TECHNICAL EFFICIENCY OF THE GILLNET FISHERY IN DA NANG, VIETNAM: AN APPLICATION OF A STOCHASTIC PRODUCTION FRONTIER

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Abstract

This study investigates the level and determinants of technical efficiency for a sample of gilnnet fishing vessels operating in Da Nang in 2009 by using a stochastic production frontier, which involved the simultaneous estimation of a translog stochastic frontier model and a model for vessel-specific technical inefficiencies. Furthermore, the other important determinants of this fleet were also examined such as the output elasticities, marginal productivities of inputs, and returns to scale. The data on per-month average variable costs and revenues, number of gillnet sheets, vessel size, engine power, vessel age, number of net-contributors, experience and education levels of the fishermen, and vessel ownership were used in the production frontier analysis. The empirical results suggest that the effects of technical inefficiencies were found to be considerably significant in explaining the differences in individual vessel efficiencies. The mean technical efficiency for the sample vessels is estimated to be a relatively low, 0.76, implying that this fleet has potential to improve the productivity at least in the short-run, given the availabilities of their technology and resource conditions. The analysis also demonstrates that engine power, vessel size, net-contributors, and owner-operated vessels were found to impact positively on vessel efficiency, although the vessel-size and owner-operator effects were insignificant. Whereas, vessel age has a strong negative effect on technical efficiency, and it may seem strange when this analysis suggests that the experience and education level of fishermen also has a negative side as well, even if the effect of fishermen's education level was found to be insignificant.

Key words: Da Nang, gillnet fishery, stochastic production frontier, technical efficiency.

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1. CHAPTER I. INTRODUCTION

1.1 Background of the study

Vietnam has many favorable conditions for fisheries development due to the extensive coast line of 3260 km and an area of Exclusive Economic Zones (EEZ) that are more than 1 million km^2 with an abundance of marine resources. The number of fishing boats has been increasing ceaselessly since 1997 and catch production grew up, too (see, Appendix 2). During the period 1997-2008 the number of vessels was increased by 1.73 times from 71,500 units in 1997 to 123,069 units in 2008 while total catch was increased by over 2,0 times from 1.062 metric tones (MT) in 1997 to 2.130 MT tons in 2008 (Chien et al., 2010).

The types of fishing gears are diversified and while trawls, sein nets and gillnets are most commonly used with high fishing catch and economic efficiency. Gillnets are known as a long-standing traditional type fishing gear in Vietnam, used by about 30.0 % of the total fishing vessels in the whole country. In recent years, the number of gillnet vessels has increased significantly from 15,006 in 2002 to 31,151 vessels in 2008. In 2008, only 1,343 (4.31%) vessels had an engine capacity of more than 90 Horse power (Hp), the number of vessels with less than 20 Hp constituted up to 68.79% of the total (Chien et al., 2010) (see, Appendix 2). The gillnet becomes very popular in the small scale fisheries because of its simple construction (fishing techniques) and low required investment capital, in general.

Da Nang City is located in the middle of Central Vietnam with a coastline of over 80 km and is known as Vietnam’s third largest city. Da Nang is considered as one of the key fisheries areas in Vietnam. In 2009, there were 1,932 fishing vessels with a total engine capacity of 76,603 Hp, of which 1,110 vessels (accounts for 57.45%) have an engine capacity of more than 20 Hp with a total of 66,490 Hp. The number of boats with less than 20 Hp are a significant amounts of the total fishing boats (constitutes 45.65 % or 882 units) with total engine capacity of 10,113 Hp, this means that the fisheries in Da Nang were mainly small scale fisheries operating with short fishing trips in coastal areas. There are lots of different fishing gears that have been used (including trawls, sein nets, hook and lines, gillnets, traps, and so on) with the most common being trawl, hook and line, and gillnet. The gillnet fisheries has been playing an important role in the Da Nang's fisheries sector followed by trawl fisheries. There are many types of gillnet (i.e. drift gillnet, drift bottom gillnet, trammel net, and bag gillnet) which are used in Da Nang for catching different target species in both pelagic and demersal fisheries. Amongst those the drift gillnet, which is considered as a wall of net that is set perpendicular to the water current and could be drifted according to the current direction, is known as the most important fishing gears and is commonly used for catching mackerel and tuna species. Of the 1,932 fishing vessels operating in 2009 in Da Nang, only 119 were drift gillnet vessels (or 6.16% in equivalently), but the total engine capacity of this fleet took over 18.00% of the total in the region. Therefore, it can be said that this gillnet fleet has the biggest size (the average engine capacity per boat is 116.67 Hp) compared to those in whole region (with 39,65 Hp per boat on average), the investments in gillnet vessels seems relative high compared to other fleets and they may able to operate in offshore fishing grounds.

Most fisheries worldwide are still open-access resources and managed by input controls as important tools (including Vietnam) and hence, an understanding of the relationship between the inputs and the outputs from fishing is considered as one of essential factors for effective fisheries management (Pascoe and Mardle, 2003). In contrast, where fisheries are mainly managed under aggregating output controls then the reduction policies in fishing effort (the fleet) has been required with the aim of establishing a sustainable balance between capacity and resources. In reality, however, various differences in efficiency across vessels can strongly affect the effectiveness of such policies since removing inefficient boats may have fewer impacts on the limitations of overfishing (Pascoe and Coglan, 2000). In Vietnam, the reduction policies in numbers of fishing boat, particularly for those vessels in small size and inefficiency, have been considered as one of the biggest challenges for fisheries management.

The measurement of efficiency (of activities as the fishery) attempts to assess the performance of firms in using resources with the aim to produce goods and services. The requirement of technical efficiency is that the maximum possible amount is produced with the resources used. Technical efficiency measurement in fisheries is considered as a key important factor, particularly when input controls are in place. Researches, however, have been directed to investigate technical efficiency in commercial fisheries is limited because of inadequate data or choice of analytical methods (i.e. Comitini and Huang, 1967; Noetzel and Norton, 1969; Hannesson, 1983). Recent literature reviews show that there are some studies that have been more comprehensive in measuring the technical efficiency in fisheries issues such as Kirkley et al. (1995 1998); Campbell and Hand (1998); Coglan et al. (1999); Sharma and Leung (1999); Squires and Kirkley (1999); Grafton et al. (2000); Pascoe et al. (2001); Pascoe and Coglan (2002); Tingley et al. (2005); Ngoc et al. (2009).

According to Färe et al. (1985, 1994), the determinants of technical efficiency could be undertaken by applying different methods such as the nonparametric programming approach, the parametric programming approach, and the parametric statistical approach. The parametric statistical approach, which is known as a stochastic production frontier analysis (Aigner et al., 1976; Aigner et al., 1977; Meeusen and van den Broeck, 1977), may appear to be appropriate for examining the relative technical efficiency of firms exploiting renewable resources because of the involvement of the stochastic characteristics in the production process (Kirkley et al., 1995, Sharma and Leung, 1999). There has been considerable study to extend and apply this approach from literature reviews such as Førsund et al. (1980), Schmidt (1986), Bauer (1990), and Greene (1993).

Estimation of the frontier production function has two main benefits compared with the average (e.g. OLS) functions that are to known as *(i)* to be strongly affected by the best performing firms and the reflection of the technologies employed, and *(ii)* representing the best output (a best-practice technology) to the responding observed output (Coelli, 1995a). A frontier production function approach is in widespread use to assess the productive efficiencies of firms in many industries. For the fisheries industry, however, the application of this approach for assessing the relative technical efficiency is still limited in reality (Kirkley et al., 1995; Sharma and Leung, 1999). Sharma and Leung argued that it is partly due to fisheries management authorities seem more concerned with the biological aspects of fisheries resources rather than with the economic performance of fisheries, and the difficulty in collecting the required data as well.

However, to maximize the social benefits from the fishing industries then both sustainable management of fish stocks and efficient utilization of resources that are related to the inputs of fishery production (such as labor, capital, and gear, and etc.) are principal.

1.2 Da Nang's gillnet fishery

The gillnet fisheries (for mainly catching mackerel and tuna) in Da Nang has been in existence since the early 1970s when some Da Nang fishermen had learned this fishing method from Thai fishermen. It is true that this kind of fisheries has started to develop more along with the offshore fishing program that the government of Vietnam initiated since the mid-1990s. The present gillnet vessels are mainly found in Son Tra and Thanh Khe districts and a few gillnetters are located in Hai Chau and Lien Chieu districts in Da Nang City. Some technical characteristics of the gillnet fleet are discussed next, and followed by a description of the operational characteristics of the vessels.

In 2009, there were 119 gillnet vessels (registered) operating in Da Nang with engine capacities ranging from 22-520 Hp and the total engine capacity of 13,884 Hp. The number of gillnet vessels having an engine capacity of more than 45 Hp consists of 91.60% and 53.78% for those vessels with an engine capacity of more than 90 Hp. Da Nang-based gillnet vessels could be categorized into three size classes based on the vessel length distribution: small (<17 meters (m)), medium (17-19 m), and large (>19 m). Amongst the 119 gillnet vessels operating in 2009, 26 were classified as small, 27 as medium, and 66 as large. The length of the gillnet depends on the size of the boat and the financial ability of the fishermen, while the height of the gillnet normally depends on the target species and most of the Da Nang-based gill-netters have a considerable homogeneity in the height of the net, about 16 m. Most gillnetters typically have a large size and are well equipped with mechanical and electronic equipment such as winches, compasses, global positioning systems, scanning sonars, radar systems, generators, and communication equipment. It means that this fleet is capable of operating in the offshore areas. The average engine capacity per boat was 116.67 Hp and the average length was about 17.28 m (ranging from 8.8-21.40 m). Compared to the average engine capacity and the length of the Khanh Hoa's gillnet fleet, which was 85.60 Hp and 14.10 m, respectively (Kim Anh et al., 2006), it can be seen that the sizes of the gillnet vessel in Da Nang were relative high. It was also implied that the investments in the gillnet fisheries in Da Nang are higher compared to the Khanh Hoa's gillnet fishery (see, Appendix 6).

The length of a fishing trip mainly depends on the size of the vessel (vessel length) and the skippers' behavior. The gillnet vessels having a hull length longer than 17 m (large vessels) are capable of making trips longer than two-weeks (the longest trip can be 24 days) this includes travel time. These gill-netters are often equipped with 300-350 gillnet sheets per boat or equivalent to 15,000-17,500 m in length (the length of a net sheet is 50 m) with a captain and a crew of 10-11 members. Compared to the large vessels, the gillnet vessels in the medium category are normally equipped with 200-280 gillnet sheets with a captain and a crew of 8-9 members and make trips lasting 7-10 days. The gillnet vessel in the small category, have 150-200 gillnet sheets, a captain and a crew of 6-7 members and make trips lasting 4-7 days.

The Da Nang gillnet fleet mainly targets the pelagic fish, including five tuna species such as the longtail tuna (*Thunnus tuna*), bigeye tuna (*Thunnus obesus*), striped tuna (*Sarda orientalis*), skipjack tuna (*Katsuwonus pelamis*), and yellowfin tuna (*Thunnus albacares*); and three mackerel species as the wahoo (*Acanthocybium solandri*), narrow barred Spanish mackerel (*Sacomberomorus commerson*), and Indo-Pacific Spanish mackerel (*Scomberomorus guttatus*). Other pelagic species are also caught by Da Nang's gillnet fishery include sailfish (*Istiophorus orientalis*), black marlin (*Makaira indica*), broadbill swordfish (*Xiphias gladius*), white check shark (*Carcharhinus dussumieri*), etc. In fact, however, tuna and mackerel are the two major species group targeted by the gillnet fleet (constituting up to 60-80 % of the total landing), typically for bigeye tuna, skipjack tuna, bullet tuna, frigate mackerel, and Indo-Pacific Spanish mackerel. It should be noted that the target species are mainly pelagic fish, so that gillnetters usually operate at night without moonlight (from the 12th to 18th, on a lunar calendar).

The fishing grounds for most Da Nang-based gillnet vessels are mainly in the offshore areas, some of the gillnetters have registered to operate in the common fishing areas of the Tonkin Gulf, which China and Vietnam have designated since 2004, while a few vessels in the small size catogory only operate in the coastal areas. Gillnet fishing activities take place in a large area from the south-east of the Paracel Islands (Hoang Sa in Vietnamese) and all the way up to the Gulf of Tonkin (see, Appendix 1), the identification of the fishing grounds mostly depends on the skipper's fishing experience and fishing seasons. The main fishing season normally lasts during the period from December to March (April), known as the north-east monsoon, and most gillnet vessels (including medium and large size) often tend to operate in the Gulf of Tonkin (covering from Quang Tri to Hai Phong seawaters, typically surrounding Bach Long Vi Island) where the main target species are mackerel species, which consists of about 50-60% of the total catch. Many gillnetters normally carry out fishing in the south-east of the Paracel Islands for the South-west monsoon (as the sub-season), which usually ranges from May (April) to August (September), during which the target species are mainly tuna species, constituting up to around 60-70% of the fishing production. In practice, however, some skippers could identify their fishing grounds based on the main target species that would be expected during fishing (mackerel or toward targeting tuna) without consideration of the seasonal effects, which means that one gillnetter could fish in the Tonkin Gulf for mainly mackerel species even during the South-west monsoon when tuna species are mainly caught by most gillnetters in the south-east of the Paracel Islands. Most vessels engage in the gillnet fishery year-round, except for the vessels come in for repairs and maintenance (about 1-2 month, annually) and in case of inconvenient weather.

Among the 119 Da Nang-based gillnet vessels operating in 2009, 98 gillnetters (82.35%) collaborate for high fishing efficiency, and are organized into teams of 22 vessels each. The catch of these groups landed over 9 million MT, constituting around 85% of the total catch. There are about 3-5 vessels for each fishing group in general. The members in a group usually are related, and this type of collaboration is based on family loyalty. This fishing style has brought benefits to all members. The members support each other in sharing fishing ground information, mechanical support in case of an engine failure, and supplies such as fuel, water and food, etc. On the other hand, the Vietnamese government encourages the fishing groups collaborated by providing the cruise particularly subsidies, fishing training and weather reports, and etc. Furthermore, the operation of these fishing groups may significantly contribute to building a steady national defense and security on the sea. This is considered as one of the most important objectives in developing an offshore fishing program by the Vietnamese government.

Some gillnet vessels are privately operated, while some others are lent by the relatives of owner. Most the time, the owner owns one vessel, but some owners may have more than 2 vessels. The investments in fishing gears could be shared between owner and crew members. The owners normally contribute about 75-90% of the total capital investment in fishing gear, and the crew members contribute about 10-25%. Each member only owns 5-20 gillnet sheets under financial support from the owner as a loan without interest rate in exchange for a one year labor contract (note that a gillnet sheet costs about 1.5-2.8 million VND). The contribution of the fishing gears in this case has many benefits in the fleets operation such as encouraging the crew members to work responsibly so that the vessels may operate more efficiently, and of course the income would be improved as well. This feature is very important in making the bond between the owners and the workers during the offshore fishing operation.

The sharing system in this fishery is based on monthly income. The income obtained, which is the difference between gross revenue and total variable costs except labor costs, was distributed into 10.5 parts, in which the vessel-owner takes 3.5 parts, and 3.0 parts for fishing gears (shared between the owner and those crew members who contributed gillnet sheets), and the remaining parts of 4.0 will be shared among the laborers.

1.3 Statement of the problem

The fisheries industry is considered as a key sector in Vietnam's economy, even so the fisheries statistics system of Vietnam is still poor, information on the fishing effort and catch (catch per unit of effort), biological information of stock structure, age-specific growth and mortality rates are not fully presented in the publication, and the management of fisheries (and marine resources as well) cannot be effective without such reliable information and knowledge (Van Zwieten et al., 2002). Vietnam fisheries sector has been in need of knowledge-based management (Kim Anh et al., 2006).

Fisheries management in Vietnam is mostly imposed through a series of input controls (such as gear restrictions, minimum mesh size, engine power, fishing licenses, etc.). Such controls, however, usually have not been fully assessed and examined in practice (Son, 2003; Truong and Dap, 2006). While other inputs that were determined as major factors impacting the level of fishing efficiencies such as skipper and crew skill may have been largely ignored in literature related to the production performance in fisheries (see, Comitimi and Huang, 1967; Crutchfield and Gates, 1985; Squires and Kirkley, 1999; Sharma and Leung, 1999).

A few recent studies have been undertaken to attempt to measure economic performance of some different types of fisheries such as longliners, gillnetters, and pure-seiners (see, i.e. Kim Anh et al., 2006; Long et al., 2008; Luong, 2009). These studies, however, have just covered some aspects of fishing efficiencies associated with costs and earnings of these fleets (in Nha Trang, Vietnam) in inadequate data and time constrain conditions, especially these studies mostly did not examine the socio-economic information about fisheries that can also be useful for fishery managers in formulating appropriate regulations.

In recent years, there has been an increase in research concerned with assessing the technical efficiency in some economic sectors by production frontier function approaches in Vietnam. For example, technical efficiency has been estimated for manufacturing industries (Minh, 2005), as well as a range of agriculture activities e.g. rice production (Song, 2006; Nhut, 2006), and in aquaculture (Den, et al., 2007). The application of these techniques, however, in Vietnamese fisheries is very limited. To our knowledge, Ngoc et al. (2009) have carried out the only one study on small-scale trawl fisheries in Nha Trang by applying production frontier approaches. The lack of such studies in fisheries sector may be explained by fishery management systems do not normally concern more the economic performance of fishermen, instead that they are tendentiously more interested in biological aspects of fish stocks. In fact, to maximize the social benefits from fishing, we need the efficient utilization of the related resources (e.g. labor, capital, etc.) and the sustainable management of marine resources, as well. Furthermore, the limited frontier studies in marine fisheries can be partly caused by inadequate data and the complexity of fishing activities. Therefore, it can be said that conducting a study on assessing the relative technical efficiency for the gillnet fishing vessels could be interesting for both research and managerial purposes. This study may also contribute to improve the gillnet fishing strategies and management in the future.

1.4 Objective of the study

The objective of this study is to examine the level and determinants of technical efficiency of a sample from Da Nang, Vietnam – based, gillnet vessels, based on their 2009 operating costs and earnings. A stochastic production frontier model is specified and estimated. These results could show whether the gillnet fleet whether operates close to the efficient frontier or not and what percentage of earnings on average the sample vessels could obtained if they are operated at full technical efficiency.

An inefficiency model is subsequently developed by applying the Battese and Coelli (1995) model with the aim to determine the relevant vessel - and operator - specific factors that may affect technical efficiency. The results are obtained from this model can be used to clarify what factors significantly impact technical efficiency and would provide some helpful indications on how to improve the economic performance of the gillnet fleet.

Furthermore, the other important outputs of this study are also investigated, such as output elasticities, returns to scale, and marginal productivities of inputs. The knowledge from this study may provide some helpful information (a reliable basis) for fishery managers and decision making, particularly in formulating appropriate regulations.

1.5 Research hypothesis

Based on the objectives of this study and the current review, some research hypotheses may arise in order to reinforce the preoccupation of the study as follows:

(i) The Da Nang-based gillnet vessels would be subject to increasing returns to scale. This hypothesis means that the fleet could increase a more than proportionate in the level of outputs produced by using a less than proportionate in all inputs.

(ii) There is inefficiency of scale in the existing gillnet fisheries operations;

(iii) The technical efficiency scores vary considerably across individual gillnet vessels with a given different set of inputs and technology;

(iv) The efficiency residuals are dwarfed by pure random residuals;

(v) There is a considerable relationship between technical efficiency and characteristics of managerial skill such as experience, and education levels in the gillnet fisheries. This hypothesis implies that some fishing skippers are better managers than other skippers, and hence they would consistently have higher production and earnings.

1.6 Structure of the thesis

The focus of this work is to investigate the level and determinants of technical efficiency for a sample of Da Nang gillnet fishing vessels operating in 2009. In order to reach the objectives and formulate the study it so that it can easily be comprehended, the thesis is divided into five chapters. The first chapter offers an introduction to the study. It provides relevant information on the general background, a description of the Da Nang's gillnet fishery, the research problem, the objectives and hypotheses of this study. The second chapter gives the reader a brief literature review with regard to some important issues to the main theme of the study, such as the basic concept of technical efficiency, the theoretical and empirical measurement of technical efficiency, and the estimates of stochastic production frontiers in fisheries. The third chapter presents the methodology used to examine the level and determinants of technical efficiency of the gillnet fleet. In this chapter, the theoretical framework of the study is outlined, followed by a description of the data used in the estimation of the stochastic production frontier, and finally empirical models. The fourth chapter provides the empirical results of the study. This chapter focuses on the stochastic production frontier function analysis, which is presented and discussed in five sub-sections such as: (1) tests of the hypothesis results; (2) technical efficiency; (3) factors affecting the technical efficiency; (4) the elasticity and returns to scale; (5) and marginal productivities of inputs. The last chapter is devoted to the discussion and conclusion of the study. The discussion section focuses on some key topics regarding to the effects of various factors influencing the efficiency and the fishing process, technical efficiency relative to input use and economic performance, and possible policy implications for the gillnet vessels. The conclusion part will clarify the final remarks to determine if this study has been able to meet its primary objective as well as outlining some limitations regarding to the main findings and the recommendations for future work.

2. CHAPTER II. LITERATURE REVIEW

2.1 The concept of technical efficiency

Following Farrell (1957) and recent literature, a firm can illustrate its economic efficiency with two measures, such as technical efficiency and allocative efficiency. The technical efficiency represents the ability to obtain the maximum potential firm performance (output) from a given set of inputs. In contrast with the technical terms, the allocative efficiency reflects the firm's ability to use the optimal input quantities, given their respective prices and technologies employed. Allocative and technical efficiency combine to provide an overall economic efficiency measure. For this study, however, our emphasis will be on technical efficiency.

In economic terms, the concept of technical efficiency is critical to measuring the firm performance and can be defined as the relationship between inputs and outputs. Farrell (1957) pointed out that a firm is technically efficient when it uses the level of inputs in an optimal way from a given output. Whilst, Koopmans (1951), Cornwell and Schmidt (1996) argued that technical efficiency of a firm is the ability and willingness to produce the maximum potential output under given set of inputs and technology. These two arguments are relative under the profit maximization assumption. Farrell's knowledge represents the minimization of costs for a given revenue levels, meanwhile Koopmans, Cornwell and Schmidt implying the revenue maximization from a given level of costs.

Technical efficiency is a considered as basic measurement for determining the level of the adoption in innovative technology and the overall production efficiency (Lambarraa et al., 2007). According to Aigner et al. (1977) and Kumbhakar and Lovell (2000), technical efficiency could be understood as a measurement of how well the individual transforms inputs into a set of outputs given set of economic factors and technologies employed. This concept implies that two firms (vessels) may significantly produce different levels of output while using the same levels of input and technology. So why is there a considerable difference that is known as the level of efficiency between these two firms? A part of this difference could be explained by random variations and the other parts may be characterized by the individual fundamental attributes and opportunities (Ortega et al., 2004).

2.2 The theoretical and empirical measurement of technical efficiency

Recent economic literature on the theoretical consideration of technical efficiency has emerged with two different notions of technical efficiency (Briec, 2000). Koopmans (1951) argued that the firm can be considered as technically efficient if a reduction in any input requires increasing at least one other input. This concept has been adopted by several authors such as Färe and Lovell (1978), in particular. Whilst, Debreu (1951) and Farrell (1957) introduced the radial-based approach for measurement of technical efficiency as the maximum equiproportionate reduction in all inputs consistent with equivalent production of observed output levels.

There has been an increase in studies in applied economics concerned with technical efficiency measurement and this approach has become a very popular research field in recent years (Coelli et al., 1995). Recent literatures refer to the relative measure of technical efficiency show that there are two principal approaches to estimating technical efficiency, non – parametric as Data Envelopment Analysis (DEA) and parametric as a Stochastic Production Frontier (SPF) analysis and both have advantages and disadvantages. The DEA methodology was introduced by Charnes et al. (1978), which is based on mathematical programmer approach without imposing any assumptions about functional forms and does not take into account random error. Therefore, the efficiency estimates may be biased under the production process, which are largely involved stochastic elements. In contrast, the SPF approach imposes an explicit functional form and distribution assumption on the data and can account for random errors (such as the weather and luck). The production frontier illustrates the maximum potential output under a given set of inputs, and it can be measured as the relative efficiency of a set of practices from the relationship between observed production and potential production. This feature clearly differs from the assumption of production function that there are no differences in efficiency in the use of the inputs between firms (Greene, 1993). However, the application of the stochastic approach in fact may have two potential problems that are specification errors (i.e., imposing the one-sided error distribution) and misspecification of the functional form (Färe et al.,1994; Kirkley et al., 1995). Further, this approach is considered as the most common form that can only incorporate a single output. Hence, where fisheries are most characterized by multispecies (multioutput) then the efficiency estimation may result in bias when assuming a single output. Otherwise, in this case, DEA can incorporate the possibility of multiple outputs.

The scientific basis for estimating non-parametric frontier production function was first proposed by Farrell (1957). The measurement of firm specific technical efficiency is based upon deviations of observed output from the best production or efficient production frontier. If a firm's actual production point lies on the frontier it is perfectly efficient. If it lies below the frontier then it is technically inefficient, with the ratio of the actual to potential production defining the level of efficiency of the individual firm.

Based on the previous parametric approaches (i.e. Farrell, 1957), Aigner et al. (1977) and Meeusen and van den Broeck (1977) did independently propose a stochastic production frontier model by adding a statistical noise term into the efficiency analysis. Thus, the estimation of a production frontier involves the specification of two components of the error term, a symmetrically distributed stochastic component that is known as random errors (captures the effects of statistical noise, measurement error, and exogenous shocks beyond the control of the production) and a stochastic component with a one-sided distribution, representing inefficiency (Aigner et al., 1977).

Pitt and Lee (1981) and Kalirajan (1981) have adopted a two-stage approach for the explanation of the inefficiency effects in cases of the Indonesian weaving industry and paddy production, respectively. The first stage of this approach is that both the stochastic frontier production function and the predicted technical inefficiency effects are specified and estimated, given the assumption that these inefficiency effects are identically distributed, while the second stage specifies a regression model for the prediction of the technical inefficiency effects, but with a contradiction in the assumption of identically distributed inefficiency effects in the stochastic frontier. Whereas, Kumbhakar et al. (1991) and Huang and Liu (1994) have proposed models (one-stage approach) for simultaneously estimating the stochastic frontier and the technical inefficiency effects, under the appropriate assumptions associated with cross-sectional data on the sample firms. However, Battese and Coelli (1995) believed that most theoretical stochastic frontier production functions have not properly examined a model for the effects of technical inefficiency in terms of suitable explanatory variables of firms involved in producing a specific output.

2.3 Estimation of stochastic production frontiers in fisheries

Schmidt (1986) believed that a production function can be estimated from the observed outputs and the level of inputs used and defines the average level of outputs for a given set of inputs. Production functions are used in cases of the individual vessel level or total fishery level for estimating the relative contribution of the factors of production, including Cobb-Douglas production functions (Hannesson, 1983), CES production functions (Campbell and Lindner 1990), and translog production functions functions (Squires 1987, Pascoe and Robinson 1998). However, recent literature on economic studies in the fisheries sector show that the translog functional form of the production frontier has been largely applied for examining the relationship between the catch in terms of money value or physical quantity and the inputs employed (Pascoe and Mardle, 2003).

Efficiency studies on production frontier estimation in fisheries has commonly adopted the output-based approach under supposing that fishers aim to maximize their revenue each trip (Tingley et al., 2005). In fact, however, the measurement of output has faced certain challenges when modeling fisheries. For most industries, the study of efficiency normally uses the physical measure of volume as a proxy variable for the output due to the individual outputs could be identified in the production process. In most fisheries, however, it is impossible to follow this approach because of different species in the total catch (multi-species fisheries). In such cases, the value of the catch is commonly used as proxies for output. Whereas, when single species are harvested then the landed weight would be used for measuring the resultant catch.

Depending on different types of fisheries, previous authors have been able to use the physical quantity or the value of catch as proxy variables for the output measure in their empirical studies on the relative efficiency of fisheries. For instance, Kirkley et al. (1995, 1998) measured the outputs as the landed weight per trip for the Atlantic Scallop fishery; Squires and Kirkley (1999) used the weighted average of landed catch annually when modeling the US Pacific Coast groundfish trawl fishery. In contrast, Sharma and Leung (1999) used value of catch per trip for examining the Hawaiian longline fishery. The author, however, argued that using revenue as an output variable may confound technical inefficiencies with allocative inefficiencies as a true measure of allocative inefficiency in multi-species fishery is difficult to calculate. In case of Vietnam, most studies related to fishing efficiencies have used the value of catch annually as proxies for the measurement of output (see, i.e. Kim Anh et al., 2006; Long et al., 2008; Luong, 2009; Dien, 2009; Ngoc et al., 2009), since Vietnam's fisheries sector is characterized by mixed outputs (different species).

Recent literature on production and efficiency in fisheries (see, for instance, Squires and Kirkley, 1999; Sharma and Leung, 1999; Grafton et al., 2000; Pascoe and Coglan, 2002, and etc.) review that there are a range of different input measures that have been used with the most common of those being mainly measures of capital, capital utilization, stock size, and labor utilization for some other studies. However, the exact choice of input variables for modeling differs between studies and normally depends on the availability of data, the expectation to capture the full range of inputs employed and the fisheries characteristics, as well. The use of inappropriate measures of the input use may lead to mis-specification problems of the model, and hence affecting the efficiency estimation (Campbell, 1991).

Following Kirkley et al. (1995, 1998), the capital levels could be measured in terms of monetary investments; while Pascoe and Robinson (1998) and Coglan et al. (1999) used the physical inputs (e.g. boat length, gross registered tons, engine power, etc.) as measures of the level of capital employed. However, Pascoe and Mardle (2003) argued that many researchers prefer to use the measure of capital value rather than physical measures in practice as it is could be possible to capture all inputs employed in fishing compared with the physical terms, although the use of economic measures of capital sometimes is a considerable problem because of measurement errors. Conversely, there are some advantages in using the physical input measures over the economic measures as they are often more robust in measuring and readily available for a large proportion of the fleet, nevertheless the physical measures generally do not encompass all inputs.

A number of capital utilization measures have been used into the analyses in terms of either time fished as days at sea or trips (e.g. Sharma and Leung, 1999) or fuel consumption (i.e. Squires, 1987; Squires and Kirkley, 1999; and Sharma and Leung, 1999). The fuel use measure could capture some of the vessel characteristics and can be used as a measure of both physical and variable inputs because of the larger vessels (engines) would consume more fuel per hour compared with the smaller ones. This feature, however, could have resulted in multicollinearity problems when modeling with both fuel use and vessel size measures, particularly the elasticity estimate might be unreliable (Pascoe and Mardle, 2003).

Following previous studies on fisheries production and efficiency (e.g. Squires, 1987; Kirkley et al., 1995,1998; and Sharma and Leung, 1999), the number of crew has been used as a variable input and in some cases, it is considered a key factor influencing the level of fishing efficiencies, particularly for pole and lines fisheries (the bigger the crew, the larger catches). In the case of trawling this feature may not be true as trawlers normally require the minimum number of crew for the production. However, more crew could be allowed to remove and process the catch faster, and hence have more time for fishing. This may make sense for most fisheries, typically as gillnet fisheries.

In reality, the larger vessels usually have more crew. This implies that there is a substantial correlation between vessel size and crew numbers, therefore the effects of crew in the production process could be captured in the vessel size variable. Furthermore, crew use for each vessel in fact normally varies from month to month, while detailed information on crew numbers generally is not available and consequently, the use of the crew measure in this case is also subject to problems that may make its contribution to the production function not significant.

The available resource is considered as a major input in the fishery production function and has been used into the analysis as an input measure (e.g. Kirkley et al., 1995, 1998). However, the measure of the stock is normally just included in the analyses when information on stock abundance is available for at a least two-period data as the stock is often assumed constant over the year. Otherwise, a series of dummy available has been used to represent the stock situation in different areas or over the year and between years (Campbell and Nicholl, 1994; Coglan et al., 1998; Pascoe and Robinson 1998; Pascoe et al., 2001; Pascoe and Mardle, 2003). However, the estimation of the stock changes on production in fact has faced certain challenges since the availability of reliable fish stock information in many multispecies fisheries may not exist, such as Vietnam's fisheries.

3. CHAPTER III. METHODOLOGY

3.1 Theoretical framework

Since the fishery activities are largely characterized by many stochastic elements, especially for cases of small-scale fisheries. Hence, the SPF approach was found as an appropriate method for examining the technical efficiency of fishing vessels in this case study. A general stochastic production frontier model can be given by:

$$\ln q_i = \beta \ \ln x_i + v_i - u_i \qquad (1)$$

where q_i is the output produced by firm *i, x_i* is a vector of factor inputs of the *i*th firm, and β is a vector of estimated parameters.

The term v_i is a random variable that accounts for random effects (beyond the control of the firms), which is assumed to be an independent and identically distributed (*iid*) $\mathrm{N}(0,\sigma_v{}^2)$, independent of u_i, and it can be positive or negative.

The term u_i is a non-negative random variable, accounts for pure technical inefficiency in production, which is assumed to be independently and identically distributed and truncations (at zero) of the normal distribution (Aigner et al., 1977) with mean, µ*i*-measures the technical inefficiency relative to the frontier and describes the distance of firm *i*th from the frontier output (Coelli et al., 1998), and variance, $\sigma_u{}^2(|\,\mathrm{N}(\mu_i,\sigma_u{}^2\,|)$. Additionally, the other distributional assumptions of the error term (u_i) have also been proposed such as an exponential distribution (Meeusen and van der Broeck, 1997), a half-normal distribution truncated at zero (Jondrow et al., *1982*), or a two-parameter Gamma distribution (Green, 1990), and all have advantages and disadvantages (Coelli et al., 1998). However, Pascoe and Mardle (2003) believed that the truncated normal distribution is a more general specification. The assumption of independent distribution between u_i and v_i allows the separation of the stochastic (statistical noise) and inefficiency effects in the model (Bauer, 1990). This is considered as one of the advantages of assessing technical efficiency by the SPF model.

The method of the maximum likelihood is proposed for estimating the parameters of the stochastic frontier equation 1. The parameters to be estimated involved β and variance parameters such as $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$ (Battese and Corra, 1977). Where, σ^2 is the sum of the error variance, while γ measures the total variation of output from the frontier attributed to the existence of random noise or inefficiency. Note that the value of γ lies between zero and one. The inefficiency is not present when γ=0, it means that all deviations from the frontier are entirely due to random noise, and against if γ=1 then the deviation is completely caused by inefficiency effects (Battese and Coelli, 1995).

Based on the Battese and Coelli (1995) model, the random variable associated with technical inefficiency, u_i, was further assumed as a function of various operator- and vessel- specific variables that are hypothesized to influence technical inefficiencies as:

$$u_i = z_i\delta + w_i \qquad (2)$$

where z_i is a vector of explanatory variables associated with the technical inefficiency of production of the *i*th firm, δ is an unknown vector of coefficients that is to be estimated, and w_i is a (*iid*) random error term, which is defined by the truncation of the normal distribution with zero mean and variance, σ_u^2 , such that the point of truncation is $-z_i\delta$, i.e., $w_i \geq -z_i\delta$. These assumptions are consistent with u_i being a non-negative truncation of the $N(z_i\delta,\ \sigma_u^2)$−distribution.

It should be noted that both the frontier model (Equation 1) and the inefficiency model (Equation 2) may include intercept parameters if the inefficiency effects are stochastic and have particular distributional properties (Coelli and Battese, 1996). Moreover, the stochastic frontier requires a priori functional form specification. This means that it is necessary to impose restrictions on the model. By doing that, these restrictions could be tested by using the following generalized likelihood ratio (LR):

$$\text{LR} = -2\{\ln[L(H0)] - \ln[L(H1)]\} \quad (3)$$

where $\ln\{L(Ho)\}$ and $\ln\{L(H1)\}$ are the values of the log-likelihood function under the null *(Ho)* and alternative *(H1)* hypotheses, respectively. The restrictions form the basis of the null hypothesis, while the unrestricted model being the alternative hypothesis. LR has a Chi-squared (χ^2) distribution with the number of degrees of freedom provided by the number of restrictions imposed.

In order to test the specification of the models, a number of tests have been proposed with the standard test being the one-sided generalized likelihood ratio-test for the existence of a frontier (the presence of technical inefficiency) (i.e. H_0: γ=0). This test has an asymptotic distribution ($0<\gamma<1$) and the critical values of the test are obtained from Kodde and Palm (1986). In case of failing to reject the null hypothesis (i.e. no inefficiency), accepted, then there is no evidence of technical inefficiency in the data and the production frontier is identical to a standard production function. The other key test is the correct functional form of the stochastic production frontier (Equation 1) is Cobb-Douglas form (i.e. H_0: $\beta_{i,k} = 0$, where *k* denotes the *k*th input variable). This null hypothesis is tested against the alternative hypothesis that the translog is the most appropriate functional form (i.e. H_1: $\beta_{i,k} \neq 0$). Further, the appropriate assumption for the inefficiency distribution as a truncated normal can also be tested under the null hypothesis so that all the parameters of the technical inefficiency model, except the intercept are zero.

Based on the model estimations, the output for each firm could be compared with the frontier level of output that is known as the best output given the level of inputs employed, and this deviation indicates the level of inefficiency of the firm. Therefore, the technical efficiency score for the *i*th firm in the sample (*TE$_i$*) under given equations (1) and (2) that would be defined as the ratio of observed output to the corresponding best output is given by (Coelli et al., 2005):

$$TE_i = \frac{q_i}{\exp(\beta \ln x + v_i)} = \frac{\exp(\beta \ln x + v_i - u_i)}{\exp(\beta \ln x + v_i)} = \exp(-u_i) = \exp(-z_i \delta - w_i) \quad (4)$$

where TE_i is relative technical efficiency of the firm (0<*TE*<*1*). Note that, when u_i=0 then the *i*th firm lies on the stochastic frontier and known as technically efficiency. If u_i>0, the firm *i* lies below the frontier, which means that the firm is inefficient.

The elasticity of output with respect to the *k*th input variable (ε_k), which measures the responsiveness of output to a 1% change in the *k*th input, that will be evaluated at the mean values of relevant data points can be derived as:

$$\varepsilon_k = \frac{\partial \ln q}{\partial \ln x_k} = \beta_k + 2\beta_{kk} \ln x_k + \sum_j \beta_{kj} \ln x_j \qquad (5)$$

where β_k is the coefficient on the $\ln x_k$ term, β_{kk} is the coefficient on the $\ln^2 x_k$ term and β_{kj} is the coefficient of the cross product of x_k and x_j, where both *k* and *j* are inputs.

The measure for returns to scale (*RTS*), representing the percentage change in output due to a proportional change in the use of all inputs, that will be estimated as the sum of output elasticity for all inputs (Chambers, 1989).

The measurement of marginal product of *k*th input at mean values of output and relevant input variables will be calculated as:

$$\frac{\partial q}{\partial x_k} = \varepsilon_k \frac{\bar{q}}{\bar{x}_k} \qquad (6)$$

3.2 Data description

The data set used in this study came primarily from both logbooks and interview. The first was a cross - sectional survey (in 2009) of a sample Da Nang - based, gillnet vessels which was obtained through fisher's logbook collection. The logbook records represent a true record of the total variable costs and gross revenue per month by each vessel and other relevant information. The second source was the interviewed data. From a total of 119 registered gillnet vessels operating in 2009, 56 gillnetters were randomly selected. These selected vessel owners and/or captains (his wife) were interviewed by using a designed questionnaire form during January through February of 2010 to collect detailed information on various aspects of the gillnet fishery, including vessel characteristics (i.e. hull length, engine power, and vessel age), fishing grounds, targets, operating months, number of trips, crew size, the characteristics of fishing gears (gillnet length), the net contribution of crew members, the capital investments of vessels (fixed costs), and the mean annual repair and maintenance costs for each vessel, etc. Furthermore, information on skipper characteristics was also collected through interviews conducted such as age, number of years fishing experience, education level, as well as whether the vessel owner-operated or not. However, the number of vessels considered in this study was fifty because of the omission of six vessels due to missing information. Thus, the data on these fifty gillnet vessels was analyzed in the estimation of the stochastic frontier.

The data on the selected vessels showed considerable heterogeneity in terms of technical and operational characteristics such as vessel size, age, crew size, variable costs, and the total length of the gillnets, as well as, the skipper's age, experience, and education level. Hull lengths for the sample gillnet fleet ranged from 14.8 to 21.0 m, with an average length of 18.1 m (see, Appendix 3). The age of gillnet vessels varied from 1.5 to 16.0 years, with a mean age of 5.5 years. In fact, the age of the vessels may be even higher since some vessels may have been second hand ones when they were bought. Thus, the vessel age here means the years of ownership by the present owner. The average crew size was 9.9 persons, with a range from 8.0 to 12.0 persons. The sample gillnets fleet also showed a considerable variation in the variable costs between fishing vessels, a range of 19.7 to 65.7 million VND, with the mean being 37.3 million VND on average. The number of gillnet sheets used for the sample gillnetters ranged from 200.0 to 360.0 sheets with a sample mean of 294.0 sheets (noted that a gillnet sheet is 50 m in length). The average monthly number of days at sea, including time spent traveling, is 17.6 days and varied from 11 to 22 days. The age of the skippers also varied from 28 to 60 years, with an average age of 43.1 years (see, Appendix 3). The skippers had relatively high levels of experience, with an average of 16.6 years of being involved in fishing activities. Summary statistics of output and key input variables, as well as vessel- and operator-specific variables involved in the analysis, are presented in Table 1.

Table 1. Summary Statistics for variables included in the stochastic production frontier and technical inefficiency models for the gillnet Fishery in Da Nang in 2009

Variable	**Mean**	**S.D.**	**Min.**	**Max.**
No. of operating months (months)	10.2	0.8	8	12
Average annual revenue	868.1	237.2	275.7	1,379.3
Average income per month	47.3	15.4	5.8	79.7
Output				
Gross revenue	84.7	21.6	27.6	125.8
Inputs				
Variable costs	37.3	10	19.7	65.7
Crew size (no. of persons)	9.9	0.9	8	12
Gillnet length (no. of sheets)	294	32	200	360
Vessel – and operator – specific variables				
Vessel size dummy: Medium (0 or 1)	0.58	0.50	0	1
Vessel size dummy: Large (0 or 1)	0.28	0.45	0	1
Engine power (Hp)	140.2	86.9	37	360
Vessel age (years)	5.5	3.7	1.5	16
Net-contributor (persons)	6.1	2.3	1	11
Skipper's experience	16.6	9.9	2	38
Education dummy: Secondary level (0 or 1)	0.26	0.44	0	1
Owner-operated dummy (0 or 1)	0.50	0.51	0	1

Note: Number of total observations: n=50. All economic values are in million VND (US$1 = 16,900 VND, in 2009). Medium vessel: 17-19 m. Large vessel: >19 m. Crew size includes captain.
Source: own data.

Table 1, furthermore, illustrates that one of the most important economic performance indicators for the sample gillnet fleet, income, is positive. The total gross revenue of the vessels substantially varied from 275.7 to 1,379.3 million VND, with an average of

868.1 million VND. Compared with the average annual revenue of a gillnetter operating in Nha Trang City, which was 851.3 million VND (Kim Anh et al., 2006), it can be said that the revenue of gillnet vessels operating in Da Nang City was relatively higher than those vessels in Nha Trang City. However, this seems not to be a very significant difference in performance among these gillnet (see, Appendix 6).

The data on per-month average variable costs and revenues was used for the analysis of the production frontier. The choice of data types for this study can be derived from the characteristics of the gillnet fisheries and data availability. The tested correlation coefficients between the output and potential inputs in the frontier model (see, Appendix 4) showed that multicolinarity is not a problem in this study. The partial correlations of variable costs (*O*) with labour (*C*), and the number of gillnet sheets employed per vessel (*N*) are 0.51 and 0.42, respectively. The correlations of labour with number of gillnet sheets is 0.47.

3.3 Empirical models

For many industries, the outputs can be defined as a physical measure of volume. Whereas, fisheries especially in tropical seawater such as Vietnam are considered mixed fisheries, which are characterized by different species in the catch and often receiving different prices on the market. Therefore, in the case of examining the relative technical efficiency of the gillnet fisheries (typically feature multiple species) the revenue is identified as a reasonable measurement of the output variable. Furthermore, to use the cross-sectional data of 2009 for the analysis of the stochastic production frontier function, it is necessary to assume that prices of output (i.e. tuna, mackerel) and all variable inputs used are the same for all vessels.

There are many different input measures that have been used to analyze fisheries production and efficiency. Most previous studies of efficiency, the common inputs have used involving a measure of capital (in terms of monetary investments or physical measures as vessel length, gross registered tons, and horse power, etc.), capital utilization (i.e. days at sea, fishing trips, and fuel consumption, etc.), and stock abundance (the effect of changes in fish stocks over time or different areas), while some others have also included a measure of labor utilization in the production function (i.e. Battese and Coelli, 1995; Kirkley et al., 1995, 1998; Squires and Kirkley, 1999; Sharma and Leung, 1999; Pascoe and Mardle, 2003).

Gillnet fishery production involves multiple inputs, including hull length, engine capacity, trip length (days at sea), number of trips, crew size, gear, fuel, ice, etc., and other miscellaneous supplies. Amongst that hull length, gross registered tons (GRT), engine power, fishing days, number of crew, and gillnet length are commonly used in some recent studies (see, for instance, Pascoe et al., 2001; Squires et al., 2003). Pascoe et al. have examined the effects of economic versus physical input measures on technical efficiency of the Danish gillnet fleet. The physical input measures are defined as the vessel gross tonnage and horse power, whereas fuel consumption was used as the key input and assumed to capture both features related to the vessel size (e.g. hull length and horse power) as well as capital utilization (i.e. days fished). Whilst, Squires et al. have used a range of different input measures for the analysis of the Malaysian gillnet fishery, such as vessel GRT as proxies of the vessel capital stock, the number of crew employed per vessel as a variable input, and the number of trips per month representing variable input usage (i.e. diesel, oil, ice, container, and other miscellaneous variable inputs).

In case of Vietnam’s fisheries, Kim Anh et al., (2006) used the hull length and the main engine power as proxies of vessel fishing effort when modeling the gillnet fisheries in Nha Trang City. This study also used some other variable as vessel age, numbers of gillnet sheets (or the total gillnet length), and monetary investments in fishing gear and equipment. While Dien (2009) used the number of days at sea and number of crew for his analysis when modeling the gillnet fleets in the Central area of Vietnam. For the purpose of our study, however, the input variables will be aggregated into four categories: namely, (1) the variable costs used by each vessel per month, including fuel, ice, and other miscellaneous items. This variable is known as a proxy of the capital utilisation rate (e.g. Squires, 1987; Sharma and Leung, 1999). (2) the numbers of crew members on vessel, including the captain. This is considered as a key variable input generating fishing effort and impacting on the level of gillnet fishing efficiencies since more crew may allow the removal and processing of the catch more quickly and, in turn, allow for more time for fishing; and (3) numbers of gillnet sheets that will be used as the main physical input - as proxy for investment in the level of capital employed.

There are several potential functional forms that can be used to specify the stochastic frontier, however, in most empirical applications, the desirable form normally is a translog function due to its flexible and easily facilitate calculation of individual values for technical inefficiency and efficiency (Kirkley et al., 1995). The appropriateness of the translog functional form of the model will be tested against a Cobb-Douglas specification, as seen in the results section. Thus, for this study the functional form of technical efficiency model can be specified as:

$$\begin{aligned}\ln(\text{Re}venue_i) &= \beta_0 + \beta_1 \ln(O_i) + \beta_2 \ln(C_i) + \beta_3 \ln(N_i) + \beta_{11}(\ln O_i)^2 + \beta_{22}(\ln C_i)^2 + \\ &\beta_{33}(\ln N_i)^2 + \beta_{12} \ln O_i \ln C_i + \beta_{13} \ln O_i \ln N_i + \beta_{23} \ln C_i \ln N_i + v_i - u_i\end{aligned} \qquad (7)$$

where the output variable is represented in terms of revenue per month in million VND; *O* denotes the variable costs used by each vessel per month, including fuel, ice, minor repairs, and other miscellaneous items, except labor cost (million VND/month); *C* is the numbers of crew on vessel, including the captain (in persons); *N* denotes the number of gillnet sheet employed by each vessel (in units); and v_i, and u_i are error terms and defined as in the previous section.

The skills of skippers and vessels characteristics are considered as important factors in how a vessel performs. Kirkley et al. (1995) argued that the skippers' skill may seem a complex concept to understand and has a profound effect on the productivity of a fishery and fisheries management models. Moreover, Salvanes and Steen (1994) and Squires and Kirkley (1999) also believed that the differences in output among individual vessels could not be explained because of the socio-economic characteristics of fishermen i.e. skipper and crew skills, management ability, and skipper education. For this study, a number of relevant vessel- and owner- specific variables hypothesized to influence technical efficiency for the gillnet vessel are as: (1) vessel size dummy (value 1 of the vessel is medium size, 0 otherwise); (2) vessel size dummy (value 1 of the vessel is large size, 0 otherwise); (3) vessel's engine power in horse power-Hp; (4) vessel age in years (the ownership of the vessel by the present owner), representing vessel characteristics; (5) the number of crew members who contribute some gillnet sheets in total net sheets employed by each vessel; (6) the skipper's experience in years; (7) the level of formal education dummy (value 1 if the operator had secondary school, 0 for those skippers who have a lower education level; no skippers had a high school education in our data set); (8) whether or not the vessel is owner-operated, which may closely relate to management and fishery performance, that is also examined as a dummy variable (value 1 if the vessel was owner-operated, 0 otherwise). Therefore, the functional form of the inefficiency model of this study is proposed as:

$$u_i = \delta_0 + \delta_1 D_{mediumvessel} + \delta_2 D_{largevessel} + \delta_3 \ln(\text{enginepower}_i) + \delta_4 \ln(\text{vesselage}_i) + \delta_5 \ln(\text{netscontributor}_i) + \delta_6 \ln(\text{experience}_i) + \delta_7 D_{education} + \delta_8 D_{owner-operated} + w_i \quad (8)$$

where *Ds* denote dummy variables and w_i is random error term defined as the previous section.

4. CHAPTER IV. EMPERICAL RESULTS

This chapter focuses on five main streams. First the results from the hypothesis tests (econometric results) are presented and discussed. The estimated technical efficiencies for the Da Nang-based gillnet vessels are described and explained in the following part. The third part discusses the effect of potential factors, which relates to vessel- and operator-specific characteristics, on technical efficiencies. The remaining two parts discuss the estimates of output elasticities, returns to scale, and marginal productivities of inputs for gillnet fishery production in Da Nang City.

The parameters of the stochastic production frontier model, equation (1), and those for the technical inefficiency model, equation (2), are estimated simultaneously by using the maximum-likelihood estimation (MLE) program, Frontier 4.1 (Coelli, 1994). These results are presented in Table 3.

4.1 Econometric results

The generalized likelihood ratio tests of some key null hypotheses involving restrictions on the parameters to be estimated involved the β-coefficients and variance parameter, γ, in the stochastic production frontier and the δ-coefficients in the technical inefficiency model are presented in Table 2.

The first null hypothesis test that technical inefficiency effects are not present in the model, $\gamma = \delta_0 = \delta_1 = ... = \delta_8 = 0$. The LR test statistic is asymptotically distributed as a mixture of chi-square distributions. This test statistic exceeds the 1% critical value $\chi^2_{0.99}(10) = 22.525$, which is taken from Table 1 in Kodde and Palm (1986), so the LR test leads us to reject the null hypothesis that there no exist a technical inefficiency in the stochastic production frontier (at the significant level of 5% or less), and also implying that the traditional average (OLS) function is not suitable for this study.

Table 2. Generalized likelihood ratio tests of hypotheses for parameters of the stochastic production frontier and technical inefficiency models for the gillnet fishery in Da Nang

Null hypothesis	Log-likelihood value	Number of restrictions	Critical value (χ^2)
$H_0: \gamma = \delta_0 = \delta_1 = ... = \delta_8 = 0$	35.202	10	22.525*
$H_0: \beta_{11} = \beta_{22} = \beta_{33} = \beta_{12} = \beta_{13} = \beta_{23} = 0$	13.560	6	12.59**
$H_0: \delta_1 = \delta_2 = ... = \delta_8 = 0$	35.610	8	15.50**

Note: *, **, statistically significant at the 1% and 5% levels, respectively. The correct critical values for the first hypothesis is obtained from table 1 of Kodde and Palm (1986, p. 1246)

The second null hypothesis, that the correct functional form of the model is Cobb-Douglas, which can be imposed by removing the squared and cross product terms from the translog production function, is rejected (at the 5% level of significance). Thus, the LR tests suggest that the translog is the most appropriate functional form for the analysis of gillnet vessels in this study (the estimated models are well specified).

Finally, the hypothesis that the technical inefficiency effects have the same truncated-normal distribution with a mean equal to δ_0, which given by all the parameters of the technical inefficiency model except the intercept are zero, is also rejected (at the 5% level of significance).

4.2 Technical efficiency

The technical efficiency score for the Da Nang-based gillnet vessels range from 0.55 to 0.98, with the mean efficiency level equal to 0.76 (more details, see Appendix 7). The mean technical efficiency for the gillnet fishery in Da Nang is substantially lower than 0.84 and 0.88 for the Malaysian gillnet artisanal fishery in the East and West coasts, respectively (Squires et al., 2002). It can be said that the arithmetic means of the individual technical scores for Da Nang-based gillnet fleets are consistent with those generally found from stochastic frontiers for developing country agriculture (Ali and Byerlee, 1991; Bravo-Ureta and Pinheiro, 1993).

The frequency distribution of the estimated technical efficiency scores, relative to the best practice frontier scores is depicted in Figure 1 (more details, see Appendix 7). It can be seen that the majority of vessels have a technical efficiency score of 0.70 to 0.79 (30%), followed by 26% of vessels with efficiency scores of 0.60-0.69. While the smallest proportion of the observed vessels (10%) have technical efficiency indices of 0.50-0.59. The sample vessels that had a technical efficiency index of 0.90 or above just accounted for just 20% and those vessels with efficiency indices of 0.80-0.89 accounted for 14%. Therefore, only more than 30% of the sample vessels have a technical efficiency score of 0.80 or higher, implying that, a limited number of vessels display substantially higher levels of technical efficiency (operated close to the efficient frontier) in 2009. Notably, however, none of the sample vessels has a technical efficiency index of lower than 0.50. In summary, the vast majority of the gillnetters have an average levels of technical efficiency and there is potential to improve the technical efficiency (productivity), given the state of their technology and resource conditions.

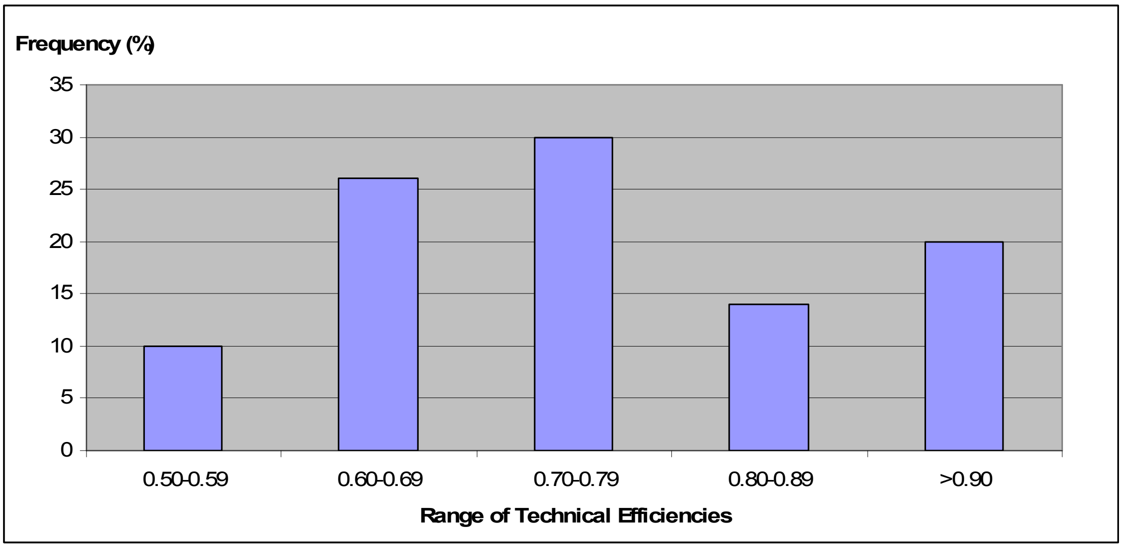

Figure 1. Frequency distribution of technical efficiencies for the gillnet Fishery in Da Nang City, Vietnam

Table 3. Parameter estimates of stochastic production frontier and technical inefficiency models

	Coefficient	**Asymptotic T-ratio**
Stochastic production frontier		
Constant	-106.347	-46.922***
ln (*Variable costs*)	0.820	3.520***
ln (*Crew size*)	10.210	28.630***
ln (*Net sheets*)	33.965	37.509***
ln (*Operating costs*)^2	-0.462	-2.444**
ln (*Crew size*)^2	-2.514	-14.608***
ln (*Net sheets*)^2	-2.680	-15.327***
ln (*Variable costs*) x ln (*Crew size*)	1.862	3.202***
ln (*Variable costs*) x ln (*Net sheets*)	-0.181	-0.326
ln (*Crew size*) x ln (*Net sheets*)	-0.932	-1.387
Technical inefficiency model		
Constant	0.965	5.092***
Vessel size dummy: Medium (0 or 1)	-0.028	-0.431
Vessel size dummy: Large (0 or 1)	-0.016	-0.237
Engine power (Hp)	-0.093	-2.247**
Vessel age (years)	0.057	1.882*
Net-contributor (persons)	-0.254	-6.340***
Skipper's experience	0.058	2.017**
Education dummy: Secondary level (0 or 1)	0.026	0.536
Owner-operated dummy (0 or 1)	-0.055	-1.295
Variance parameter		
σ^2	0.011	5.511***
γ	0.78	12.045***

Notes: *, **, *** Statistically significant at the 10%, 5%, and 1% levels, respectively.

4.3 Factors affecting technical inefficiencies

Given the specifications of the stochastic production frontier model, defined by Equations (1) and (2), the results of the generalized likelihood-ratio tests indicate that the joint effect of vessel- and operator-specific variables on technical inefficiencies (the technical inefficiency effects) is highly significant in explaining the variation in productive performances of the Da Nang-based gillnet vessels. However, as shown in Table 3, none of the coefficients associated with vessel size, skipper's education level, and the owner-operator dummies have a significant effect on technical efficiency. Whilst, the individual effects of the remaining variables (i.e. engine power, vessel age, net-contributor, and skippers experience) are statistically significant (based on asymptotic t-ratios).

The value of γ in the models is 0.78, and this is statistically significant at the 1% level. This result confirms that the output variability of the gillnet vessels is dominated by technical inefficiency rather than uncontrollable random shocks. This result is not too surprising because the skippers may have a good knowledge of resource abundance, availability, and spatial distribution (Kirkley et al., 1995) or even the willingness to take more risk by the skippers, given the nature of fishing (i.e. weather, resource and environment conditions) is normally characterized by many uncertainties. Otherwise, the high gamma value in the models implies that the relative contribution of inefficiency to the total variation is high. This also means that most of the variation in the output accounted for by potential factors in the production frontier function that was attributed to the differences in efficiency rather than random error or "luck".

The factors affecting technical inefficiency can be explained by the magnitude, algebraic sign, and significance of the estimated coefficients in the inefficiency model (Equation 2), which are reported in Table 3. It should be noted that a negative sign indicates a decrease in technical inefficiency (implies a positive effect or an increase in technical efficiency) and inversely, the positive sign would imply a negative effect. Given the estimated technical inefficiencies (Table 3), it can be seen that although not significant, the negative coefficients for the vessel size dummies suggest a positive effect of vessel size on technical efficiency. The fact that, the coefficient for engine power is negative means a positive influence, while vessel age has a negative influence on the technical efficiency of the gillnet fleet. As expected, owner-operated vessels are likely to be technically more efficient than those operated by hired captains. Similarly, the more gillnet-contributors the more technical efficient gains, implying that the net-contributed variable has a positive effect on the vessel's technical efficiency. In contrast, both operator fishing experience and educational attainment have a negative effect on technical efficiency. These estimated values are quite different from previous studies which often found the experience and education level of the captain to have a (strong) positive influence on vessel efficiency (Kirkley et al., 1998; Squires and Kirkley, 1999; Sharma and Leung, 1999).

4.4 The elasticity and returns to scale

The output elasticity is a useful way to characterize the responsiveness of potential inputs to changes in output. Since the coefficients of the translog stochastic production frontier, equation (1), do not have a straightforward interpretation. Thus, the estimated values of the output elasticities are calculated at the point of the means of relevant data point as defined by equation (5).

The estimates of output elasticities for the Da Nang gillnet fishery showed that the output elasticity for variable expenses, crew size and the amount of gear used is positive (an expected finding) and less than 1. The output (revenue) elasticity of variable costs is found the highest value (0.72), followed by the total length of gillnet (0.71), and finally this is 0.14 for the labour variable. The estimated output elasticities do not vary with variations in two input levels related to variable costs and the net length. In contrast, if comparing to some earlier studies that examined output elasticities in fisheries, the estimated elasticity of gear length from this study is contrary to the estimation from those studies. For example, Kompas et al. (2003) found that the length of net has a negative effect on efficiency in Australia's prawn fishery. Similarly, Fousekis and Konaris (2003) also concluded a negative influence of the gear use on vessel efficiency in Greece. These findings mean that the vessels in their case may use more gear than is the optimal level. Inversely, in case of Vietnam, it suggests that there is potential for further development of the offshore fishery (increasing fishing efforts), at least in the short run. This is also consistent with the suggestion from a biological perspective that the maximum sustainable yield for the Vietnamese offshore EEZ is about 1.1 million MT, but in fact that the offshore landing (excluding illegal, unreported and unregulated foreign fishing) was estimated at around 0.6 MT (FAO, 2005).

With regard to the elasticity associated to the number of crew member, the positive estimated value (0.14) is consistent with most previous studies (see, Kirkley et al., 1995; Pascoe and Robinson, 1998; Sharma and Leung, 1999; Pascoe et al., 2001). However, this estimated value is relatively small and may be not a significant parameter in the production frontier, particularly for all practical purposes. This also implies that the differences in technical efficiency between vessels caused the effect of the labour factor to seem not considerable (more details, see Table 4: page 44). An explanation for this is that because crew members receive a share of the fishing income, so there may be few or no attempts to increase the number of crew operating the fishing vessels.

The return to scale for the gillnet fishery in Da Nang, which was computed as the sum of output elasticities for all inputs, is found to be 1.57. Thus, it can be said that the gillnet fishery production can be attributed by increasing returns to scale based on 2009 data. This is a reasonable result for static gear boats, such as the gillnetters. The empirical finding of increasing returns, therefore, implies that an expansion of all three inputs (variable costs, labour, and the amount of gear use) by 10% increases output by more than 15%, given that stock abundance is constant. The estimation of returns to scale for this fishery is consistent with some previous researches (i.e. Kirkley et al., 1995 and 1998; Pascoe and Robinson, 1998; Pascoe et al., 2001; and Sharma and Leung, 1999).

4.5 Marginal Productivities of Inputs

The estimates of the marginal contributions of each input to the gross revenue for the Da Nang gillnet fishery were derived from Equation (6). It should be noted that, the estimated is the value of marginal product since the output variable used in the production frontier analysis was measured in value instead of quantity. Thus, given the 2009 data of gillnet fishery production, the estimated marginal product of variable costs, crew size, and the amount of gillnet employed is estimated to be 1.626, 1.223, and 0.204, respectively. These results show substantial variation in marginal productivities among different inputs used, suggests that the contribution of each input to the vessel gross revenue is also quite different.

5. CHAPTER V. DISCUSSION AND CONCLUSION

5.1 Discussion

5.1.1 Factors affecting efficiency and the fishing process

Given the estimated stochastic production frontier model, the ability to determine which potential factors are affecting the efficiency and the production process can be investigated. As can be seen from the estimated inefficiency model, both vessel size dummies for the sample gillnet fleet has a positive influence on technical efficiency, even though these influences are not significant as their coefficient values are relatively small, and indicate that those variables are minimally affect efficiency. One possible explanation is that in the gillnet fisheries, a larger vessel allows more gear (gillnet sheets) to be worked in a wider range of conditions, implying that the fishing effort of those vessels is substantially higher, and consequently get proportionally higher levels of output (Pascoe and Mardle, 2003). Another possible reason for this positive effect could be explained by that the larger vessels may have more capacities to operate in the remote fishing grounds (offering more resources for exploitation) or difficult weather conditions. Moreover, these vessels could also take a longer fishing trip with available of ice, provision, and fuel stores. The larger vessels, however, would consume more fuel per hour compared to the smaller ones, and hence would have higher trip operational expenses.

One interesting finding from the inefficiency estimation was that engine power has a statistically significant positive impact on vessel efficiency (at the level of 5%). This result may be surprising because the gillnets are considered as the static gear boats, so the engine power may not defined as a key factor influencing the level of fishing efficiencies as those for the case of mobile fishing gears (i.e. trawling). However, there may be two rational explanations from our estimation. First, the greater engine power can extend the carrying capacity and allow more hauls to be worked (take place over a given period). Second, more horse power enables the vessels to move faster between the fishing grounds, and hence reduces the time for traveling and fuel cost consumption, as well.

Regarding to the influence of the vessel age, like many earlier studies, this factor has a negative effect on technical efficiency and is found statistically significant at the level of 10%. This finding is consistent with the suggestion of Kim Anh et al. (2006) that the age of vessel also has effects on Khanh Hoa's gillnet vessel revenues. This may make sense as the older vessels have much more trouble due to i.e. construction material, hull design, size, winch equipment or engine. In addition, they may be required repairs and maintenance regularly. Thus, the operating time of those vessels may be reduced and have higher cost of operational expenses. Therefore, it can be said that as the age of a vessel increases, the efficiency is decreased.

The estimated technical inefficiencies for the Da Nang-based gillnet vessels also shows that vessel gross revenue increases with the number of net-contributors who own some gillnet sheets from the total gear operated by each vessel. This positive influence is an expected result, statistically significant at 5% level or better, and could be explained by those fishermen working harder. They have more responsibilities for the vessel's operation and are encouraged to work as if they are working for their own benefit. This explanation seems more plausible since the sharing obtained from the fishing gears (benefits) will be distributed to the members who have invested in equipping the vessel with fishing gear based on the amount of gear owned, consequently the earnings of these fishermen would be improved significantly. Another possible reason for this is that the labour force for the vessel operating may have been more stable during at least one year because the net-contributors will have to work on board as a labour contract with the owner. This characteristic is also considered as an important factor for the gillnet fisheries since the gillnetters usually require the minimum number of crew (at least seven members) for the fishing operation. In fact, some fishermen tend to leave their present vessel owner in order to find a new job (new vessel), especially after some fishing trips they were involved in were unprofitable. It's not too surprising because those fishermen have to provide finance for their family as the main income source of most fishermen family is derived from his fishing activity.

From the inefficiency model, it can also be seen that the positive sign for the fishing experience and formal education of the captains is contrary to expectations and suggests that an increase in the values of those variables leads to a decrease in efficiency. These estimation results look unreasonable because in reality, fishing experience of captains usually provides better information on locating fishing ground, weather patterns, current and tide conditions, and how to catch the best fish. Related to the education level of the captain, it may make sense to realize that the technical inefficiency of a vessel may be reduced by improving the literacy and cognitive skills of captains in order to adopt technical innovations. It should be noted that the estimated gamma value above (γ=0.78), suggests that the differences in technical efficiency across individual vessels are dominantly attributed to technical inefficiency rather than to random effects. There are a few important questions that may arise here which are as what are the main determinants of vessel production without concerning the effect of the skipper's skills (i.e. years of fishing experience and education level)? Why the effectiveness of the Vietnam's offshore fishing program was limited? The answers for these questions may be related to the lack of information on offshore resources and/or insufficient understanding of the economic realities of the offshore fleets, and the onboard technologies seem unsuitable as well. To our estimation, however, the positive estimated coefficients of the skipper's experience and education level could be explained by that the gillnet fishery may be characterized by risky behaviors and uncertainties because of the remote fishing grounds, severe weather condition, and the variability of fishing targets which are highly migratory species (i.e. tuna, mackerel, swordfish), so the younger skippers with less experience or lower schooling level may also have more efficient than those skippers who normally get more number of years fishing experience or better schooling level. A potential reason for this is that these younger skippers are often more willing to change their fishing patterns in order to succeed (ready to cope with such difficulties or take more risks) and thus, the effects of more experience or formal education level of the captains on efficiency, in this case, appears uncertain. Moreover, the Vietnamese fishery, like many developing countries, is generally characterized by small-scale fisheries, and the development of fishery technology seems limited. Therefore, the cognitive skill requirement of captains to adopt new technologies in the fishery may not play as an important role as those in the developed fisheries. Another possible explanation for these unexpected estimates may be related to the reliability of the data collected as the information on socio-economic factors of fishermen is normally difficult to determine exactly.

Another interesting result from our study is that both owing and operating a vessel can have a positive effect on vessel efficiency, suggesting that owner-operated vessels tend to be more efficient than those operated by none-owner captains. This finding is consistent with the results of the other fisheries studies previously cited that incentives affect the level of technical efficiency. However, the owner-operator dummy variable is insignificant in explaining differences in technical inefficiency for the Da Nang gillnet fishery. A possible explanation for this is that the vessel owners may have a very good relationship with hired captains who normally are the relative of owner. Thus, the vessel owners may increase the rate of return by using their relatives working as a captain or by operating the vessel by themselves.

In the frontier model, most of coefficients estimated for parameters were significant and showed their significant influence on the production process (vessel gross revenue). The positive estimated coefficients of variable costs, crew size, and the net length and the negative coefficients of their squared terms imply that the relationship between vessel gross revenue and these variable inputs is hump shaped. As expected, vessel gross revenue increases with variable costs, crew size, and the total gillnet length, but at a decreasing rate. The output elasticities of variable costs, labour and the total length of net were estimated to be 0.72, 0.14 and 0.71, respectively (based on Equation 5). It is clear that elasticity value estimates less than 1 indicate that output (revenue) is less sensitive to changes in the level of input, or ‘inelastic’. In such a case, a one per cent increase in the level of the input would lead to a less than one percent increase in the level of the output. Therefore, from our estimation it can be seen that a 10% increase in variable expenses, crew, and the net length use would lead to increases in the vessel gross revenue by 7.20%, 1.40%, and 7.10%, respectively.

The estimates of marginal product for gillnet fishery production concluded that overall, fishermen could be increase their per-month gross revenue by more than 1,6 million VND by adding a variable cost of or over 1,2 million VND for a crew member added, respectively. Similarly, an average gross revenue per month of gillnet fishery in Da Nang would increase by more than 0.2 million VND by using a gillnet sheet more.

5.1.2 Technical efficiency relative to input use and economic performance

5.1.2.1 Technical efficiency and factor utilization

Based on data shown in Table 4, as can be seen that for the vessels have the mean technical efficiency lower than 0.89 then the higher technical efficiency was found for those vessels have more variable costs. The distribution of technical efficiency contained 28 (56%) number of the gillnet vessels with an estimated range of 0.60 to 0.79 have the total variable costs, on average, ranged from 34.598 million VND to 37.342 million VND per month by each vessel, and 43.051 million VND spent on operating expenses for the 7 vessels with estimated technical efficiency between 0.80 and 0.89. While, the 5 vessels receiving the lowest efficiency range of 0.50 to 0.59, have the smallest variable costs with an average level of 28.616 million VND. However, the mean technical efficiency was found to be higher than 0.90 for the 10 vessels that have the lower costs (41.268 million VND) in comparing with those vessels having a technical efficiency lower than 0.89 (between 0.80 and 0.89), but a higher costs (43.051 million VND). One possible explanation for this interesting result may be related to the number of days at sea, since some vessels could improve their performance by increasing the days fished or by operating in a wider range of conditions (remote fishing grounds), particularly in the main fishing season. Thus, the total costs of these vessels would increase along with days spent on their fishing as using more fuel, ice, and provision, etc. In fact, these gillnet vessels could not spend more days at sea than their available capacity in vessel size and onboard technologies allowed. Furthermore, as the landings are unprocessed fish preserved with simple catch preservation techniques (all of the catch is kept on ice), so the quality of fish catch would be reduced and, in turn, receive a lower price (earnings) if a vessel takes a very long fishing trip.

Table 4. Average technical efficiency, input use, and economic performance, 2009

Efficiency	Variable costs	Crew size	Net length	Gross Revenue	Total Income	Average crew share
0.90-0.99 [10]	41.268	10.10	305.00	106.630	65.360	2.706
0.80-0.89 [7]	43.051	10.00	314.29	104.414	61.360	2.338
0.70-0.79 [15]	37.342	10.00	290.00	84.787	47.440	1.807
0.60-0.69 [13]	34.598	9.77	291.54	69.328	34.730	1.265
0.50-0.59 [5]	28.616	9.20	262.00	52.484	23.870	0.988

Note: Variable costs, gross revenue, and total income is in terms of million VND, respectively; Crew size is number of crew; Net length is number of net sheets; Average crew shares denote the earnings per crew member per month.
All measures, except number of net sheets and crew size, are on per-month basis.
Numbers in brackets indicate number of observations.

The technical efficiency values with regard to crew size was found to be the high (0.80-0.89) and lower than that level (0.70-0.79) for those vessels are the same crew, averaging 10.00 persons. Whilst, an average crew size for the vessels with the highest technical efficiency score (>0.90) is a little more labour, 10.10 persons. Whereas, the smallest technical efficiency was achieved by the lowest crew size, with an average of 9.20 persons, and 9.77 persons for those vessels had the higher technical efficiency level (0.60-0.69). Therefore, it can be said that clear patterns between technical efficiency and the level of crew size may not be clearly evident for policy implication purposes

5.1.2.2 Technical efficiency and physical fixed inputs

As shown in Table 4, the trend effects of the amount of gillnet use on vessel efficiency were found similarly with the operating cost impacts. In general, higher technical efficiency was found for gillnet vessels, with a mean efficiency level lower than 0.89, having more gillnet sheets employed. For instance, the smallest efficiency range of

0.50-0.59 was found for vessels using the average length of net at the shortest level (13,100 meters or 262.00 sheets). While, the estimates of technical efficiency ranged from 0.80 to 0.89 for those vessels which used the maximum length of net, with an average length of about 15,714 meters (314.29 sheets). An explanation for this is that for the gillnet fishery, the length of net can be considered as the main physical fixed input, representing the operational characteristic and generating fishing effort. Thus, it does make sense when the vessel's efficiency could be increased by expanding the level of fishing effort (a longer gillnet) given the stock availability. This is also consistent with Kim Anh et al. (2006) in the case of Khanh Hoa's gillnet fishery. However, in reality, the vessels also could not fish with a very long gillnet since it depends on the labour force available, fishing process (the time is limited), and other vessel characteristics. This may explained why some gillnet vessels got the higher technical efficiency (above 0.90) with the shorter length of gillnet (15,250 meters or 305.00 sheets).

5.1.2.3 Technical efficiency and economic performance

As can be seen from Table 4 that the estimated technical efficiency of individual vessels could be compared with its economic performance for the sample gillnet fleet operating in 2009. The results shows that, the average monthly income of the gillnet vessels substantially varied from 23.870 million VND to 65.360 million VND, with an average of 46.552 million VND. The average crew share per month per member by the vessel also varied greatly from 0.988 million VND to 2.706 million VND, with a mean of 1.821 million VND - higher than the average monthly crew share of a longliner, which was 1.700 million VND (Long et al., 2006). This result implies that the owner and crew of an average gillnetter is not only capable of covering all total operating expenses, but also have significant net returns for each operating month.

Table 4 also shows clearly that vessels with higher average technical efficiency per month also had higher average total income, which was obtained after the deduction of total variable costs, per month per vessel, and had higher average crew share per member per month, as well. For the 10 vessels of the sample gillnet fishery with estimated technical efficiency between 0.90-0.99 had the highest average total income per vessel per month (65.360 million VND) and highest average crew share per member per month (2.706 million VND). While, the average income and crew share of 5 vessels with the lowest estimated efficiency range of 0.50-0.59 were only 23.870 million VND per month per vessel, and 0.988 million VND per month per member, respectively.

5.1.3 Policy implications

Based on the production frontier analysis for the sample gillnet vessels in 2009, it can be said that the majority of gillnet vessels have a potential for improving efficient performance, although some observed vessels were found to be highly efficient which operate close to the efficient frontier. In theory, on average, the sample vessels could have increased their 2009 per-month gross revenue about more than 32% by operating at full technical efficiency. This seems quite reasonable in the short-term, and can be done by increasing the level of fishing effort (i.e. employing a longer gillnet length, increases the level of variable costs). However, in the long-term, these productivity gains may not exist in reality as the addition of more fishing effort would cause a negative influence on resource stocks. Thus, is it possible to avoid a decline in stocks for the Da Nang gillnet fishery in the long-run (allow the stock to recover)? The fact is that middlemen are the ones that normally control the output prices instead of the fishermen who have little control over the prices that they receive. Otherwise, the vessel's revenue is mostly improved by increasing the landings at a higher level of technical efficiency. Therefore, there may exist in potential for increasing revenue without increasing the vessel's landing harvested by applying suitable fish-market systems and improving catch preservation methods in order to get higher price for the fish catch.

The estimates of technical inefficiency may also provide some helpful information for improving the performance of the Da Nang-based gillnet vessels. For example, the vessel owners could increase the gross revenue by helping many crew members to contribute some gillnet sheets in order to encouraging them working harder and more responsibilities for the vessel's operation. On the other hand, the technical efficiency of the gillnet vessels is also expected to increase if the owners operate lager vessels (i.e. higher engine power), given that everything else remains the same. Furthermore, the owners may improve vessel efficiency by operating their vessel by themselves or employing their relatives to work as a captain.

The estimated marginal productivities of inputs for gillnet fishery production may provide some useful ideas for fisheries managers in formulating management and regulatory policies. For instance, the gillnet vessels could benefit by using more variable costs and/or employing a longer gillnet length. The result also suggests that the gillnetters would benefit from adding more crew members.

5.2 Conclusions

This study conducts a research on assessing the technical efficiency based on the cross-sectional survey of costs and earnings of a sample of Da Nang-based gillnet vessels operating in 2009. The average monthly revenue and input use, as well as technical and operational characteristics of the sample gillnet fishery were examined by applying a translog stochastic production frontier, including a model for the relevant vessel- and operator-specific technical inefficiency. Moreover, some other aspects of this study, which are considered as important determinants, were also investigated, such as output elasticities, marginal productivities of variable costs, crew size, and total length of the gillnets, and scale efficiency.

The results from the frontier analysis clarify that the technical inefficiency effects are considerably significant in explaining the levels of and variation in vessel revenues. The technical efficiency score ranged from 0.55 to 0.98, with the mean equal to 0.76. Some relevant vessel- and operator-specific variables were found to be key factors influencing technical efficiency, such as engine power, vessel age, and number of net-contributors. A vessel with bigger engine power tends to be more efficient than those vessels which have less engine power. Vessel age also has a strong negative influence on technical efficiency, meaning that newer vessels seem to operate more efficiently than the older vessels. Gillnet vessels with more net-contributors would tend to have relatively more efficient gains than those vessels with fewer contributors.

The results of this study also indicate that a sample of Da Nang gillnet fishery production was characterized by increasing returns to scale. Thus, in theory, this sample of gillnetters could increase their average monthly gross revenue by more than 32% in 2009 by operating at full technical efficiency. The estimates of marginal productivities of inputs also suggest that it is economical for those gillnet vessels using more variable costs or fishing with a longer gillnet length, and/or by adding more crew members.

Since this study relies on a cross-sectional survey (in 2009) of the sample gillnet fishery, meaning that only a single observation per vessel has been examined. Thus, the efficiency analysis based on this data could also subject to problems that may make the results from stochastic production frontier analysis less than desirable (biased estimates of technical efficiency). In addition, the choice of input measurements used in the estimated frontier models may also be subject to problems and may bias the estimated results. Moreover, although this study has used reliable data (a true record) of total variable costs and cross revenue per month by each vessel from fishermen's logbook records. However, various relevant information about socio-economic factors of fishermen (i.e. fishing experience, education levels), as well as the main technical and operating characteristics for each vessel are very difficult to obtain exactly by face-to-face interviews; due to that the literacy and cognition of most fishermen is relative low with the limited time and financial constraints of this study. On the other hand, the estimation of the production frontier in this case requires strong distributional assumptions on the error components in order to separate the stochastic (statistical noise) and inefficiency effects in the model. In fact, however, the reliability of those assumptions has not been well documented. Therefore, further work is recommended to improve the gillnet efficiency estimation by collecting more data (panel data) with higher numbers of gillnet vessels in the sample. In addition, a suitable logbook should be designed and provided to all fishermen by the fisheries management authorities in company with training activities that are essential to all skipper. This is a very important database for both fisheries managerial systems and research purposes, because of the present logbooks just mainly focus on variable costs and total gross revenue data while various other important information are not available.

In other words, this study also could not determine the effects of the availability of fish stocks, on-board technology including equipment used, and seasonal variation on the performance of the gillnet vessels because of this information was not available or because of the a lack of adequate observations in the sample. Allocative and scale efficiencies are also considered as important issues in fisheries management, however, these topics have not been included in this study because of data constraints. Thus, further studies should be undertaken to evaluate these aspects for the Da Nang gillnet fishery in coming time.

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APPENDICES

Appendix 1

Figure 1. The illustration of fishing grounds for the Da Nang's gillnet fishery

Note: The yellow colour areas presenting the fishing grounds which mainly catch mackerel species (50-60%) while, the red areas are the fishing grounds for tuna in primarily (60-70%); V. BAC BO (in Vietnamses)= The Tonkin Gulf (in English); Q.Đ. HOANG SA=The Paracel Islands; Q.Đ. TRUONG SA=The Sparatly. The fishing ground information present here that cited as own data.

Appendix 2

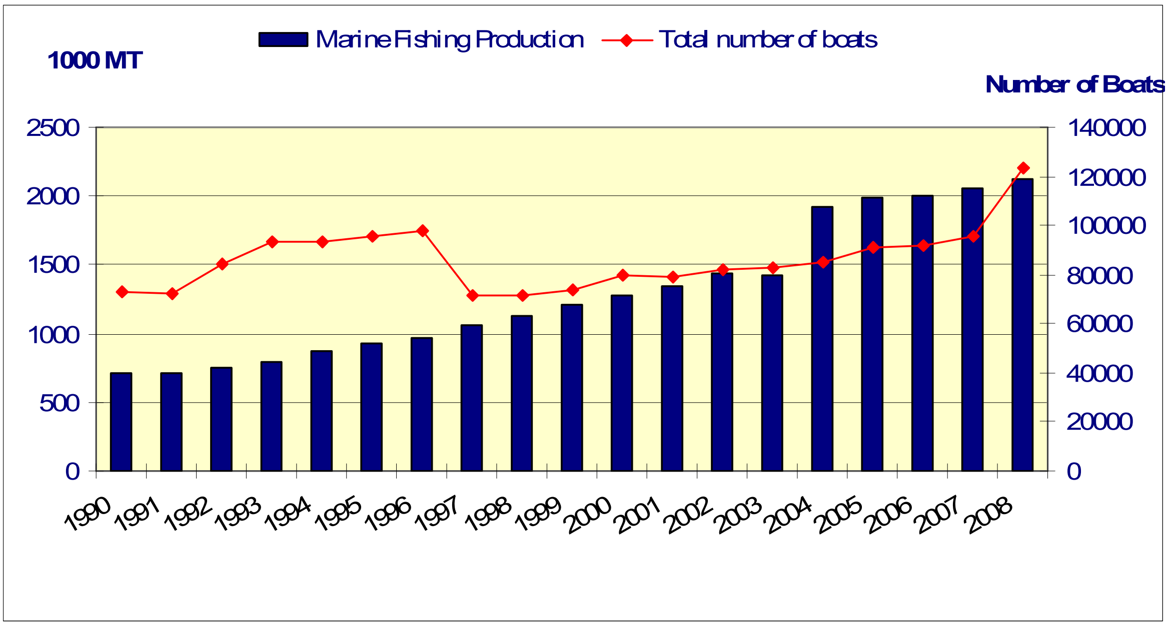
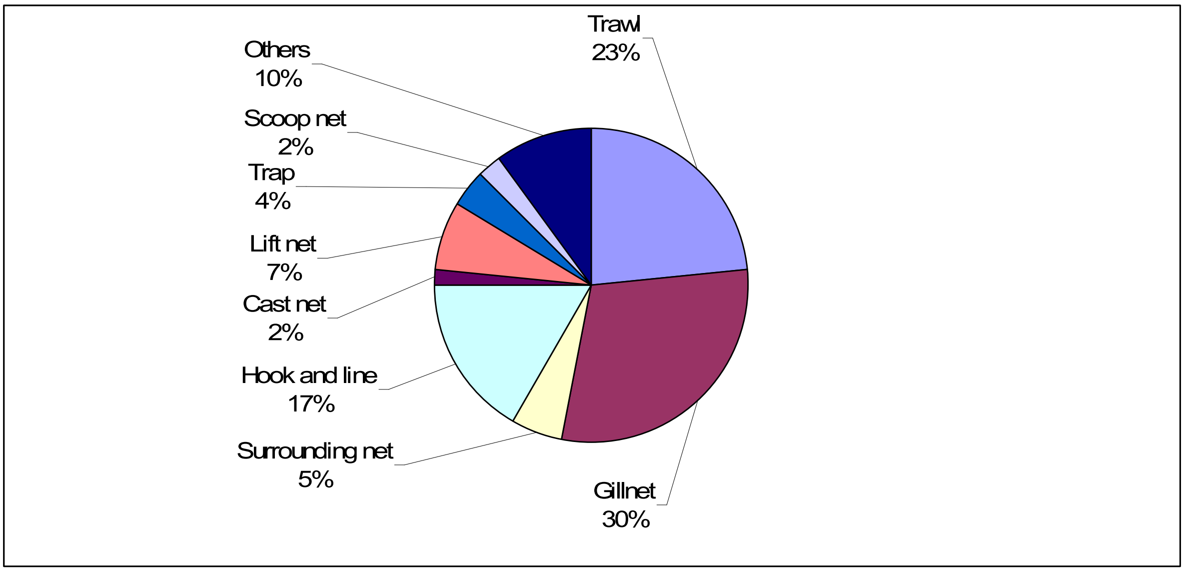
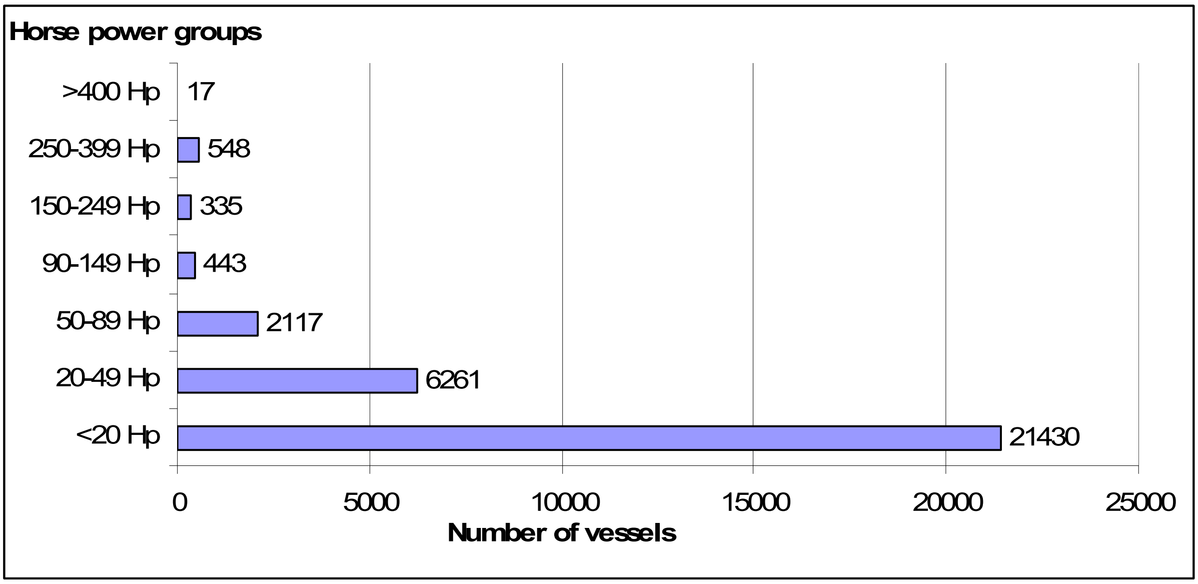


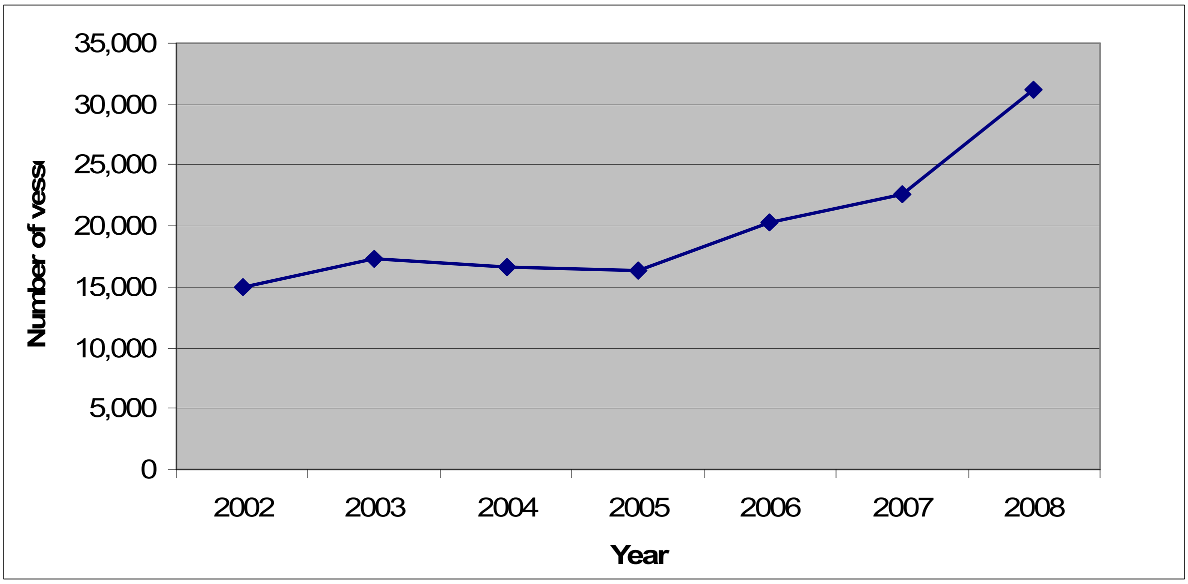
Figure 1. Trends in marine capture fisheries and number of fishing boats (1990-2008)



(*a*)



(*b*)



(*c*)

Figure 2. The proportion of Vietnam's fishing fleets by fishing gears (*a*), number of gillnet vessels by horse power groups (*b*), and trends in number of Vietnam's gillnet fleet (2002-2008) (*c*)

Note: Figure 1-Figure 2, cited as Chien (2010). The reference year of the data related to (*a*) and (*b*) is the year 2008.

Appendix 3. Summary statistics of the data

Vessel and fishing characteristics	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Vessel length (meters)	18.15	1.27	14.80	21.00
Vessel age (years)	5.52	3.66	1.50	16.00
Engine power (horse power)	140.20	86.90	37.00	360.00
No. of net sheets (sheets)	294.00	32.01	200.00	360.00
Crew size (persons)	9.88	0.92	8.00	12.00
Skipper age (years)	43.14	8.44	28.00	60.00
Experience (years)	16.64	9.98	2.00	38.00
Net-contributor (persons)	6.08	2.34	1.00	11.00
No. of operating months (months)	10.22	0.82	8.00	12.00
Average monthly days fished (days)	17.62	2.42	11.00	22.00
No. of trips per year (trips)	12.78	3.99	9.00	20.00
Average annual revenue	868.089	237.150	275.732	1379.314
Average annual variable costs	380.951	102.236	157.792	656.691
Average annual Income	487.138	170.390	58.236	908.221
Average monthly revenue	84.653	21.645	27.573	125.844
Average monthly variable costs	37.340	10.046	19.724	65.669
Average monthly income	47.313	15.372	5.824	79.739
Total capital investment	1260.600	470.069	250.000	2200.000
Repair/Maintenance expenses	56.840	30.559	24.000	190.000
Number of total observation	50			
Number of vessels: <17 meters	7	(14%)		
Number of vessels: 17-19 meters	29	(58%)		
Number of vessels: >19 meters	14	(28%)		
Number of skippers with:				
No schooling	12	(24%)		
Primary schooling	24	(48%)		
Secondary schooling	14	(28%)		
Number of owner-operators	25	(50%)		

Note: All economic values are in million VND

Appendix 4. Correlation between output (real revenue) and potential inputs for Da Nang gillnetters

	Output (real value)	Variable costs	Crew size	No. of net sheets	Large vessel	Medium vessel	Engine power	Vessel age	Net-contributor	Experience	Education	Owner-operated
Output (real value)	1.00											
Variable costs	0.77	1.00										
Crew size	0.43	0.51	1.00									
No. of net sheets	0.59	0.42	0.47	1.00								
Large vessel	0.35	0.43	0.47	0.34	1.00							
Medium vessel	-0.09	-0.19	-0.20	-0.02	-0.73	1.00						
Engine power	0.39	0.46	0.41	0.25	0.19	-0.09	1.00					
Vessel age	-0.17	-0.16	-0.02	-0.15	-0.19	0.05	-0.27	1.00				
Net-contributor	0.58	0.30	0.25	0.21	na	0.13	0.07	0.11	1.00			
Experience	-0.01	-0.05	0.15	0.23	0.05	0.03	0.04	-0.32	0.09	1.00		
Education	-0.09	-0.05	-0.07	-0.12	-0.17	0.23	0.01	0.31	-0.14	-0.42	1.00	
Owner-operated	0.21	-0.16	na	0.29	na	-0.04	0.13	-0.08	0.35	0.23	-0.23	1.00

Note: na= Not available

Appendix 5. Frequency distribution of technical efficiency scores

Range	Total	Crew size	Fishing experience (years)	Captain education			Owner-Operator		Net-Contributor (persons)	No. of Vessels in size			Vessel age (years)	Engine power (Hp)
				None	Primary	Secondary	Yes	No		Small	Medium	Large		
0.90-0.99	10	10.10	13.70	3	5	2	7	3	8.00	0	6	4	4.3	181.80
0.80-0.89	7	10.00	24.29	1	6	0	5	2	7.29	1	3	3	6.07	155.00
0.70-0.79	15	10.00	13.13	3	5	7	6	9	6.00	3	7	5	5.17	140.07
0.60-0.69	13	9.00	18.06	4	4	5	4	9	5.15	1	10	2	6.77	117.62
0.50-0.59	5	9.20	15.80	1	4	0	3	2	3.40	2	3	0	5.00	95.40
Mean technical efficiency				***0.76***	***0.74***	***0.74***	***0.76***	***0.73***		***0.70***	***0.74***	***0.77***		

Notes: - Measures are in terms of efficiency and not inefficiency.

- Vessel size is categorized by hull length: Small (<17 m); Medium (17-19 m); and Large (>19 m).
- The contribution of net of crew members in persons.

Appendix 6. Comparison of some main technical characteristics and economic performance indicator among gillnet vessels operating in Da Nang City and Nha Trang City

Variable	*Gillnet vessels operating in Nha Trang City*				*Gillnet vessels operating in Da Nang City*			
	Mean	**S.D.**	**Min.**	**Max.**	**Mean**	**S.D.**	**Min.**	**Max.**
Hull length (meters)	16.3	1.2	13.5	19.0	18.1	1.3	14.8	21.0
Engine power (Hp)	125.7	85.2	37.0	350.0	140.2	86.9	37.0	360.0
Vessel age (years)	8.3	4.1	2.0	18.0	5.5	3.7	1.5	16.0
Number of gillnet sheets (sheets)	235.9	41.1	130.0	300.0	294.0	32.0	200.0	360.0
Total capital investment	989.45	-	-	-	1,260.60	470.06	250.00	2,200.00
Average annual variable costs	556.95	155.30	262.10	1,111.20	380.95	102.24	157.79	656.69
Average annual gross revenue	851.33	280.30	311.50	1,920.00	868.09	237.15	275.73	1,379.31

Note: All economic values are in million VND

Appendix 7. Summary output of the stochastic production frontier analysis using FRONTIER 4.1 (Coelli, 1994) for the Da Nang-based gillnet vessels

The final mle estimates are :

	coefficient	standard-error	t-ratio
beta 0	-0.10634655E+03	0.22664447E+01	-0.46922192E+02
beta 1	0.81951406E+00	0.23278612E+00	0.35204594E+01
beta 2	0.10209578E+02	0.35660338E+00	0.28630064E+02
beta 3	0.33964865E+02	0.90550100E+00	0.37509473E+02
beta 4	-0.46242425E+00	0.20557831E+00	-0.24439555E+01
beta 5	-0.25144397E+01	0.18034519E+00	-0.14607762E+02
beta 6	-0.26836888E+01	0.17659074E+00	-0.15327467E+02
beta 7	0.18622777E+01	0.58166649E+00	0.32016246E+01
beta 8	-0.18140616E+00	0.55568932E+00	-0.32645249E+00
beta 9	-0.93200857E+00	0.67219743E+00	-0.13865102E+01
delta 0	0.96450235E+00	0.18942375E+00	0.50917709E+01
delta 1	-0.28102267E-01	0.65263317E-01	-0.43059820E+00
delta 2	-0.15783786E-01	0.66621288E-01	-0.23691806E+00
delta 3	-0.92840438E-01	0.41323578E-01	-0.22466699E+01
delta 4	0.57482388E-01	0.30543024E-01	0.18820136E+01
delta 5	-0.25421156E+00	0.40097011E-01	-0.63399129E+01
delta 6	0.58348543E-01	0.28931164E-01	0.20168059E+01
delta 7	0.26374552E-01	0.49219530E-01	0.53585542E+00
delta 8	-0.55455568E-01	0.42829960E-01	-0.12947845E+01
Sigma-squared	0.10521417E-01	0.19091165E-02	0.55111447E+01
gamma	0.78090628E+00	0.81430875E-01	0.12045877E+02

Log likelihood function = 0.46201345E+02

LR test of the one-sided error = 0.35201665E+02

Technical efficiency estimates:

firm	year	eff.-est.
1	1	0.54553691E+00
2	1	0.57267912E+00
3	1	0.65038208E+00
4	1	0.57130856E+00
5	1	0.62503882E+00
6	1	0.63815238E+00
7	1	0.61428127E+00
8	1	0.56157821E+00
9	1	0.68338441E+00
10	1	0.66919613E+00
11	1	0.68414566E+00
12	1	0.76446311E+00

13	1	0.61079993E+00
14	1	0.59480024E+00
15	1	0.70850825E+00
16	1	0.63826476E+00
17	1	0.65604631E+00
18	1	0.71828909E+00
19	1	0.68444095E+00
20	1	0.64608986E+00
21	1	0.98207128E+00
22	1	0.70564992E+00
23	1	0.70082177E+00
24	1	0.76886996E+00
25	1	0.68852602E+00
26	1	0.78690859E+00
27	1	0.74933935E+00
28	1	0.91676819E+00
29	1	0.75005292E+00
30	1	0.76299383E+00
31	1	0.81307230E+00
32	1	0.77129446E+00
33	1	0.89926718E+00
34	1	0.79124904E+00
35	1	0.76591583E+00
36	1	0.74383329E+00
37	1	0.87525118E+00
38	1	0.79796850E+00
39	1	0.77205621E+00
40	1	0.85763944E+00
41	1	0.84256142E+00
42	1	0.83944547E+00
43	1	0.91435506E+00
44	1	0.88231617E+00
45	1	0.92446470E+00
46	1	0.95519962E+00
47	1	0.95936371E+00
48	1	0.97652417E+00
49	1	0.92775774E+00
50	1	0.92472331E+00

Mean efficiency = 0.75767293E+00