.813	-21.175	26.632
α	0.857	0.226	3.790	0.001	0.382	1.333
ϕ	0.268	3.205	0.084	0.934	-6.466	7.002
γ	3.569E-02	0.007	5.395	0.000	0.022	0.050

In model 6, an attempt has been made to bring back the temperature parameter. The re-introduction of ϕ has not caused a significance change in parameter estimates in moving form M5 to M6. However, F was rather reduced to 12.177 from 19.270 but this does not make M6 insignificant. M6 is still significant and R^2 is the same as 67% as that for M5. DW – value is 1.848 and still close to 2. M6 is thus also not autocorrelated. Thus, the temperature parameter does not seem to be of significance importance (moving from M4 to M5) in improving the statistical performance of the model. This is even justified by the increase in AIC value to –70.369 against –72.361

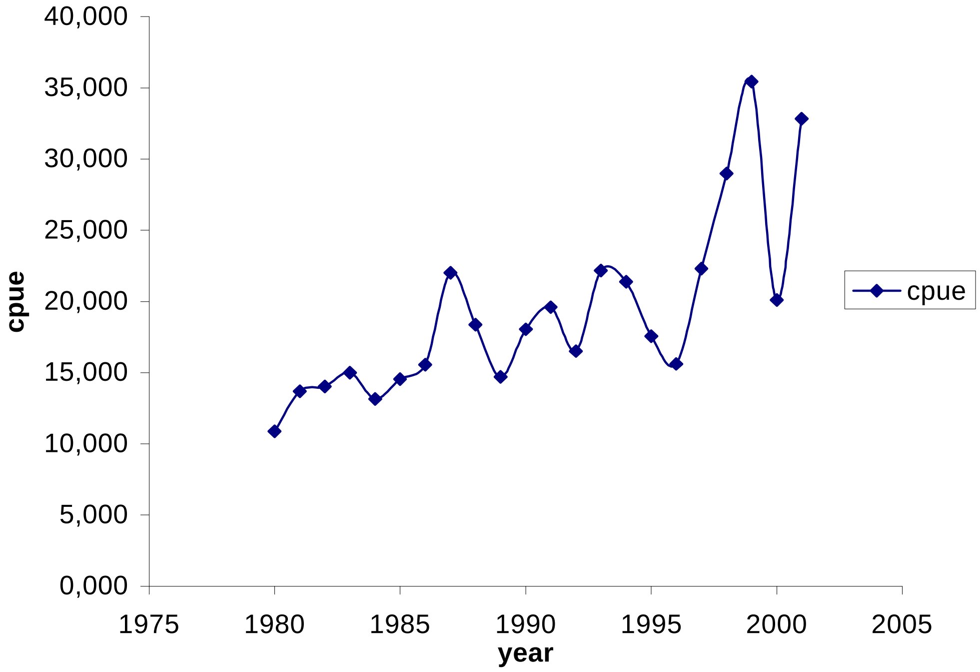
for M5. In addition, γ and α are just weakly affected by the inclusion of ϕ in the model. The temperature parameter is hence considered as superflous while time trend parameter is rather a useful parameter.

For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models, which include an intercept. Models M1 and M2 are among such models with no intercept and hence the acceptance or rejection of any of the models should not be based on only R^2.

Both M5 and M6 have their stochastic error terms, μ to be normally distributed as depicted by the histogram charts (see appendix I for histogram charts, scatter plot and normal p-p plot). This is quite different from M1, M2 and M3 where the normality assumption is not satisfied. For models M1, M2 and M3 therefore, I cannot assess their statistical reliability by the classical tests of significance (t, F, etc) because the latter are based on normal distributions.

4.2.2. *Catch Per Unit of Effort*

Figure 4.1 below shows cpue trend for the three species of tuna.



For the investigated period, there has been an upward trend in cpue. This is rather inconsistence with cpue observed by Conrad and Adu – Asamoah, where cpue showed a declining trend for the different species. This inconsistency may be due to the different study periods where 1967 – 1980 was the period for Conrad and Adu – Asamoah while the study period for this work is 1980 – 2001.

Although for tropical species like tuna cpue may lead to an overestimate of population size as already stated, at least for now it is giving an idea of how the stock biomass looked like during the period 1980 – 2001. The stock data is hence expected to follow an increasing trend during my investigation period.

4.2.3. *Technical – Economic Interactions Among The Species*

In the period 1980 – 2000, the ε_{ij} is calculated for the Ghanaian tuna fishery as:

$$\varepsilon_{ij} = (\Delta H_i/\Delta P_j)^* (P_j/H_i)$$

Where: $\varepsilon_{ij} \equiv$ is the elasticity of transformation that measures how a fleet substitutes fishing one species for fishing another species as the relative price for the two species changes.

$H_i \equiv$ Harvest of Species *i*

$P_j \equiv$ Price of Species *j*

The data set shows large changes in price and harvest so we use the idea of *arc elasticity* whereby we use the averages of price and harvest. Thus, the percentage change in harvest is found by dividing the change in quantity harvested by the average of the two quantities likewise, the percentage change in price is found in the same way. In 1980, Conrad and Adu – Asamoah found that the prices of Bigeye and Skipjack were $1300 and $1200 respectively but Yellowfin and Bigeye fetch the same price.

For harvests, in 1980 Bigeye and Skipjack caught were 332MT and 5,812MT respectively while Yellowfin was1,974MT and in year 2000, the harvest was 5,586MT for Bigeye, 29,950MT for Skipjack and 17,010MT for Yellowfin. The table below summarises the results of the elasticities.

Table 4.7: Cross elasticities for year1980-2000

Change in harvest of	With respect to price of		
	Skipjack	Bigeye	Yellowfin
Skipjack		-1.39	-1.39
Bigeye	-1.78		-1.83
Yellowfin	-1.58	-1.63	

The following results on elasticities are based on figures in tables 4.4 and 4.1

Table 4.8: Cross elasticities for year1998-2000

Change in harvest of	With respect to price of		
	Skipjack	Bigeye	Yellowfin
Skipjack		0.16	0.16
Bigeye	0.95		1.02
Yellowfin	0.05	0.05	

Table 4.9: Cross elasticities for year1995-2000

Change in harvest of	With respect to price of		
	Skipjack	Bigeye	Yellowfin
Skipjack		-0.89	-0.89
Bigeye	-0.02		-0.02
Yellowfin	-1.02	-1.12	

4.2.4. The Maximum Economic Yield

In the context of the Ghanaian tuna fishery, I found the more appropriate short – run harvest function to be:

$$H = q\cdot e^{w\gamma}\cdot E^{\alpha}\cdot X^{\beta} \qquad (25)$$

Making X the subject in equation (25) and substituting in the logistic growth function, the long run – harvest function for the Ghanaian tuna fishery is defined as:

$$H = H(E) = q\cdot e^{w\gamma}\cdot E^{\alpha}\cdot K[1 - q\cdot e^{w\gamma}\cdot E^{\alpha}/r], \qquad \text{for } H \equiv F(X). \qquad (26)$$

Here, I have set $\beta = 1$ and have been used as such throughout this work since there is lack of observations for X.

Due to the complicated nature of the harvest function as compared to the Schaefer harvest function, finding marginal revenue function is a bit rigorous. As a result, *a* *mathematica computer programming* was used. The programme gave marginal product of effort as:

$$dH(E)/dE = qK\alpha E^{\alpha-1}/r\,[r-2qE^{\alpha}] \qquad (26)$$

And if we multiply (26) by price, p we have the marginal revenue of effort as:

$$MR\,(E) = p\cdot dH(E)/dE \qquad (27)$$

Equating (27) to TC = aE will give us the optimal effort level that will achieve the MEY. The following are the graphs of equation (27) with different values of q.

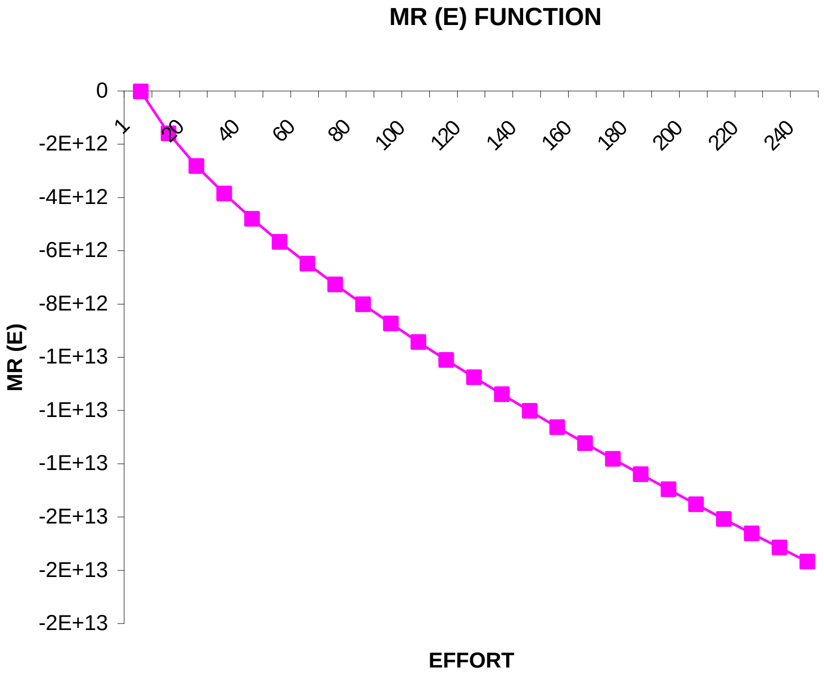


Figure 4.2: MR (E) function when q = 40.639

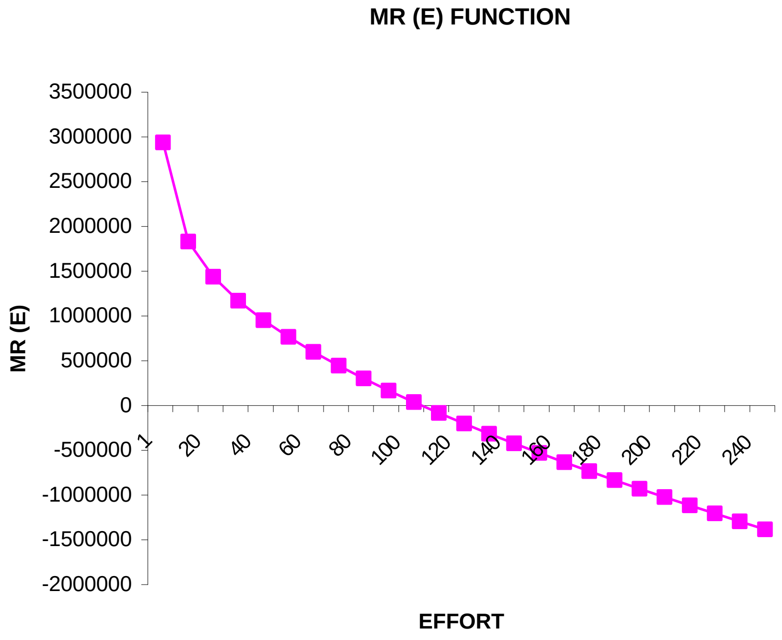


Figure 4.3: MR (E) function with q = 0.01574 (q was adopted from Conrad and Adu – Asamoah).

5. DISCUSSION AND POLICY IMPLICATIONS

5.1. Discussion

In the result, M2 had the largest R^2 and the lowest AIC value over M1. For models M3, M4, M5 and M6, M5 is the best performing model according to the AIC value and R^2 although R^2 for both M5 and M6 is equal. A choice between M2 and M5 cannot be done using R^2 and AIC value. M2 is no intercept model while M5 has an intercept. For a regression through the origin, R^2 measures the proportion of the variability in the dependent variable about the origin explained by regression. This cannot be compared to R^2 for models, which include an intercept. Moreover, the AIC for models with transformed data (M5) cannot be compared to AIC for models, where the data is not transformed (M2). Statistical performance is a good criteria for selecting a model, however, another dimension is how the model fits the theoretical basis of catch production. The regression estimates for M5 would have had even better estimates if biomass had been included. However, the estimates presented are unbiased and can be used for the purpose of this study. M5 is the most advanced model, including all two features that define the different models: the autoregressive error term and the technological change term. The following discussion therefore focuses on model 5.

Model 5 explains 67% of the total variation in the data set. This is rather a high explanation rate, especially with only two parameters (biomass not included). According to the α estimate, when effort increases 1%, harvest increases 0.849%, ceteris paribus. This gives insights into the responsiveness of harvest of tuna to changes in effort (cet. Par). The α estimate shows also that the percentage increase in harvest is less than the percentage increase in effort. Thus, anytime effort will be increased by a percentage, harvest will increase by less than the percentage increase in the effort (cet. Par) and vice versa. Thus, $\alpha < 1$ and hence shows that harvest is effort inelastic. This is as expected because harvest does not only depend on effort but others like biomass availability. Hence the α estimate is not expected to give a harvest percentage increase to be greater than the percentage increase in effort so that biomass, etc could take up the rest. The α estimate also shows that at least we do not have 100% information on the fish availability, either by observaitions of the positions of other vessels or by directly sharing of information between vessels.

The time trend parameter γ may be interpreted as the annual percentage technological change. In model 5, technological change increases the efficiency with about 3.6% on an annual basis, which is close to findings of Flaaten (2003) and also consistent with Hannesson (1993). Flaaten (2003) found a technological progress of 2% while Hannesson (1993) found it to be 2 – 7%. Technological progress is treated here as neutral, shifting the harvest function upward overtime. However, it is possible, that technological progress affects the parameters of the function, in particular the stock – output and effort – output elasticity. The changes in R^2 as a result of including the term for technological progress was great (moving from M4 to M5) indicate that such an effect on parameters could be the case. The reason to expect that technological progress may affect α is if it takes the form of better fish finding equipment, which will enable fishermen to locate concentrations of fish more effectively.

Since biomass data was not available, β estimate was adopted to be 1 (see Flaaten, 2003). This means that β predicts a harvest increase of 1% when the stock biomass increases 1%. One interpretation of this is that the density of tuna at the purse seining or baitboat grounds is equal to proportionally affected by changes in the total stock biomass. A priori one would expect that β could assume any value between 0 and 1. If $\beta = 0$ then we are talking of a case where fishermen don’t actually search for the school but know exactly where the school is. This means that fishermen in Ghana would at any point in time go straight to where the school is and fish there. This is not what actually happens in the Ghanaian tuna fishery. The schooling behaviour is in such a way that the schools are dotted and that the schools (population) does constantly diffuse out, so that fishermen have to search for schools consequently, the coefficient on β would be equal to 1. Assume that the harvest depends on the density of the tuna population. To maximise their profits, fishermen would exploit the areas of highest density first. For the harvest to fall faster than the population the density of tuna must fall faster than the population. This occurs when there are areas of high and low density. An example will illustrate the point. Assume there are 3 areas of 100 cubic feet each with the populations given in table 5.1 below.

Table 5.1: Example of the Relationship between Population and density

Population			Density	Population	Per 1000m3
Area 1	**Area 2**	**Area 3**	**Area 1**	**Area 2**	**Area 3**
10	5	2	0.1	0.05	0.02
9	5	2	0.09	0.05	0.02
8	5	2	0.08	0.05	0.02
7	5	2	0.07	0.05	0.02
6	5	2	0.06	0.05	0.02
5	5	2	0.05	0.05	0.02
4	4	2	0.04	0.04	0.02
3	3	2	0.03	0.03	0.02
2	2	2	0.02	0.02	0.02
1	1	1	0.01	0.01	0.01
0	0	0	0	0	0

The density of tuna in each separate area is also given. Fishermen would operate in area 1 first because it has a high density of tuna. When the density in area 1 reaches 0.05, they will begin to exploit area 2 as well. When the density reaches 0.02, they will move into area 3. By the time area 3 comes under exploitation, the density and the population will fall proportionately. At any given stock level, the concentration being exploited is the maximum concentration. If the population did constantly diffuse out, the coefficient on β would be closer to one. The case of constant diffusion is shown in table 5.2 below:

Table 5.2: Maximum Density for Each Population Level

Maximum Density	Constant Diffusion	Total Population
0.10	0.057	17
0.09	0.053	16
0.08	0.050	15
0.07	0.047	14
0.06	0.043	13
0.05	0.040	12
0.04	0.033	10
0.03	0.027	8
0.02	0.020	6
0.01	0.010	3
0	0	0

In this case, the density is the total population divided by 300 cubic feet, the combined volume of all three areas. Here, density and the population fall at the same rate.

For the investigated period, there has been an upward trend in cpue. This is rather inconsistence with cpue observed by Conrad and Adu – Asamoah, where cpue showed a declining trend for the different species. This inconsistency may be due to the different study periods where 1967 – 1980 was the period for Conrad and Adu – Asamoah while the study period for this work is 1980 – 2001.Right from the 1980 to 1995, cpue was steadily ups and downs but the increase in cpue from 1996 to 1999 was so sharpe and large. This might probably be due to the fact that there was no purse seining between the periods 1988 – 1995. As a result, there was a build up of the stock, which contributed the abrupt increase in cpue between 1996 and 1999. However, just as the cpue was increasing to the delight of fisheries managers, then came another sharpe change but this time a decline from 1999 to 2000. This I believe could be due to the serious fishing activities by purse seiners during the period 1996 – 1999 after years of no fishing.

CPUE analysis have shown an increasing trend for the period considered. This is rather inconsistent with the findings of Conrad and Adu – Asamoah but however consistent with findings of Marbel Verstraaten, 2002. An increasing CPUE could indicate a good standing biomass although CPUE is not a good criterion to determine biomass for species like tuna. Intuitively, the result have shown that ICCAT have been effective in the period of my study compared to the period before 1980 when there was no international management which culminated in declining CPUE for Conrad and Adu – Asamoah.

Between the periods 1980 – 2000 and 1995 – 2000, ε_{ij} calculated for all the species indicated that there was a substitution possibility among the species since ε_{ij} was negative for all the interactions. However, for the period 1998 – 2000, the calculated elasticities were all positive across the species showing a case of complementarity. There is thus mixed significance. Thus, there is mixed positive and negative signs which gives room for the existence of technical – economic interactions among the species over the years considered. Lack of complementarity across all the species suggests a degree of selective harvesting and incomplete joint production on the part of fishers. Because of the substitution possibility among the species, effort will be allocated among the species on the basis of differences in relative prices. It should be noted that any management action that restricts the harvest of Skipjack would lead to increased exploitation of Yellowfin and Bigeye.

However, it should be stated that, although relative price could cause a shift in the type of species being caught, it is also highly possible that species abundance may contribute to the shift. Fishermen could shift from a particular species to another based on relative abundance of the species and this remains a further research area for the tuna species.

The elasticities calculated for the different periods considered showed some kind of differences in magnitude. This is probably due to increases in elasticity of harvest over time as it takes time for fishermen to respond to price changes. Moreover, it is seen that the magnitude of elasticities for the species is not so wide. A look for example, the cross elasticities for year 1980 – 2000 showed that though there are variations, at least the figures are all close to each other. These close figures could probably be due to the fact that the resources used in the production of the different species is much less specialised and can be transferred much more easily in the long run to and from one species to another.

When the 1980 data was used together with $q = \bar{q}e^{w\gamma}$, where Ln q = 3.669 and $\bar{q} = e^{3.669}$, the marginal revenue curve (see figure 4.2) showed uncharacteristic behaviour by dropping from the origin to negative with no positive side. This is highly inconsistent with theory where marginal revenue falls as harvest increases, gets to zero at the maximum of total harvest and then becomes negative when harvest is falling. However, despite this unfamiliar nature of the marginal revenue function, its curvature nature is in accordance with the specialisation of my harvest function. At least it is showing that the MR (E) is non – linear in α as compared to the Schaefer model where MR (E) is a linear function of effort due to the linear specification of the harvest function. This thesis though does not analyse the demand side of the fishery, it is however inherent in the curvature of the MR (E) that the demand curve for the fishery may be nonlinear. Although the MR (E) curve has not behave as expected, at least for now an important revelation has been the curvature of the function in line with the harvest function specification. The strange behaviour of the MR (E) could also be due to the use of national effort of Ghana instead of total effort in the Eastern Atlantic. Another reason why only the negative portion of the MR (E) is showing up in figure 4.2 may be that demand for the products of the fishery is may be inelastic. If demand is inelastic, marginal revenue is expected to be negative because an increase in harvests would reduce total revenue. The negative MR (E) indicates therefore that total revenue may be falling.

Such an unexpected result could cause one to investigate further into the cause of such a problem. But in a thesis of this nature where time constraint is a major limitation, little could be done. Nevertheless, in an effort to rectify the anomaly, q value has been adopted from Conrad and Adu – Asamoah and it has brought the behaviour of MR (E) in accordance with theory whiles maintaing its curvature (see figure 4.3). Figure 4.3 is actually how MR (E) should have behaved so that the optimal effort that would achieve MEY could be obtained at where MR (E) = MC (E). Given enough time, a more thorough analysis could be made and a more appropriate q would be found for the Ghanaian tuna fishery so that MR (E) will behave as in figure 4.3 to be able to calculate for the optimal effort and its corresponding MEY.

5.2. Adjustment to changes in harvest

The result have shown that the harvest function of the Ghanaian tuna fishery is subject to a shift as a result of the technological change (though other factors as environmental conditions, resource prices, biomass availability etc. can also cause a shift of the harvest function) all things being equal. The analysis showed a 3.6% annual technological change and given that all other factors remain constant, the harvest function is expected to shift annually. In an annual harvest shift like this, the market demand of tuna products is expected to also change in line with the harvest so as to maintain price of tuna products. Given a constant market demand of tuna, then with a 3.6% technological improvement annually, the prices of tuna products will continue to fall, cet. par. This is more likely to happen in the Ghanaian tuna fishery since it is not a quota-restricted fishery. In quota fishery, the harvest function has no room for shifting irrespective of the technological improvement unless the quota is adjusted yearly. Under quota restriction the harvest function will be perfectly inelastic and any increase in demand in the course of the year has the tendency to increase price of the tuna products.

5.3. Policy Implications

The estimated α shows that if the resource manager wants to reduce harvest by say 10%, probably to reduce overexploitation of the stock, then the corresponding percentage of effort that will help to achieve this (Cet. Par) should be:

$$0.849 \cdot E = 10$$

and $E = 11.7$

Thus, approximately, the effort – output elasticity indicates that should we find that input control is desirable to manage the resource, then to reduce harvest by say 10%, effort should be reduced by approximately 12% to achieve the desire harvest reduction of 10%.

The various statistical analyses have shown that an assumption of linearity between fishing mortality and fishing effort has to be modified, at least regarding the Ghanaian tuna fisheries. The statistical results of the various harvest function indicates that the long – term strategy of how to exploit the resource should not be based on linear relationship between fishing mortality and fishing effort.

With a high technological change of 3.6% per annum, a proper scientific assessment of the stock is needed since the improved technology will mean that there are stock abundance, which probably may not be the case. The schooling behaviour of tuna means that the high technology will help fishers to locate schools easily, which will be increasing the CPUE, but the actual stock may be in the decline. Otherwise, this high technological change is really good for the fishery since the change is a positive one in the form of selective gears, by-catch reducing devices, Fish Aggregating Devices etc.

The CPUE in this study does not support any extra management practice, as the cost of doing so will outweigh the benefits. At least for now two studies have shown that the biomass isn't going down suggesting that management measures put in place by ICCAT is achieving the desire result.

The existence of substitute relationships highlights the concern that single species management of the tuna fishery may have negative effects on non – regulated species through unanticipated shifts in harvests. This suggests that single species management may be inappropriate for the tuna fishery.

6. CONCLUSION

The aim of this thesis has been to develop an appropriate harvest model for the Ghanaian tuna fishery, analyse the technical – economic interrelationships among the different tuna species and to estimate MEY for the tuna fishery. A set of annual catch, effort and sea surface temperature have been obtained for the period 1980-2001. By maximizing the log – likelihood function by numerical methods, parameter estimates and performance indicators of the different harvest functions were obtained. Several models were tested and this thesis presents those that are most robust from a statistical point of view. The best result was obtained for a model allowing for the inclusion of a technological trend term. For this model, the effort – output elasticity is estimated at around 0.849, which implies that a 1% increase in effort level increases harvest by approximately 0.849%. The annual technological progress has been estimated at 3.6% for the tuna fishery.

The analysis of the technical – economic interrelationships among the species has shown mixed significance over the periods considered. At least it has come to light that there exist technical – economic interrelationships among the species, which should serve as a guide for the management of the fishery. Both substitute and complementary relationships have been seen to occur during the period. Though there has been a variation in the magnitude of the elasticities, this is not large variation. The elasticities has been seen to be close to each other which could probably be due to the fact that the resources used in the production of the different species is much less specialized and could be transferred much more easily in the long – run to and from one species to another.

In calculating the MEY of the fishery, the marginal revenue function has not behaved in accordance with theory making it difficult to make any progress. The behaviour of MR (E) could be brought to a more tolerable form probably if we use effort level of the entire Eastern Atlantic. At least, one would not expect the MR (E) for the just found harvest function to behave so simply as MR (E) that depends on the Schaefer simple harvest model. The Schaefer model at least uses comparative static and hence its MR (E) is expected to depict the fishery in a fairly good manner.

However, even if the statistical methods used are robust and have given significance results for the harvest models, there are still unanswered questions to be left for further research. First, would a more thorough analysis of technological change give other results, both for the annual technological progress parameter and for other model parameter? Second, would the parameter estimates vary much compared to the estimates presented in this thesis if biomass data were available? Such a data were not available for this study and it still remains to see if the inclusion of biomass data could increase the explained percentage of the observed variation. Furthermore, if the MR(E) function has behaved in an unexpected way, would the aggregate of effort (total for Eastern Atlantic) bring credibility in the result?

Finally, since tuna is a shared resource, a more general harvest function for the entire Eastern Atlantic, which incorporates each country’s specific dummy variable, would be beneficial for management of the fishery. This is necessary as a way of testing if differences in productivity exist among the countries. Here the coefficients on the dummies are thought to capture differences in productivity across countries.

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APPENDIX

Fig 4.1: Histogram; frequency against Regression Standardized Residual for model M1

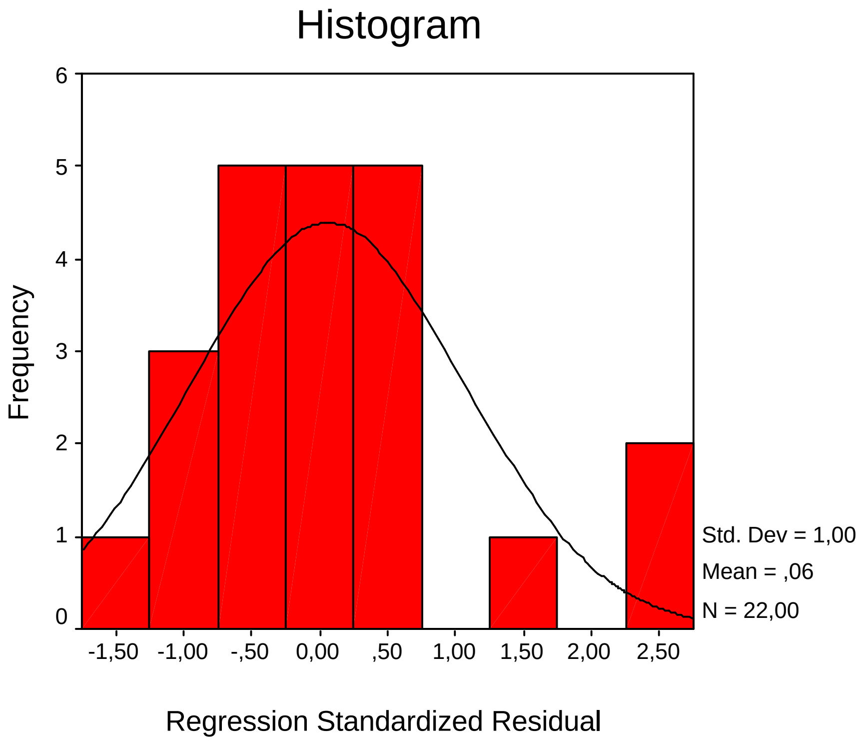

Fig. 4.2: Scatter plot; Predicted value against Regression Residual for M1

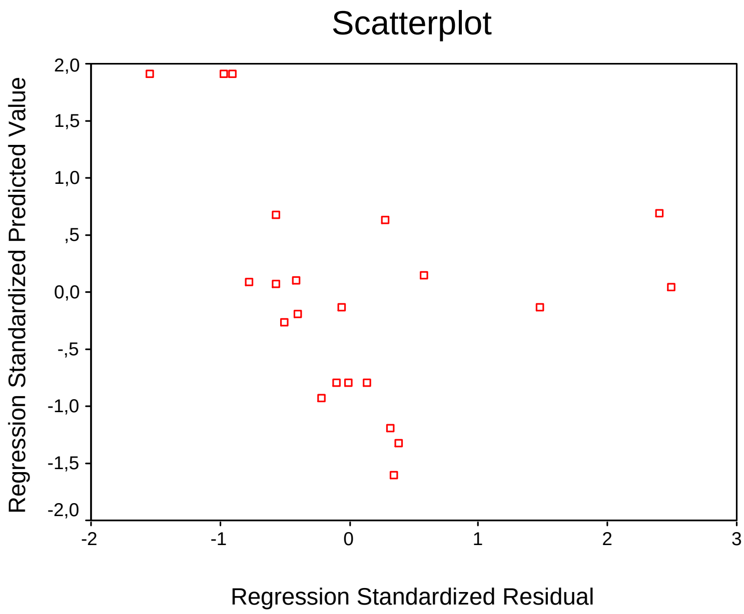

Fig. 4.3 Normal P – P Plot; Expected probability against Observed probability for M1

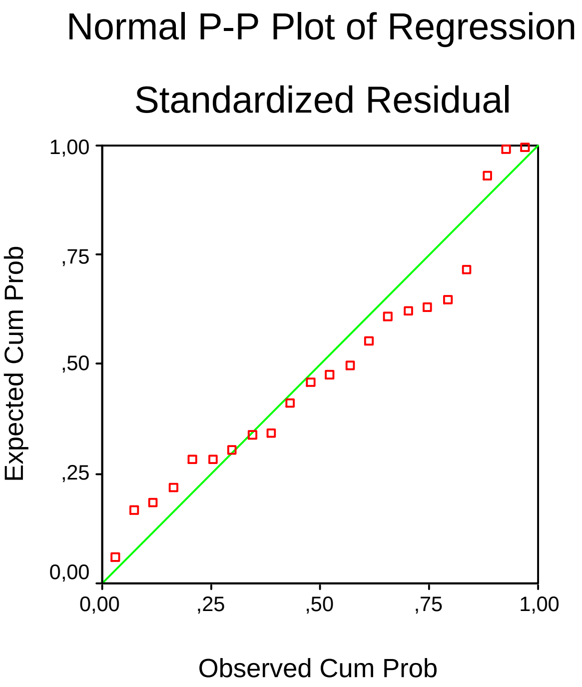

Fig 4.4: Histogram; frequency against Regression Standardized Residual for model M2

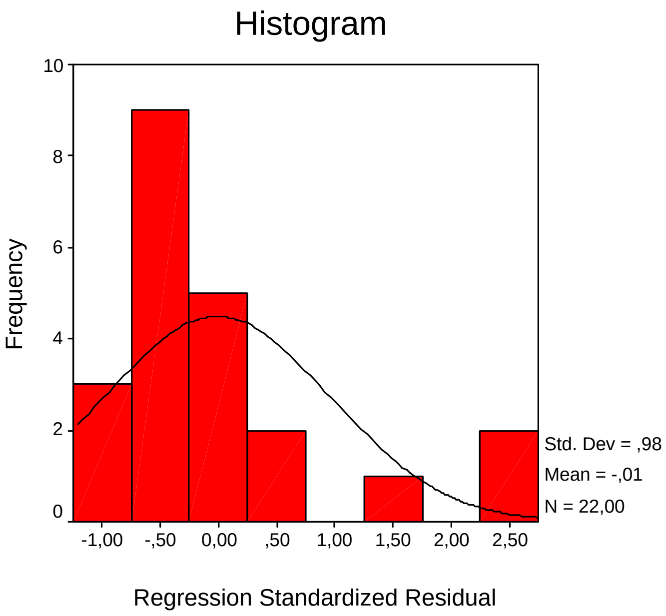

Fig. 4.5 Normal P – P Plot; Expected probability against Observed probability for M2

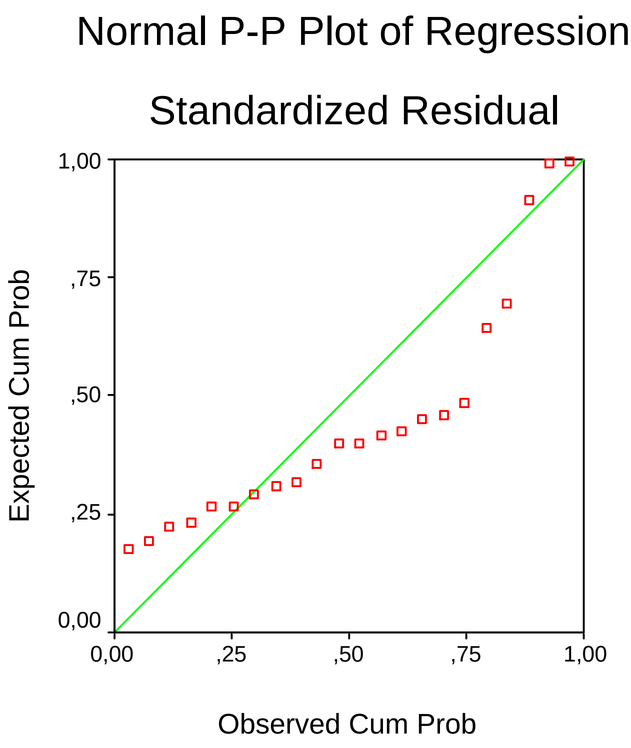

Fig. 4.6: Scatter plot; Predicted value against Regression Residual for M2

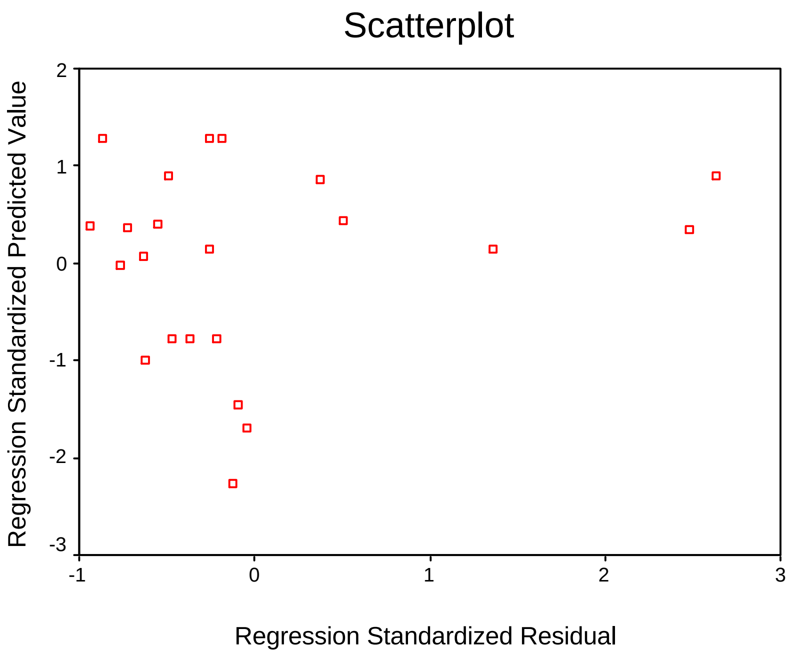

Fig 4.7: Histogram; frequency against Regression Standardized Residual for model M3

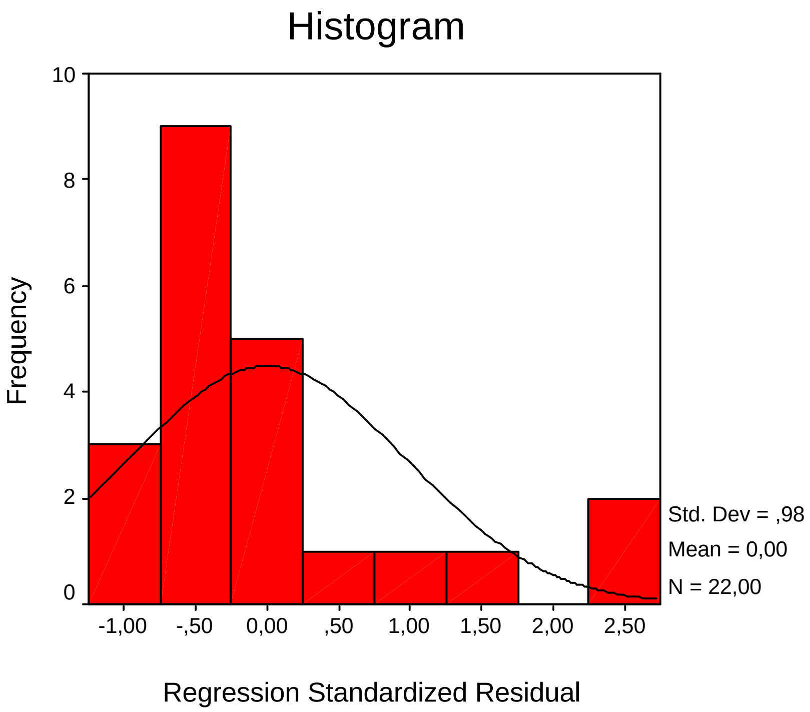

Fig. 4.8 Normal P – P Plot; for M3

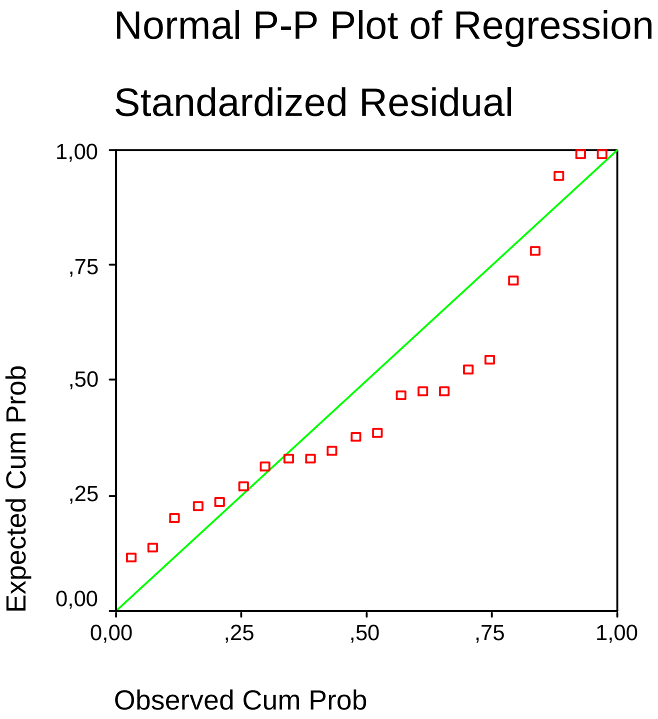

Fig. 4.9 Scatter Plot; for M3

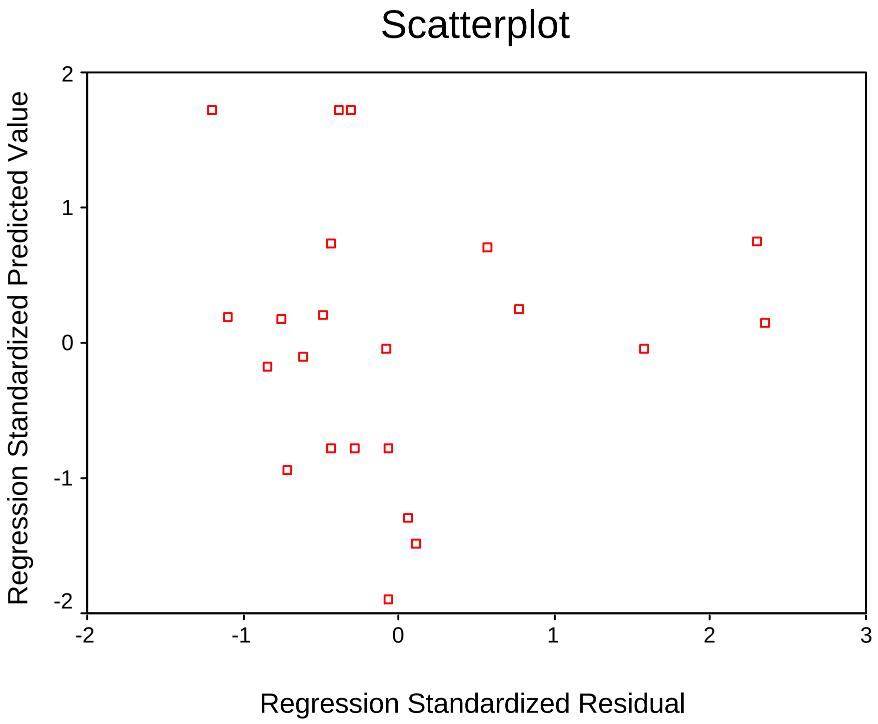

Fig. 4.10 Histogram; for M4

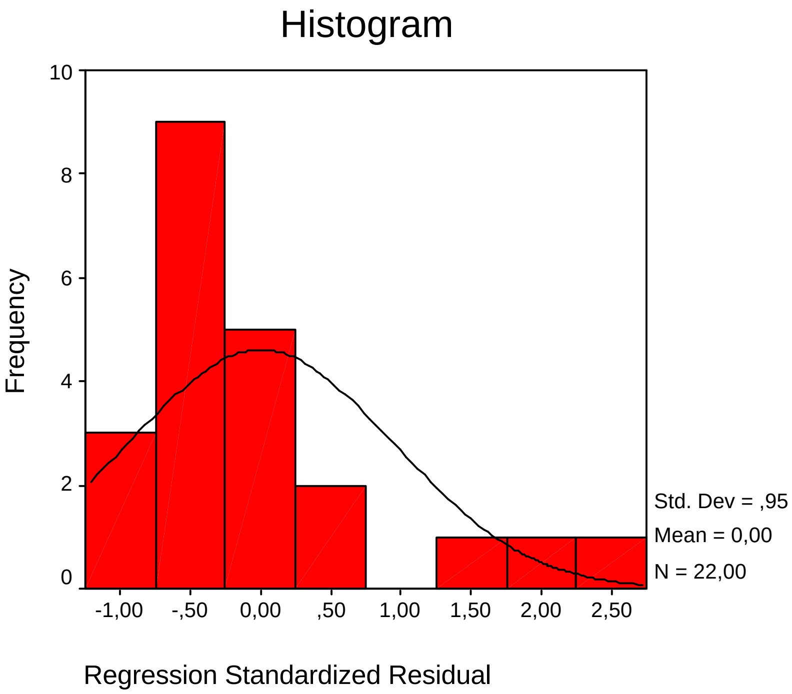

Fig. 4.11 Normal P – P Plot For M4

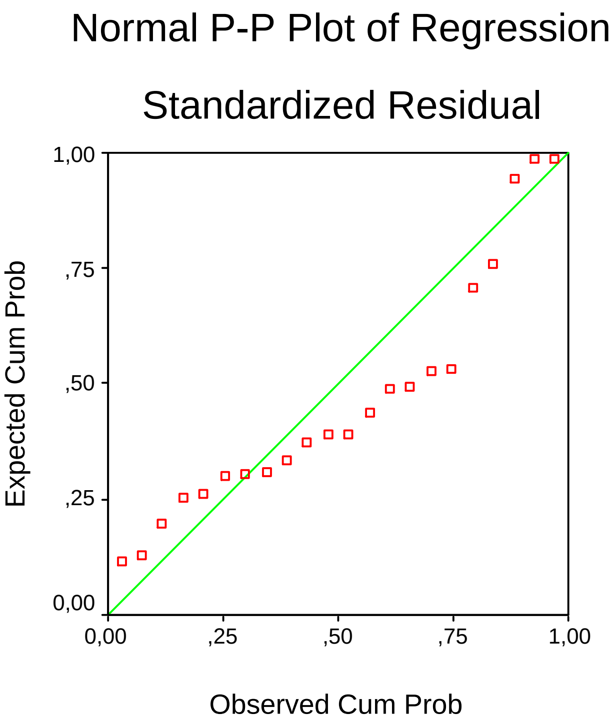

Fig. 4.12 Scatter Plot for M4

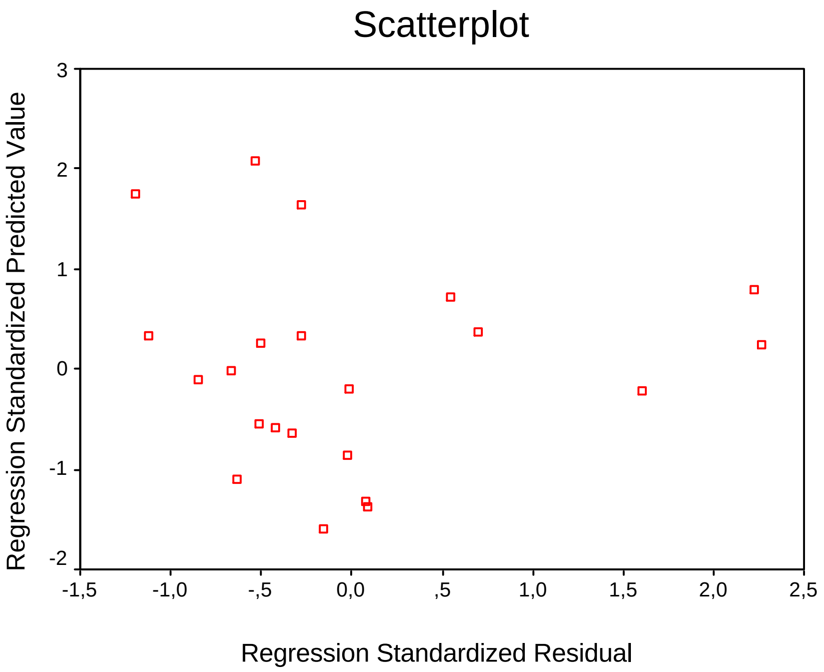

Fig. 4.13 Histogram for M5

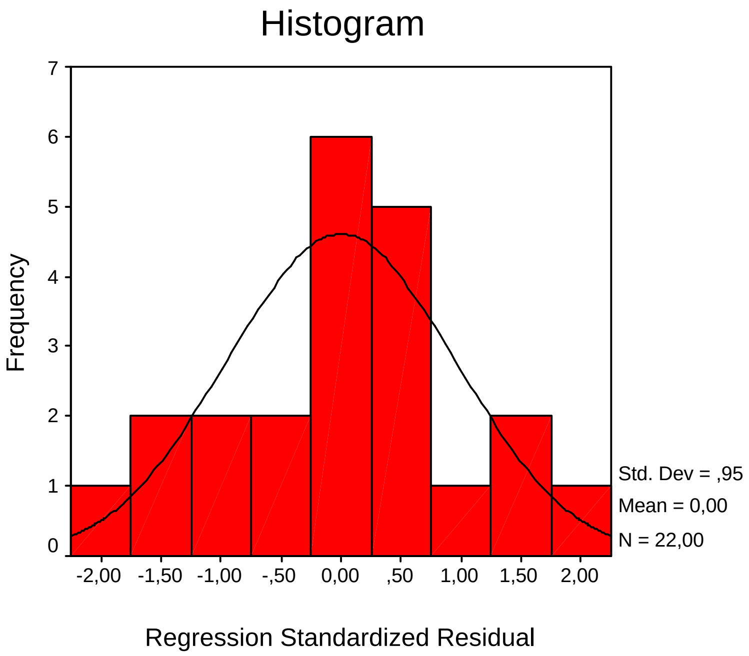

Fig. 4.14 Normal P – P Plot for M5

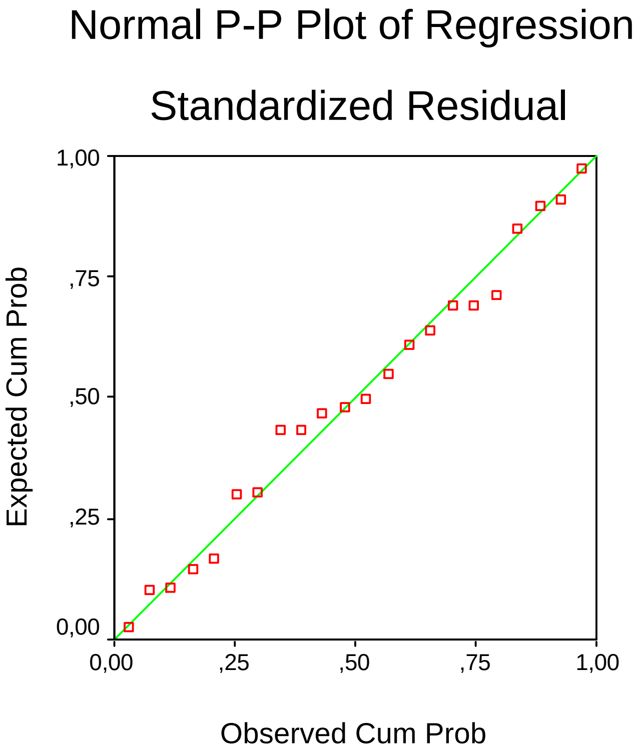

Figure 4.15: Scatter plot for M5

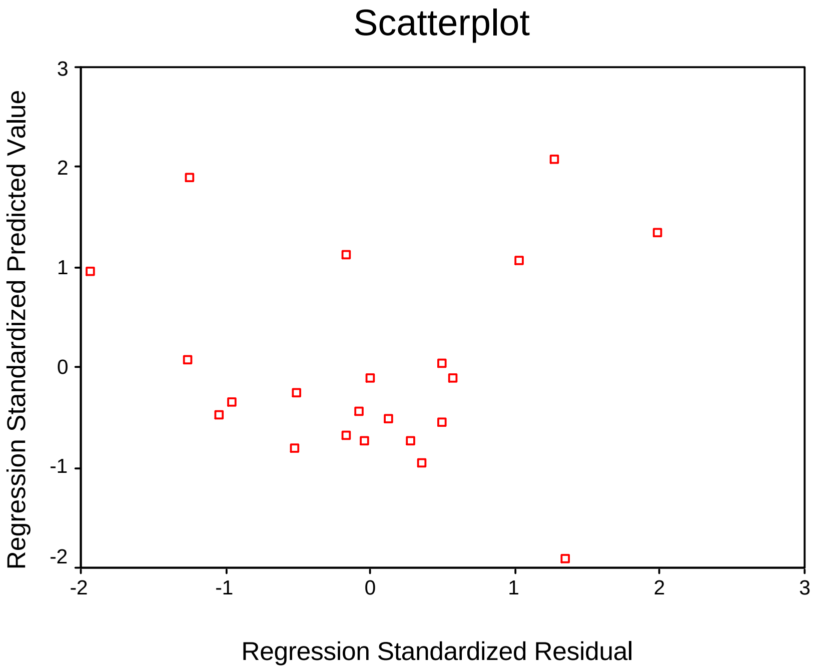

Fig. 4.16 Normal P – P Plot for M6

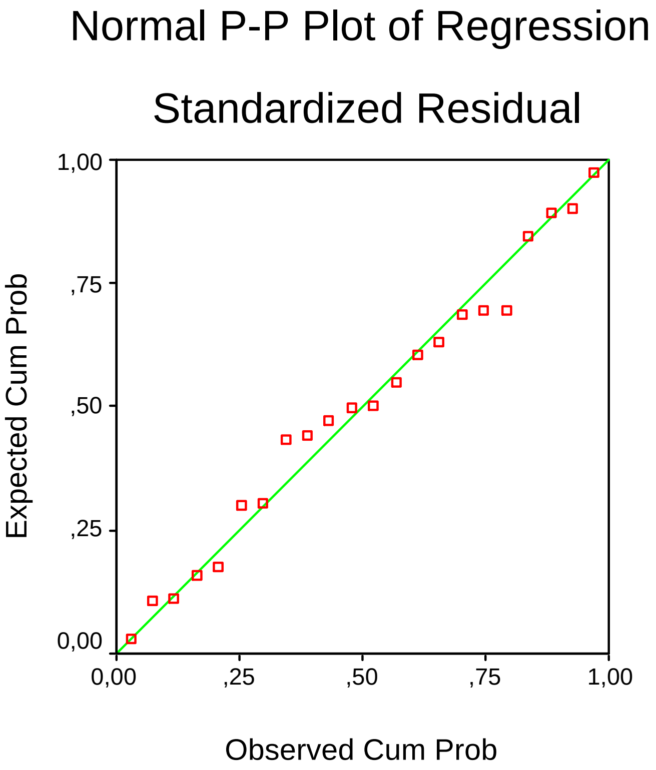

Fig. 4.17 Scatter Plot for M6

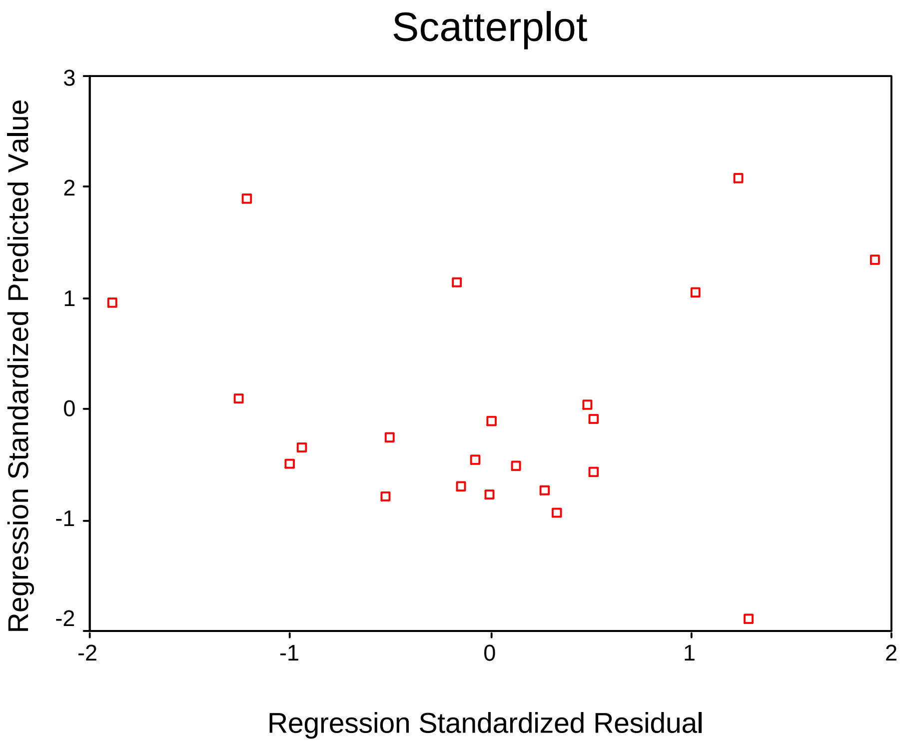

Fig. 4.16 normally distributed histogram for M6