MICROECONOMIC INFLUENCE OF MARINE ENVIRONMENT CONDITIONS ON RED SEABREAM FISHERY OF THE STRAIT OF GIBRALTAR

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ABSTRACT

This paper is aimed at determining the impact of the variability of marine environment conditions on the capture of a vessel that exploit the red seabream fishery of the Strait of Gibraltar. This paper estimates first and second order elasticities of a Translog approximation of a Stochastic Distance Functions of multiple outputs assuming time unvarying technical efficiency in order to get this aim. The evidences that sea surface temperatures have influence on growth and maturation and on the development of hermaphroditic gonads of different kinds of seabream support the consideration of sea surface temperatures as an approximation of the variability of marine environment conditions. Additionally, the growth pattern of red seabream provides meaningful information of this fish species that justifies looking in the relation between landings or red seabream abundance, and sea surface temperatures during spring with a lag of no less than two seasons.This paper concludes that technical efficiency of red seabream fleet is of 88% in period 2002-2004 and that an increase of 1% of mean sea surface spring temperature lagged 2 seasons results on a 27.50% decrease of captures. This paper also concludes that the relationships between the marine environment factors and the evolution of red seabream exploited fish stock take place a couple of year before the season and therefore the expected recruitment is known before it. This allows the policy-maker to design an adaptive management strategy accounting these relationships for a certain season once the historical evolution of the marine environment factors is known.

Keywords: Stochastic distance functions, marine environment conditions, Strait of Gibraltar, red sea bream.

INTRODUCTION

The scientific community has intensively studied the relationship between marine environmental conditions and fish stock populations during last decade. Marine environmental conditions are closely related to climate; and its changes provide a certain evolution of the ecosystem functions that influence the reproduction and growing of commercial fish stocks among other aspect of their biology and habits (Sharp, 1995). Small pelagic fisheries, including clupeids like sardine or anchovy, have been the most affected by these changes in short and long term because of their diet based on plankton, their migratory habits, their short reproductive and life cycles, or their ability to cope with these changes (Hunter & Alheit, 1995; Klyashtorin, 2001); thought this relationships are also found in other fish species like different kinds of seabreams (Novuo, 2004; Lim, *et al*. 2004).

The fisheries management system should take into account marine environment variability for succeeding at the aim of biological sustainability of fisheries (Hilborn & Walters, 1991). Well funded policy-makers' decisions require a scientific based knowledge of the interaction between the marine environment and commercial fish stocks given that the role of marine environment in the evolution of fish stocks is sometimes even more important than the one plays by fishers in the commercial exploitation of them. Therefore, the biological overexploitation of commercial fish stocks may result not only by high levels of fishing effort but also by its combination with bad environmental conditions for the reproduction of them.

Several bioeconomics models were developed to take into account marine environment variability through the consideration of uncertainty during the decade of 70ths and the beginning of the 80ths producing more conservative and protective fisheries policies (Reed, 1974; 1979); however the explicit

consideration of marine environmental factors in the models allows delimiting uncertainty and that fisheries management is adapted to actual conditions of the fisheries resource favoring the definition of the management objectives for the fleet and the planning of the fleet activity (Serrano, *et al*. 2002).
Additionally, it is important to valuate economically the influence of the potential change of the fishing industry production induced by the potential change of the ecosystem functions due to global climate change in order to provide the policy-makers with arguments for society to preserve and exploit fisheries resources on a sustainable basis.
This paper is aimed at determining the impact of the variability of marine environment conditions on the capture of a vessel that exploit the red seabream fishery of the Strait of Gibraltar. Currently, most of red seabream (*Pagellus bogaraveo*, Brünnich 1768) fisheries of the European Economic Exclusive Zone (EEZ) are being overexploited or are depleted. The red seabream fishery located in the Strait of Gibraltar is one of the most important of the EU. It produces a significant added value given that is one of the most expensive fishes sold in the Andalusia fish public exchanges and plays an important role for the socioeconomic development of an important area of Andalusia. It was evident that the red seabream fishery of the Strait of Gibraltar was overexploited in 1998 as a consequence of an open access regime and two recovery plans aimed at sustainability were implemented in periods 1999-2002 and 2003-2005. The measurement of the fishing capacity, capacity utilization and overcapacity is of interest to evaluate the success of these recovery plans.
This paper will begin with the description of the red seabream fishery of the Strait of Gibraltar and the data set used. Then, it will describe the methodology used in order to get this aim: stochastic distance functions. This methodology will be used to study the microeconomic impact that the evolution of the marine environment conditions could have on red seabream fleet production. This paper will finalize summarizing and concluding with the main results.

RED SEABREAM FISHERY

Target specie

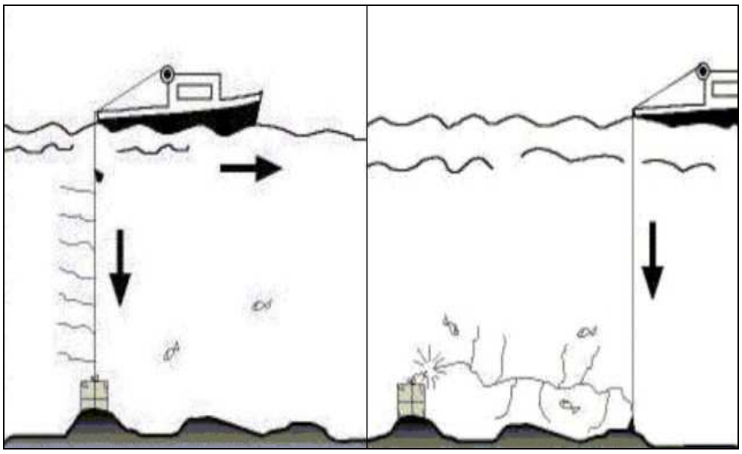
The target specie of the red seabream fishery of the Strait of Gibraltar is the red seabream (*Pagellus Bogaraveo*, Brünnich, 1768). Red seabream is a benthopelagic hermaphrodite fish that lives during its early stages of its life close to shore and goes to deeper waters at it becomes mature up to 400 m. in Eastern Atlantic and Western Mediterranean sea. Its diet consists of small fishes, mollusks and crustaceous and its size is generally between 20 and 35 cm. (Gil, *et al*. 2000; Gil & Sobrino, 2001; Sobrino & Gil, 2001).
This fishery is of great importance for two reasons (García, *et al*. 2003). Firstly, it is the second most important red seabream fishery in the Eastern Atlantic. Hence, this fishery can be considered one of the most important red seabream fleets in Europe. Secondly, there is a high regional dependency of employment generated by this fishery. Fishery employees have full-time jobs and represent a significant percentage of total employment in the ports of Algeciras and Tarifa. Direct employment in fishing sector at the port of Tarifa represents 12.81% of total employment in Tarifa. Addionaly, Tarifa is one of the 33 geographical areas (NUT 3) which have a fishing dependency higher than 10% in the EU (EC, 1999). Moreover red seabream is one of the most valuated fish species in Spain.

Fleet

The red seabream fishery was firstly exploited by vessels based on the port of Ceuta (North of Africa) in the seventieths. The fleet increased significantly during the eightieths due to new entries from the South Atlantic and South Mediterranean coast of Spain attracted by high profitability; and capital investment of the previously existing fleet. Nowadays, most of the fleet is based in the ports of Tarifa and Algeciras and consists of 103 vessels around 10 m. total length and 6.5 gross tonnage (GT) equipped with an engine

of around 64 HP according the last census published in 2007. This fleet is commonly called voracera fleet.
This fleet use a very fishing gear locally known as voracera that consists of a special kind of deep sea longline (Diputación Provincial de Cádiz, 1991, 1994) that operates as shown in Figure 1. This fishing gear is very selected and most of the catches landed at port by vessel equipped with it consists of red seabream (Bravo, *et al*. 2000), though there are other species that contribute to fishermen revenue and bycatch including black scabbardfish (*Aphanopus carbo*) or atlantic pomfret (*Brama brama*) among other fish species.

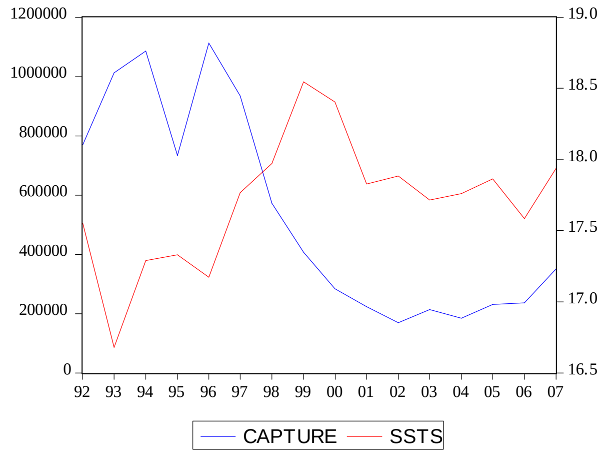
Figure 1: Voracera gear operation



Environmental conditions of the red seabream fishery

The impact of the evolution of marine environment conditions on benthopelagic species has been study in a less extend than on pelagics, however there are some evidences that sea temperatures have influence on growth and maturation (Novuo, 2004) and on the development of hermaphroditic gonads (Lim, et al. 2004) of different kinds of seabream. These evidences make reasonable looking for on relations between sea temperatures and the size of these fish stocks or the landings of the fleet that exploit them.
The insight on the biology on the growth pattern of red seabream provides some meaningful information of this fish species that allows determining the nature of the aforementioned relations. The red seabream spawning takes place during the first quarter of the year (Gil & Sobrino, 2001) and then currents move eggs and larvae close to coastal areas both sizes of the Strait of Gibraltar. Larvae and juvenile spends the early years of their life there and becomes fishable three years later in deep sea areas of the Strait of Gibraltar (Sobrino & Gil, 2001; Gil, *et al*. 2000). This behavior justifies looking at the relation between landings or red seabream abundance and sea surface temperatures during spring with a lag of no less than two years. Accordingly Figure 9 shows this relation for the red seabream fishery of Strait of Gibraltar and can be concluded that this relation exist and that it is negative correlated.
This paper will go through these relations using the stochastic distance function approach described in the next section.

Figure 2. Spring SST lagged 2 periods (SSTS) and red seabream catches (Capture) in period 1992-2007



DATA

Data consists of a panel data set of the red seabream fishery of the Strait of Gibraltar (Spain) including vessels licensed for this fishery that reported captures of the target species on a regular basis. The panel data of red seabream fishery of The Strait of Gibraltar includes vessel landings of this fish specie from 2002 to 2004 and represents more than the 75% of the landings all years (Table 1).

Table 1. Sample representativity of red seabream fishery of The Strait of Gibraltar panel data

Year	Strait of Gibraltar (SG)	Sample	% Sample/SG
2002	160626	143927	0,90
2003	197548	173247	0,88
2004	170813	133936	0,78

The data include data on technical characteristics of vessels from the operating fleet census of Spain (Ministerio de Medio Ambiente y Medio Rural y Marino). Table 2 shows the descriptive statistics of these characteristics: tonnage measured in GRT and GT, total length measured in m and power of main engine measured in HP.

Table 2. Descriptive statistics of technical characteristics of vessels

Variable	Year	N	Mean	SD	Minimun	Maximum
Tonnage (GT)	2002	70	5.68	2.44	1.25	12.23
Tonnage (GRT)		70	5.93	2.83	1.36	12.24
Total lenght		70	8.76	3.03	5.83	13.70
Engine power (HP)		70	63.72	31.45	12.00	128.00
Tonnage (GT)	2003	70	5.68	2.44	1.25	12.23
Tonnage (GRT)		70	5.93	2.83	1.36	12.24
Total lenght		70	8.76	3.03	5.83	13.70
Engine power (HP)		70	63.72	31.45	12.00	128.00
Tonnage (GT)	2004	70	5.68	2.44	1.25	12.23
Tonnage (GRT)		70	5.93	2.83	1.36	12.24
Total lenght		70	8.76	3.03	5.83	13.70
Engine power (HP)		70	63.72	31.45	12.00	128.00

The panel data also includes data on vessel landings measured in kg. and the fishing trips that vessels develop during each year (Table 3).

Table 3. Descriptive statistics of landings and trips

Variable	Year	N	Mean	SD	Minimun	Maximum
Red Seabream (Kg.)	2002	70	2056	1474	55	6657
Others (Kg.)		70	782	732	24	3444
Trips		70	42	26	1	118
Red Seabream (Kg.)	2003	70	2475	1482	67	6539
Others (Kg.)		70	1241	1047	18	4713
Trips		70	45	25	2	112
Red Seabream (Kg.)	2004	70	1913	1354	122	7686
Others (Kg.)		70	1002	910	32	4622
Trips		70	43	28	4	149

Finally, the exogenous variables used were the mean Spring SST of the nursery area of red seabream lagged two periods from the Hadley Centre for Climate Change from HadISST data base (Rayner, *et al*. 2003).

METHODS

It is a common case in fisheries the capture of different species using the same fishing gear in the same fishing trip this obliged to use a multi-species approach to handle the measurement of efficiency and productivity together with the measurement of the potential impact of the evolution of the exploited fish stock and/or marine environment exogenous variables on the capture of a certain vessel or a fleet. This study use the stochastic distance functions approach to tackle the multi-species issue.
Färe & Primont (1995) defines an output distance function in the framework of the dual theory of production by mean of Equation 2, where x is a vector K inputs, y a vector of M outputs, T a feasible technology set (Ecuation 1) and θ is the deflator of the actual output to T.

$$T = \left\{(x,y): x \in \Re_{+}^{K}, y \in \Re_{+}^{M}, x \text{ can produce } y\right\} \tag{1}$$

$$D_0(x,y) = \inf_{\theta}\left[\theta: \left(x, \frac{y}{\theta}\right) \in T\right] \tag{2}$$

The value of D_0 represents the distance between the actual output to the maximum potential output that can be attained by a certain DMU. This distance is the result of a combination of stochastic factors (v_i) and inefficiency (u_i), so that the distance function of Equation 2 can be expressed in the form of Equation 3 as stochastic distance function.

$$1 = D_0(x,y) \cdot e^{v_i + u_i} \tag{3}$$

The stochastic distance function of Equation 3 can be approximated empirically through a flexible Translog functional form that take the form presented in Equation 4 for each period t (Coelli & Perelman, 1996, 1999, 2000). α, β y δ are the parameters to estimate in Equation 4. This approximation requires the normalization by one of the productive outputs in order to impose homogeneity of degree one of outputs conditions (Equation 5).

$$1 = \alpha_0 + \sum_{m=1}^{M}\alpha_m Ly_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M}\alpha_{mn} Ly_{mit} Ly_{nit} + \sum_{k=1}^{K}\beta_k Lx_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{klt} Lx_{kit} Lx_{lit} + \\ + \frac{1}{2}\sum_{k=1}^{K}\sum_{m=1}^{M}\delta_{km} Lx_{kit} Ly_{mit} + u_{it} + v_{it} \tag{4}$$

$$\sum_{m=1}^{M}\alpha_m = 1,\ \sum_{n=1}^{M}\alpha_{mn} = 0,\ m = 1,2,\ldots,M\ y\ \sum_{m=1}^{M}\delta_{km} = 0,\ k = 1,2,\ldots K \tag{5}$$

The adaptation of the stochastic distance function to the fisheries case implies a Translog form (*TL*) that among its inputs includes the exploited fish stock (S_t), the activity (τ_i) and K productive inputs (x_{ki}), including exogenous variables if available. Homogeneity of degree 1 in outputs should have also be imposed normalizing by one of the outputs as shown in Equation 6 where α, β y δ are vectors of parameters to be estimated econometrically.

$$-L|y_{1it}| = TL\left(S_t, \tau_{it}, x_{kit}, \frac{y_{it}}{|y_{1it}|}; \alpha, \beta, \delta \right) + u_{it} + v_{it} \tag{6}$$

The Translog approximation of the stochastic distance function showed in Equation 6 allows determining the impact of a certain evolution of the exploited fish stock and/or exogenous variables that approximate the evolution of marine environment conditions; on the capture of a certain vessel or the whole fleet through the elasticity of that input. Equation 7 shows how could be get the elasticity in the case of the exploited fish stock ($\varepsilon_{y,S}$).

$$\varepsilon_{y,S} = \frac{\partial Ly}{\partial LS} = \frac{\partial y}{\partial S}\frac{S}{y} \tag{7}$$

The expression in Equation 7 represents the percent change of the capture of a certain vessel due to a 1% change of the exploited fish stock size (or an exogenous variable that approximates wholly or partially its evolution) and allows to valuate the potential impact of different exploited fish stock evolution associated to different conditions of the marine environment according to the aim of this paper. Additionally is possible to get other inputs elasticities and output trade off together with their decomposition in first and second order elasticities shown in equations 8 and 9 as done in this paper (Morrison, *et al.* 2002; Lambarraa, *et al.* 2008).

$$\varepsilon_{y_1,x_k} = \beta_k + \sum_1^K \beta_{kl} Lx_{li} + 2\sum_1^M \beta_{km} L\frac{y_m}{|y_1|} = \beta_k + \sum_1^K c_{kl} + 2\sum_1^M c_{km} \tag{8}$$

$$\varepsilon_{y_1,y_m} = \alpha_m + \sum_1^M \beta_{mn} L\frac{y_n}{|y_1|} + 2\sum_1^K \beta_{km} Lx_{ki} = \alpha_m + \sum_1^M c_{mn} + 2\sum_1^K c_{km} \tag{9}$$

RESULTS

A stochastic distance function haS been estimated using the panel data sets described in Data section. The model used the Translog flexible functional form approximation to the distance function and imposed homogeneity of degree one of outputs normalizing by one of them (red seabream). This model specification included as outputs the captures measured in Kg. of red seabream, other deep sea species that cohabits in the same grounds and bycatch; whereas it included as inputs the activity, the tonnage and the mean Spring SST lagged two periods as an approximation of the red seabream exploited fish stock evolution caused by the evolution of marine environment conditions. This model has been estimated assuming that the one-side error term of inefficiency takes Truncated Normal distribution truncated at μ with constant variance.

The estimation output of the model estimated by maximum likelihood is presented in Table 4 where dss is deep sea species, os, other species and rsb, red seabream. Table 4 shows that most of the parameter estimates are significant at levels that vary between 0,01 and 0,1. The log-likelihood ratio test was implemented confirming the assumptions taken on the functional form the distance function and the one-side error term, and existence of inefficiency at significance levels that vary between 0,01 and 0,05.

Table 4. Estimation output of the red seabream stochastic distance function

Variable	Parameter estimates	SD	T
Intercept	64.919,246	3,7345907	**17.383,229*** **
dss	-14,431511	6,4884023	**2,224201** **
os	6,7161058	7,1257261	**0,94251529**
dss^2	-0,0341598	0,0216697	**-1,5763839***
dss x os	0,0057962	0,0157045	**0,36907996**
os^2	-0,0292280	0,0163911	**-1,7831616***
Rsb trips	32,168538	4,5387911	**7,0874682*** **
GRT	12,035423	2,6970979	**4,4623606*** **
Spring SST	-45.128,955	3,9990829	**-11.284,826*** **
Rsb trips ^{2}	0,02394167	0,0339510	**0,705183**
GRT^2	-0,00947305	0,0949746	**-0,099743**
Spring SST^2	15.686,541	3,62535	**4326,8994*** **
Rsb trips x GRT	-0,0493871	0,039003	**-1,266234**
Rsb trips x Spring SST	-10,801116	1,571714	**-6,872190*** **
GRT x Spring SST	-4,086345	0,942659	**-4,334915*** **
Rsb trips x dss	0,068542	0,0196502	**3,488113*** **
GRT x dss	-0,0027168	0,0267507	**-0,101559**
Spring SST x dss	4,8944269	2,25377	**2,171657** **
Rsb trips x os	-0,0397945	0,0194506	**-2,045929** **
GRT x os	-0,0265529	0,0289156	**-0,918291**
Spring SST x os	-2,3066139	2,4751484	**-0,931909**
σ^2	0,0322799	0,007708	**4,187711*** **
γ	**0,831355**	**0,0506504**	**16,413611*** **

*** 1% significance level, ** 5% significance level and * 10% significance level

Table 5 shows the descriptive statistics of technical efficiency estimates of the vessels of the red seabream fishery of the Strait of Gibraltar in the considered period (Battese & Coelli, 1988). As can be seen in this table, the technical efficiency of the fleet that exploit this fishery range from 69% to 98% taking a mean of 88% in period 2002-2004.

Table 5. Descriptive statistics of technical efficiency scores.

Period	N	Mean	S.D.	Minimum	Maximum
2002-2004	60	0,88	0,072	0,69	0,98

Finally, first order and second order output elasticities and output trade offs together with their significance levels are showed in Tables 6 and 7.

Table 6. Output elasticities.

Output elasticities	Value	SD	T
$\varepsilon_{\text{rsb-rsb trips}}$	1,045258	0,00120972	864,049536***
$\beta_{\text{rsb trips}}$	32,168538	4,538791139	0,230294291
$C_{\text{rsb trips- GRT}}$	-0,079746	0,024154854	-0,146047073

$C_{rsb\ trips-\ Spring\ SST}$	-31,090384	0,54602935	-56,93903446***
$C_{rsb\ trips-dss}$	-0,097072	0,013874925	-6,996225689***
$C_{rsb\ trips-os}$	0,076455	0,010123901	7,551962221***
$\varepsilon_{\ rsb-GRT}$	0,19	0,000810767	229,2231903***
β_{GRT}	12,035423	2,697097866	4,462360506***
$C_{GRT-rsb\ trips}$	-0,181699	0,010601344	1135,273362***
$C_{GRT-\ Spring\ SST}$	-11,762306	0,327489214	-35,91662201***
$C_{GRT-dss}$	0,003848	0,018888568	0,203701093
$C_{GRT-\ os}$	0,051015	0,015050399	3,389608534***
$\varepsilon_{\ rsb-Spring\ SST}$	-27,50	0,001951205	-14.091,8028***
$\beta_{\ Spring\ SST}$	-45.128,955	3,999082895	-11284,82609***
$C_{\ Spring\ SST-rsb\ trips}$	-39,738128	0,427203372	-93,01922764***
$C_{Spring\ SST-GRT}$	-6,598273	0,583793425	-68,06881686***
$C_{Spring\ SST-\ dss}$	-6,931679	1,591380212	-4,355765664***
$C_{Spring\ SST-\ os}$	4,431590	1,288298701	3,439877817***

Table 7. Outputs tade-off

Outputs trade off	Value	SD	T
$\varepsilon_{\ rsb-dss}$	14,277948	0,000224483	63603,65057***
$\alpha_{\ dss}$	-14,431511	6,488402268	-2,224201029**
$C_{\ dss\ -os}$	-0,011136	0,008174073	-1,36235356
$C_{rsb\ trips-\ dss}$	0,252172	0,005341073	47,21370955***
$C_{GT-\ dss}$	-0,004387	0,016566867	-0,264795528
$C_{Spring\ SST-\ dss}$	14,088323	0,782984406	17,99310812***
$\varepsilon_{\ rsb\ –\ os}$	-6,893421	0,000918505	-7.505,04609***
$\alpha_{\ os}$	6,716106	7,125726138	0,942515285
$C_{\ os\ -dss}$	-0,008209	0,011088851	-0,740276044
$C_{dsb\ trips-\ os}$	-0,146407	0,005286811	-27,69287138***
$C_{GRT-\ os}$	-0,042875	0,017907602	-2,394256628**
$C_{Spring\ SST-\ os}$	-6,639454	0,859891774	-7,721266919***

SUMMARY AND CONCLUSIONS

Figure 2 shows evidences that the mean Spring SST lagged two periods vary during the last decade influencing the evolution of the recruitment of this fishery significantly for the reasons noted in red seabream fishery section.

A stochastic distance function of the red seabream fishery of The Strait of Gibraltar has been estimated in this study based upon the relationships noted in last paragraphs. Results attained provide red seabream fish capture related to the marine environment conditions using a flexible Translog approximation with different assumptions on the one-side error term that represents inefficiency.

The stochastic distance function estimated in last section provided the elasticity of the mean Spring SST lagged two periods for the red seabream fishery of The Strait of Gibraltar. The value of these elasticities allow to conclude that a 1% change of the mean SST lagged two periods produce a 27.50% change of the capture/revenue of a vessel in the opposite direction for the red seabream fishery of The Strait of Gibraltar. These results allow estimating the direct potential impact on vessels capture of a certain evolution of the ecosystem functions for the red seabream fishery of the Strait of Gibraltar.
The stochastic distance function estimated in last section provided the elasticity of the substitution of outputs (Table 7) for the red seabream fishery of The Strait of Gibraltar. The value of these elasticities allows concluding that red sea bream and other deep sea species captured by the fleet are complementary outputs, while other outputs are substitutives.
The stochastic distance function estimated in last section has also allowed estimating technical efficiency of this fleet (Table 5). This results allow concluding that the technical efficiency of the fleet that exploit this fishery range from 69% to 98% taking a mean of 88% in period 2002-2004.
This paper allows concluding that marine environment conditions impact the evolution of red seabream capture more than the evolution of other species capture that live in the same ecosystem according second order elasticities. We can conclude that the impact of the environmental conditions on the by-catch is different from the influence on the target species as expected. Additionally, capital stuffing is possible under the absent of regultory constraints between trips and GRT.
These results allow the policy-maker to design an adaptive management strategy accounting these relationships for a certain season once the historical evolution of the marine environment factors is known.

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