A Stochastic Frontier Model to Determine Technical Efficiency of the Purse Seine Fishery in the Gulf of Cádiz (Spain)

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Abstract. In this paper we analyse different econometric procedures of technical efficiency to estimate fishing capacity. These procedures are then applied to the purse seine fishery located in the Gulf of Cádiz. The target species of this fishery has changed quite a lot over the past few years. It used to be mackerel (Scomber spp.). Afterwards, it was anchovy (Engraulis encrasicholus) and, recently, sardine (Sardina pilchardus). The regulation of anchovy and sardine fisheries by European Union is only based on Total Allowable Catch for vessels which are longer than 10 metres. This management measure could be unsuitable in this fishery for two reasons. Firstly, most of the vessels measure less than 10 metres and, secondly, there is a small interrelation between vessel efficiency and length.

Keywords: stochastic frontiers, fishing capacity, panel data, purse seine fishing, Gulf of Cádiz, management policies.

1. INTRODUCTION

Fishing Effort is crucially important since a biological point of view. However, its definition does not usually appear in papers and it is almost always quite different depending on the type of fishery and the objective of the study. Most of the recent theoretical contributions support the definition of Fishing Effort which considers it as a multiplicative combination of Fishing Power, generally interpreted as a combination of productive inputs, and Activity, generally measured by time, which represents the intensity of fishing in a certain area [Beverton & Holt (1957)].

Until 1970s, optimal management models which were based on Optimal Control Theory[2] used as control variable catch rate instead of Fishing Effort which was eliminated from the analysis or substituted for other variables in the catch equation of Schaefer´s model. Consequently, this has had important negative effects on the proposal of management measures, since it provokes overcapitalization and economic rent dissipation.

Recently, the concept of Fishing Capacity, related to the concept of Fishing Effort, has appeared in fisheries literature. In economic literature, Fishing Capacity is generally more related to potential output (capacity-output) than production inputs (capacity-input). Nonetheless, the latter (capacity-input) is the most interesting for this paper. This meaning is widespread in fisheries literature. Accordingly, Fishing Capacity is *the maximum available capital stock in a fishery that is fully utilized at the maximum technical efficiency in a given time period given resource and market conditions*[3]. This concept is equal to the concept of Fishing Power.

In fact, the main problem associated with fisheries concerns a surplus of Fishing Capacity because of open access or regulated open access, which provokes the dissipation of economic rent and/or resource overexploitation. For this reason, plenty of states and international organizations usually try to measure the consequences of this problem and sort it out by means of legislation.

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[1] Contact e-mail: hoyo@uhu.es
[2] See Crutchfield and Zellner (1962) or Fullenbaum et al. (1971).
[3] Kirkley and Squires (1999), page 73.

European fisheries management is governed by the Common Fisheries Policy (CFP). Conservation Policy, oriented to protect fish resources, is the centre of CFP and it focuses on annual Total Allowable Catch (TAC) for some species. This policy is complemented by the Estructural, Control, Markets and External policies and all of them are part of CFP. The application of CFP is possible thanks to the European Union (EU) aid and Multi-Annual Guidance Programmes (MAGP) of the Estructural Policy[4].

In MAGP each Member State analyses its fleet evolution for the following four years. When MAGP are approved, all Member States are obliged to fulfill them. MAGP pose aims related to the reduction of Fishing Effort and consecuently Fishing Capacity. According to EU regulations, the Fishing Effort exerted by a vessel is the multiplication of the number of fishing days (Activity) by its Fishing Capacity (Fishing Power), which is measured by means of Gross Registered Tons (GRT) and/or engine power [in Horse Power (HP)] depending on the kind of gear[5].

2. MEASURING OF FISHING POWER OR FISHING CAPACITY

In the previous section, we have mentioned that Fishing Power can be interpreted as a composed variable of fishing production inputs, and Fishing Effort is the multiplication of Fishing Power by Activity (fishing time). Fishing Power and input oriented Fishing Capacity are synonyms.

In relation to fisheries management, it is very important that Fishing Capacity should be properly measured. In a fishery subject to biological restrictions, the amounts of capital, labour and other production inputs can be determined by maximising the net flow of social benefits. If the current inputs are compared with their optimal amounts, plans can be established in order to reduce the Overcapacity. This section therefore focuses on studying in detail some methodologies which can measure Fishing Capacity and Fishing Effort.

Differents mathematic and/or econometric techniques have started to be widely applied by fisheries economists to measure Fishing Capacity. In particular, it is worth pointing out techniques such as the Stochastic Frontier Analysis (SFA) and nonparametric models such as Data Envelopment Analysis (DEA). In this section, we briefly intend to sum up production function theory. Next, we show the link between the concepts of Fishing Capacity and Technical Efficiency. Finally, we focus on SFA as technique to measure Fishing Capacity.

2.1. Fishing Effort and Production Function

A fishing production function can be defined as a function which indicates the maximum capture which a vessel can attain at each moment in relation to fishing production inputs as shown in (1), where S_t denotes the Exploited Fish Stock at the moment *t*, W_{it} is the Fishing Power (Fishing Capacity), E_{it} is the Fishing Effort, T_{it} represents the Activity (fishing time) of the i-th vessel at the moment t and g(.) represents the Fishing Effort exerted by a vessel in the period considered.

$$h_{it} = f(E_{it}, X_t) = f[g(T_{it}, W_{it}), S_t] \quad (1)$$

It is apparent that each vessel output can be changed by modifying any input and remaining the rest inputs constant. Each vessel should use the most efficient production technique so that it does not incur unnecesary production costs. In the case of fisheries, there is an input which is not under the fishermen's control, namely, the Exploited Fish Stock (S_t). As seen above, in fisheries modelling literature, two production inputs are only considered: Fishing Effort and Exploited Fish Stock. While the latter has a straightforward interpretation (the higher the stock density is, the more catch is yielded), the former has a difficult determination and interpretation.

In principle, Fishing Power should result from an appropiate combination of all production inputs. To estimate production functions like (1), cross section data, time series data or a combination of both types of data can be used[6]. For cross section data, we should formulate some hypotheses on the stock distribution in the fishery because stock is an unobservable variable. Stock is usually assumed to be the same for all vessels and all net

[4] See Jensen (1999), Council Regulation (EEC) No 3970/92, Council Regulation (EEC) No 1263/99 and Council Regulation (EEC) No 2847/93.
[5] Council Regulation (EEC) No 685/95.
[6] See Hanesson (1983), Campbell (1991) or García et al. (1998, 2001).

throws in the period of time considered. This hypothesis can be sometimes plausible, but it can be completely erroneous as well.

In contrast, for time series data there should be information available about the stock evolution or techniques which can statistically treat this input. Finally, panel data models are interesting because they can estimate stock as a different fixed effect for each period but equally for each vessel at each moment. Additionally, stock can be estimated directly.

2.2. Technical Efficiency and Fishing Capacity

The first approximations of the efficiency problem are found in Farrell's paper (1957) in which some radial efficiency indicators are proposed. Farrell made two very important contributions. Firstly, an empirical method is proposed to compute these indicators by means of the comparision of the output in the production frontier and the effective output of a certain firm and, secondly, defines Economic Efficiency as a combination of two components: Technical Efficiency, which is defined as the ability of a firm to obtain tha maximum output given a set of production inputs, and Allocative Efficiency, which is defined as the ability of a firm to combine its inputs in optimal proportions.

In this sense, Tecnical Efficiency measures proposed by Farrell (1957) coincide with the definition of Relative Fishing Power proposed by Beverton and Holt (1957, 172-73). This refers to the *ratio of the catch per unit fishing time of a vessel to that of another taken as standard and fishing on the same density of fish on the same type ground*, provided that technical efficiencies of all vessels are compared with the standard efficiency. Therefore the applicability of the methods designed to measure efficiency is direct for these kinds of problems. Hence, Technical Efficiency can be considered as a measure of Relative Fishing Capacity.

In order to determine Farrell's efficiency measures, the production function of the completely efficient vessel should at least be known. However, this hypothesis is not realistic. In order to solve these problems, two large groups of techniques which measure Technical Efficiency can be mentioned. Firstly, there are parametric procedures which are based on econometric models. They can be directly applied to the type of problems we are analysing. Secondly, there are nonparametric techniques which are based on mathematical programming methods. In particular, DEA and Free Disposal Hull (FDH) should be highlighted.

Parametric techniques consider a functional form which comes from the technological characteristics of the production process. These techniques estimate parameters beginning with the selected sample. Frontier models are classified into deterministic and stochastic models. Deterministic Frontier Analysis considers that any deviation from the frontier is produced by inefficiency. On the other hand, SFA distinguishes two components in the deviation from the frontier: an ineffiency component and a random component.

Nonparametric techniques do not require a certain functional form. It is enough to define certain formal properties which should verify the points of the production set. These properties could be free availability of inputs and outputs and, sometimes, constant returns to scale or the condition of convexity. In these cases, data are enveloped in a frontier under the above properties. These techniques are not stochastic which is an important drawback because of the stochastic nature of fishing.

2.3. Stochastic Frontier Analysis

SFA was developed originally by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). They consider that deviations of producers from the frontier are not exclusively caused by situations which could be under the control of the implied producers, which provokes differences in efficiency. In contrast, a random component which is different from the technical inefficiency exists. If we consider the logarithm of Coob-Douglas production technology, the so called composed error model, can be written as shown in (2).

$$LnQ_{it} = \alpha + \beta \ln x_{it} + \varepsilon_{it} = \alpha_{it} + \beta \ln x_{it} + v_{it} - u_{it} \qquad (2)$$

where u_{it} represents the random error which is asymmetric and nonnegative ($u_{it} \geq 0$), whereas v_{it} is not subject to any restriction. In principle, both random errors can be distributed in different ways. v_{it} is usually Normal distributed, with zero mean and constant variance, whereas the distribution for u_{it} is assumed to be truncated or very asymmetric. There are no a priori reasons to prefer some specific type of distribution on the inefficiency errors. However, different simulation exercises carried out by Greene (1990) indicate that the most straightforward model (i.e. half normal) is preferrable to other models from an econometric point of view[7].

In (2), subscript i refers to each producer and the second subscript t refers to the moment in which that observation was produced. If the subscript t is eliminated from (2) we have a cross section data model. If it is not eliminated we have a panel data model. When u_{it} and v_{it} are independent, the use of panel data models is then irrelevant.

The estimation procedure depends on the kind of data used. Cross section data and panel data models can be estimated by Maximum Likelilihood (ML). In the case of panel data is possible to consider time-invariant or time-variant Technical Efficiency, or to incorporate a technology change. Panel data models can be also estimated by Least Squares with Dummy Variables (LSDV) or the Fixed-Effects Model, Generalized Least Squares (GLS) or the Random-Effects Model, or by Hausman-Taylor estimator (HT)[8].

Models used to estimate statistically the technical inefficiencies have been widely applied in different industrial sectors[9]. Nonetheless, there are only a few applications in fisheries. Kirkley et al. (1995) applied SFA to the scallop fishery in the coast of New England and Virginia, obtaining interesting results to implement management models. Likewise, Sharma and Leung (1998) established a model for the industrial fishery of pelagic long-line. Recently other papers have been published by researchers from CEMARE at the University of Portsmouth such as Pascoe and Coglan (2000), Pascoe et al. (2000) and Pascoe et al (2001). All these papers are concerned with fisheries located in the English Channel. It is also very interesting the paper by Lindebo (2001) which is about the Danish cod-fishing fleet. Finally, Álvarez and Orea (2001) try to apply these techniques in multi-species fisheries.

3. APPLICATION TO THE PURSE SEINE FISHERY IN THE GULF OF CÁDIZ

Purse seine is a fishing method capable of harvesting large quantities of surface-schooling pelagic fish by surrounding the school with a net. A line which passes through rings on the bottom of the net can be tightened to close the net so that the fish are unable to escape. In general, the purse seine fleet should have at least 20 GRT. The mesh size, which has to be wet and used, should measure at least 14 milimetres. Fishing gears can not be more than 450 metres long and 80 metres high. Although there is a specific census which includes the authorised vessels in the purse seine fishery, temporary licences could be issued to other vessels according to Fishing Plans yearly passed by Secretaría General de Pesca Marítima[10]. This fishing gear is designed to catch middle and small-sized pelagic species which compose large shoals of fish. In the Gulf of Cádiz the target species are the anchovy (*Engraulis encrasicholus*), the sardine (*Sardina pilchardus*), the mackerel (*Scomber spp.*) or the horse mackerel (*Trachurus trachurus*).

The purse seine fleet whose usual ports are in the Gulf of Cádiz can be divided into two groups. The first group comprises vessels which are included in the purse seine census. These vessels are single-gear and have quite different sizes. They are concentrated in the ports of Barbate, Punta Umbría and Isla Cristina. Vessels located in Barbate are large-sized and they also fish in Moroccan waters. However, in our study we have only taken into account trips in EU waters. For this reason, we have excluded those vessels which have a license to fish in Moroccan waters. Vessels from other ports only fish in the Gulf of Cádiz, namely, from the Strait of Gibraltar to the cape San Vicente.

The second large group consists of multi-gear vessels. This group comprises trawl and/or artisanal fishing gear vessels, which are given a temporary purse seine license. There are two kinds of fisheries for this type of vessels: the anchovy fishery, which is overexploited, or other pelagic species fisheries (i.e. sardine and mackerel). Actually, vessels which are included in this group are almost always devoted to fish mackerel.

In order to estimate these models, we have selected a balanced panel data. They consist of trips undertaken by fourteen vessels of the fleet which were fishing during the summer seasons in 1998 and 1999. Apart from these vessels, there were logically other fishing vessels in this period of time, but they did not work throughout the

[7] See Kumbakhar and Lovell (2000), pp. 90-91.
[8] See Álvarez (2001), pp. 41-76.
[9] See Harris (1992) or Battese and Coelli (1988).
[10] Secretaría General de Pesca Marítima is a government organization depending on the Ministry of Agriculture, Fisheries and Food.

whole of the two summer seasons. For different reasons, they only worked in certain periods of time. As 80% of this small fleet has been substituted by new-built vessels in the year 2000, we have not taken into account this year. Likewise, year 1997 has not been considered because there was no available information.

In addition to the above trips regarding the purse seine fleet, we have also selected trips in which sardine and, to a lesser extent, the anchovy were the target species. We have not taken into account trips in which mackerel was the target species because this fishing activity was exclusively developed by trawl vessels with temporary licenses. As long as these vessels did not reach 20 GRT required by the Spanish Royal Decree 7349/1984, they could not be included in the purse seine census only until 1997, when legal requirements were changed.

The increase in the sardine catch showed in Table 1, has been caused by changes in the exploited stock density and the national market demand. Mackerel is caught because large shoals of this fish appear in the Gulf of Cádiz during summer seasons. This stock was quite high until 1993, and subsequently a gradual stock reduction has ocurred until 1998. This reduction is caused by the significant dependency between recruitment and weather conditions in the spawning season. This issue has been analysed by our research group in depth.[11]

Furthermore, changes in the mackerel fishery have coincided with the collapse of the sardine fishery in the Spanish North-East region (Galicia) and the increase in the sardine catch in the Gulf of Cádiz. Sardine stock has possibly moved southwards due to changes in ocean currents and isotherms which these species follow when they migrate[12].

As sardine catches have sharply fallen in Galicia, its average price has increased in the national market. This has provoked the fishery consolidation in waters of the Gulf of Cádiz.

Table 1. Composition of fleet landings

SPECIES	1998			1999		
	Metric Tonnes	Thousands of Euros	Euros/Kg.	Metric Tonnes	Thousands of Euros	Euros/Kg.
Anchovy	89.1	228.33	2.56	13.9	31.80	2.28
Mackerel	12.5	4.06	0.32	9.8	6.43	0.66
Sardine	282.4	393.87	1.39	362.8	432.99	1.20
Other	80.0	32.49	2.12	15.5	24.45	1.58
Total	399.4	658.75	1.65	402.0	495.67	1.23

Source: Ex-vessel markets in Huelva and Punta Umbría

In order to carry out the fishery analysis, we have used data corresponding to catches of purse seine vessels, as sold in the ex-vessel markets in Huelva and Punta Umbría during 1998 and 1999. Yearly we have only considered catches of the eight weeks with the highest production, that is, July and August. We have exclusively chosen those vessels which were fishing during the whole period of time so as to work with a balanced data panel. The time frequency of data is weekly. As we have daily data, we have added all observations corresponding to each week. Therefore, total catch of the fleet was equal to 399 Metric Tonnes (MT) in 1998 and 402 MT in 1999. Due to the similarity between figures, we can state that this fishery is relatively stable in this period. Table 1 displays catch distribution and prices by species. It is worth noting that our sample represents between 50% and 60% of total landings during summer seasons.

Average daily catch per vessel was equal to 543.2 Kg. in 1998 and the average daily revenues per vessel were 908.38 Euros. In 1999 sardine prices sharply decreased. Despite the fact that the average daily catch per vessel grew slightly (549.5 Kg./day), average daily revenues per vessel were 707.33 Euros.

[11] González Galán (2001).

[12] The last ICES report points out this phenomenon for the first time. It is interesting to note that spatial changes in the distribution and a change towards older age stock in the exploitation model in south areas are being observed [ICES (2001), section 9.1.].

The information about production inputs has been collected from the Census of Operative Fleet provided by the Secreataría General de Pesca. In addition, we have also used lists of crew members given by the Social Security. We have considered vessel characteristics (GRT, GT, engine power, length, building year) as fixed inputs. On the other hand, we have used the number of fishing days and crew members as variable inputs.

Similarly, we have taken into account other variables such as the presence of the shipowner among crew members, the nominal fishing gear of each vessel, materials used for the vessel hull (wood or polyester) or the fact that the vessel has recently been regauged. These variables were included in models by means of dummy variables. None of them was statistically significant. Correlation between size variables is very high; the linear correlation coefficient between GRT and GT is 0.91, whereas correlation between these variables and length is lower (0.66 with GRT and 0.75 with GT). As a result, if all these variables were included in the models, multicollinearity would appear. Fishing days, crew members, vessel age or engine power are less correlated among themselves. Finally, their correlation is much lower with size variables as well.

3.1. Functional Form of Production Function

According to the methodology described in García et al. (1998, 2001), a series of linear restrictions have been tested on a flexible translog function. These hypothesis tests provide enough information about the properties of the fishery production function. Regarding vessel size variables, we have only considered GRT as input. Once we have included GRT in the model, neither GT nor length were significant.

Table 2. Critical values for 1998 and 1999

Estimate Translog Function	1998			1999		
	F statistic	Degrees of freedom	Critical value	F statistic	Degrees of freedom	Critical value
Homogeneity	1.60	3;112	3.97	0.41	3;112	3.97
Constant scale returns	21.77	4;112	3.51	11.26	4;112	3.51
Global separability	2.83	6;112	2.98	1.22	6;112	2.98
Unitary elasticity of trips	2.48	7;112	2.81	1.29	7;112	2.81

Engine power is not significant as well. It is worth pointing out that engine power is not too important for purse seine vessels. However, to a large extent, this fishing gear is labour-intensive. As a result, the number of crew members was included in models and was significant. Finally, the number of fishing days per week is also significant. Currently, it is the variable which best explains catch per week.

Results displayed in Table 2 allow us to accept the homogeneity hypothesis, to reject the hypothesis of constant returns to scale, to accept global separability and, last but not least, to accept unitary elasticity of trips. Consequently, a Cobb-Douglas functional form is the most appropiate. The logarithm of the production function can then be expressed as follows:

$$\mathrm{Ln}(\mathrm{Catch}) = \alpha_0 + \alpha_1 \mathrm{Ln}(\mathrm{FD}) + \alpha_2 \mathrm{Ln}(\mathrm{GRT}) + \alpha_3 \mathrm{Ln}(\mathrm{CM}) + \varepsilon \qquad (3)$$

where the output (catch) of the production function is the weekly catch per vessel. We have considered the weekly number of fishing days (FD), GRT and the number of crew members (CM) as independent variables. As a result, the sample consists of 112 observations. Hence, we have considered 14 vessels and 8 weeks per year.

3.2. Estimate of Technical Efficiency

As a Cobb-Douglas production function was the most appropiate for the fishery, we have determined efficiency measures. Several econometric techniques have been applied on 214 observations corresponding both years:

- Deterministic Frontier Model for cross section data estimated by Corrected Ordinary Least Squares (COLS)[13].

- Stochastic Frontier Production model for cross section data estimated by ML. It was considered a Half-Normal distribution for the asymmetric and non-negative error term (inefficiency term). Inefficiency terms were estimated by the procedures described in Jondow et al. (1982) [JLMS (1982)] and Battese and Coelli (1988) [BC (1988)].

- Fixed-effects model for panel data estimated by LSDV.

- Stochastic Frontier Production model for panel data estimated by ML. It was considered a Half-Normal distribution for the inefficiency term. Inefficiency terms were estimated by the procedure described in BC (1988).

Table 3. Panel data model estimated by ML

Dependent variable =		Ln (catch)	
Included observations =		224	
Variable	Coefficient	Standard Error	t-Statistic
Intercept	2.643	0.723	3.659
Ln (FD)	1.135	0.082	13.775
Ln (GRT)	0.918	0.237	3.881
Ln (CM)	0.621	0.128	4.851
λ^2	0.196	0.174	1.122
σ_u		0.348	
σ_v		0.376	
Log-L		121.773	

For cross section data, the Deterministic Frontier Model estimated by COLS provides much lower estimates of inefficiencies than the Stochastic Frontier Production estimated by ML, but vessels are sorted in the same way in relation to inefficiencies. Nonetheless, the BC (1988) efficiency indicator has more dispersion than the JLMS (1982) indicator and its average efficiency is a little bit lower. The stochastic frontier production model estimated by ML is nearly the same as the frontier production model estimated by COLS, except for the intercept. We expected this result due to the consistency of estimators.

Table 4. Average efficiencies according to several estimation procedures

	Mean	Standard deviation	Variation coefficient (%)
Deterministic frontier model	0.3092	0.1336	43.1910
Stochastic frontier model for cross section data [JLMS (1982)]	0.6668	0.2051	30.7623
Stochastic frontier model for cross section data [BC (1988)]	0.7516	0.0851	11.3768
Fixed-effects panel data model (LSDV)	0.8130	0.1265	15.5602
Stochastic frontier model for panel data [BC (1988)]	0.8691	0.0244	2.8076

[13] See Gabrielsen (1975).

For panel data, the variable GRT is not significant in the Fixed-effects model estimated by LSDV because it does not change for all the observations of each vessel and it would be highly correlated with the dummy variables, which determine the fixed effects. However, fishery is quite well explained by this model. After normalization, the fixed effects can be interpreted as the efficiencies of each vessel. As Schmidt and Sickles (1984), and Cornwell et al. (1990) have suggested, these fixed effects could be interpreted as a deterministic frontier panel data model.

With regard to the Stochastic Frontier Production model for panel data estimated by ML, shown in Table 3, efficiency indicators determined by the BC (1988) estimator are quite different from the results of the Fixed-Effects Model. This is caused by the scale change which is carried out when efficiencies are determined through the fixed-effects model. The incorrelation between error terms and the regressors have been tested by the Hausman and Taylor´s test (1981) concluding that ML estimation is preferible to the Fixed Effects Model for the panel data model. The Fixed-Effects Model sorts vessels in the same way as the aforementioned models. In addition, its dispersion is the lowest of all the indicators. Table 4 shows average efficiencies of the differents models estimated.

4. CONCLUSIONS

This methodology has allowed us to obtain Technical Efficiency indicators. These indicators represent somehow the Fishing Power of vessels. Each efficiency indicator could be used to represent the Relative Fishing Power. Additionally, if we multiply each efficiency indicator by the fishing time, the Fishing Effort exerted by a vessel could be obtained. By summing up all individual fishing efforts, we could determine the Fishing Effort exerted by the fleet.

It is apparent that our results are not definite. However, they at least indicate how the fishery production process should be interpreted. Fishing Power is determined by taking into account vessel characteristics. In purse seine vessels, GRT and crew members are especially important.

In the future, additional changes in models should be carried out to take account of possible changes in technology and vessel characteristics. For bottom trawl fleet, multi-species production functions appear to be the best approach because it is difficult to determine only one target species for each type of trip.

The regulation of anchovy and sardine fisheries by EU based on Total Allowable Catch (TAC) for vessels which measure more than 10 metres is inappropiate in this fishery because there is a small interrelation between vessel efficiency and length (the only vessel in the sample that is less than 10 meters is the most technically efficient) and, secondly, most of the vessels measure less than 10 metres.

We have observed that when the usefull life of vessels increases, Technical Efficiency decreases. What that means is that efficient vessels, which are more profitable, invest their capital in renovating the vessel before the less technically efficient vessels in our sample of data. The Pearson´s correlation coefficient was calculated and it was around –86%.

Finally, nonparametric techniques such as DEA can be interesting when stochastic characteristics of the fishing production process could have been determined suitably.

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