Analysis of the Mix Efficiency of the Spanish Deep Trawl Fleet.

Ines Herrero[1] and Sean Pascoe[2]
1. Modelizacion Economica y Matematica de Pesquerias (MEMPES), University of Huelva, Spain
2. Centre for the Economics and Management of Aquatic Resources (CEMARE), University of Portsmouth, UK

Abstract.
Recently, there has been an increasing interest among researchers on efficiency in fisheries. They have not just been focused on the analysis of the efficiency itself but also for other purposes as measures of capacity utilisation. However, often, efficiency analyses do not offer clear results regarding the sources of the inefficiency. Radial measures of efficiency have been commonly used whereas newer additive measures are of rare use. However, the combined implementation of both types of measures can be used for the study of mix inefficiency, that is, the inefficiency due to a wrong composition of inputs or outputs. Analysing the input and output mix is essential for a better understanding of the production process. In this paper we deal with this issue and apply it to the Spanish Deep Trawl fleet that operates in Moroccan Waters. Results show that some of the physical inputs are over-dimensioned. The efficiency with respect to the composition of the catch has also been examined, showing distinct strategies amongst fishermen.

Key words: Technical efficiency, mix efficiency, Data Envelopment Analysis.

1. INTRODUCTION

Over the last decade, a large number of papers on efficiency analysis applied to fisheries have been produced, mostly using the stochastic production frontier approach. More recently, Data Envelopment Analysis (DEA) has been applied in fisheries. As well as the usual and most direct purpose of analysing the efficiency of a fleet, DEA has been used in a wider variety of applications as measures of capacity utilisation, estimating misreported catch, technical progress or estimation of the stock biomass.

However, often, when efficiency is used in the most common and simple application of DEA, the analyses do not offer clear results regarding the sources of the inefficiency. Radial measures have been widely applied whereas newer models based on additive measures are of rare use. Moreover, models using the oriented version of the additive measures are even less common. However, the combined implementation of an input (or output) oriented additive model with a standard radial measure can be very useful for the study of mix inefficiency, that is, the inefficiency due to a wrong composition of inputs or outputs. While this is a very useful technique it has hardly been applied to empirical analyses and it has never been applied in fisheries.

Analysing the input and output mix is essential for a better understanding of the production process. In this paper, we deal with this issue and apply it to the Spanish Deep Trawl fleet that operates in Moroccan Waters. Results show that some of the physical inputs are over-dimensioned. The efficiency with respect to the composition of the catch has also been examined, showing distinct strategies amongst fishermen. In this paper we apply the input and output oriented slacks-based-measure for the estimation

2. THE SPANISH DEEP TRAWL FISHERY

The study is based on a sample of 26 vessels from the Spanish Andalusian fleet that operated during 1993-1998. The fleet consist of deep-water trawl vessels that are based in the Port of Huelva and fish in Moroccan Waters North of the 28^{o} 44’ parallel. The main target species in the fishery are crustaceans (deep water rose shrimp, scarlet shrimp, and scampi) though some other types of fish (like European Hake) are also targeted. The species are often caught together (as they are all bottom dwelling species), but the proportion of each in the catch varies by area fished. Hence the fishers are able to alter their catch composition through fishing in different areas at different times or by discarding the species that are not of their interest. A number of other species are also caught as bycatch, which may represent a high percentage of the total catch by weight. The fishery is characterised by relatively large vessels (see table 1) that operate mainly from March to December. Trip lengths are generally for 12 days.

Information on landings of individual vessels was obtained from the records of the fish auction market in Huelva. Data on the physical characteristics of the boats were obtained from the fleet registers of the different ship-owners' associations and from the existing census of the Official Institutions. The database included daily landing data from 1993 to 1998. Information on 1999 was also available though due to very few observations in the data, was not included in the analysis. It was in November 1999, when this fishery stopped operating in the area due to a lack of an agreement between the EU and Morocco. The last agreement took place in 1995 and severe restrictions were imposed until November 1999. All data were aggregated into monthly observations.

Table 1. Technical characteristics of the fleet (Trawl fishery)

	Mean	Standard Deviation
Gross Registered Tonnage (GRT)	59	15
Horsepower (HP)	324	83
Trips	1.74	0.7

This fishery was subject to a complex set of regulations[1], which varied constantly over time depending on the agreements with Morocco. Regulations restrict the capacity of these vessels, not allowing more than a certain amount of GRT per year for the whole Spanish trawl fleet operating in Morocco[2] (see table 2). Moreover, a certain amount of taxes are imposed per GRT and they have been increasing over time (Barroso, 1998). On the contrary, no restrictions on the engine power has ever been imposed. This resulted in a steady increase of the average engine power of the fleet (which was 313 in 1985[3]) and a decrease in the average capacity (which was 91 GRT in 1985[4]). In the years considered, there was a close season imposed during January and February[5].

Table 2. Maximum tonnage allowed for the Spanish North Trawl fishery operating in Moroccan Waters.

	1/12/95-30/11/96	1/12/96-30/11/97	1/12/97-30/11/98	1/12/98-30/11/99
Max. tonnage	11,200	10,000	9,000	8,200

source: Barroso, 1998

We used monthly cross sectional data to avoid the inclusion of the stock variable. The key inputs in the model were the size of the boat (represented by its gross registered tonnage, or GRT), the engine power of the boat (in horsepower) and the number of trips each month. These three variables were included in the analysis of the fishery by Garcia-Hoyo and Herrero-Chacon (1998). In our case, outputs were aggregated into two, crustaceans and fish. The first one being more valuable than the second one.

3. ANALYSIS OF THE INPUT MIX EFFICIENCY

The use of a combination of an output (or input) oriented CCR model and an output (or input) oriented Slacks-Based-Measure output model can be very useful for the determination of the output (or input) mix efficiency. The Slacks-Based-Measure model (SBM model) was firstly developed by Tone (2001). While the SBM extends the usual additive model in the sense that it possesses the unit invariant property, it does so at the cost of losing the property of translation invariance.

The model is given by,

[1] Some of these regulations include contracting a certain number of Moroccan crew members depending on the size of the boat (and on the different agreements), the obligation of a certain number of landings in Moroccan ports, the size of the mesh etc.

[2] Note that this table includes figures from 1995 onwards. These figures could not be compared with those of the previous agreements because it was not until 1995 when the North Trawl fishery was distinguished from other types of trawl fisheries also operating in Morocco.

[3] See García Hoyo and Herrero, 1998

[4] See García Hoyo and Herrero, 1998

[5] This information has been obtained from the fishermen´s guilds

$$\min \quad \rho = \frac{1 - \frac{1}{I}\sum_i s^-_{ij_0} / x_{ij_0}}{1 + \frac{1}{R}\sum_r s^+_{rj_0} / y_{rj_0}}$$

$$s.t. \qquad (1)$$

$$x_0 = X\lambda + s^-$$

$$y_0 = Y\lambda - s^+$$

$$\lambda, s^+, s^- \geq 0$$

where X={x_{ij}} represent the *i*-th input (i=1,…,I) of DMU *j* and Y={y_{rj}} represents the *r*-th input of DMU *r* (r=1,…,R). The zero sub-index stands for the unit being evaluated and s^-_{ijo} and s^+_{ijo} are the slack variables associated to x_{ijo} and y_{rjo} respectively.

An analysis of the input mix-efficiency was carried out and applied to the fishery described above. The mix efficiency is calculated by the combination of two different DEA models, an input oriented slacks based measure (SBM) model (Tone, 2001) and an input oriented standard CCR model.

The input-oriented slacks-based-measure (SBM) model is defined in a similar way to the standard SBM model above though minimising only the numerator (Tone, 2001), that is,

$$\min \quad \rho_{in} = 1 - \frac{1}{I}\sum_i s^-_i / x_{i_0}$$

$$s.t.$$

$$x_0 = X\lambda + s^-$$

$$y_0 = Y\lambda - s^+$$

$$\lambda, s^+, s^- \geq 0 \qquad (2)$$

The optimal value, ρ_{in} , verifies that $\rho \leq \rho_{in} \leq \theta_{in}$, where θ_{in} is the optimal solution to the standard CCR input-oriented model and ρ is the solution to the standard SBM model. The equality $\rho_{in} = \theta_{in}$ holds if the optimal solution to the CCR model has zero slacks for the unit under evaluation. Moreover, a CCR-input efficient unit is a SBM-input efficient unit and vice-versa.

Whereas θ_{in} represents the radial contraction of the inputs to make a unit efficient, the value of ρ_{in} includes not only that radial measure but also a measure of the slack variables. The input-oriented mix efficiency measure for a given unit is then defined as (Cooper, Seiford and Tone, 2000),

$$\text{Input mix inefficiency (IMI)} = \rho in / \theta in \qquad (3)$$

This value is bounded by 0 and 1 and represents a measure of a wrong input composition. A value equal to 1 is associated to a unit that has a right composition of inputs. Moreover, the study of the standardised slack variables (by their associated inputs) can provide a measure of the proportional contribution of each of the inputs into the inefficiency of the unit being evaluated.

In order to study the relation between the two main physical inputs of the vessels (volume and power) and the number of trips, the mix-efficiency was calculated using those three inputs. The total value of the two different groups of species was used as outputs. Results showed an average input mix-efficiency score of 0.86, with a standard deviation of 0.14. More than 68% of the units were mix-inefficient, meaning that they had some positive slack variables in the CCR model.

When the standardised slack variables of the input-oriented SBM model were analysed, it was concluded that approximately 42% of the total corresponded to the standardised slack variable associated to the engine power of the vessels, 37% to the standardised slack variable associated to the volume and 20% to the number of trips. These results suggest that some of the inputs are under-utilised, especially the engine power so that in most of the cases as the majority of the vessels could get the same amount of output not just by radially reducing its inputs but also by an extra reduction of some of them.

Previous studies of this fishery for 1985 and 1986 (Garcia-Hoyo and Herrero, 1998), using stochastic production functions, showed that the elasticity associated with the engine power was higher than the elasticity associated with the boat size whereas results of this study showed that in many cases a higher decrease in the power of the vessels is needed to reach efficiency than in the level of the volume or in the number of trips and agree with recent studies (work in progress) where it is shown that the elasticity associated with the power of the engines have decreased over time for this fishery. The reason could be that the average engine power in 1985 and 1986 was lower than for the period under studied in this analysis (1993-1998). The policy management is based on regulations on the capacity whereas the engines power of the vessels is not under any control. This has brought about an increase in the engine power since the late eighties whereas the average vessel size has been reduced[6]. This has also implied a change in the roles of the associated elasticities. Currently, the engine power of the vessels seem to be under-utilised and a better combination of the inputs would be able to be obtained if the regulations had been more proportionate regarding both physical inputs.

As a consequence, it could be concluded that a management system based in the control of just some of the inputs can bring about either an expansion of the inputs that are left out of the control of the managers producing the reverse effect, more efficient boats, as it seemed to happen during the first years after the regulations were imposed and finally, the fleet can get to a point in which the non-controlled inputs reach too high levels as it seems to have happened in the last few years. Hence, for an adequate management of the fishing resources and of the productive inputs it seems necessary to establish a management system that control not just some but all the inputs that are involved in the production process.

A similar analysis was carried out to study the output mix efficiency, that is the inefficiency due to a wrong composition of the outputs. Assuming profit maximising behaviour, it is expected that fishers would aim to maximise their revenue per trip. The proportion in the catch of the different species may results in higher or lower benefits. With a mix of high value and low value species, high revenue may be derived from essentially a low quantity of catch and vice versa. Some studies[7] have studied the output mix efficiency by the comparison of the results of the efficiency analysis when using catch as output and the results when using value of the catch. Boats that appear inefficient when considering the total quantity of output may, in fact, be highly efficient when considering the revenue derived from the catch. However, boats with similar value and catch efficiency may present some mix inefficiency value which can not be detected. An output mix efficiency analysis of the vessels using the combination of two different DEA models can provide useful information on the behaviour of the fishers and information on the sources of the output mix inefficiency.

This analysis is similar to the previous one where the input-oriented models are substituted by the output oriented versions. For the SBM model this is equivalent to maximising the denominator of the original model (Tone, 2001),

$$\begin{aligned} &\max \quad \rho_{out} = 1 + \frac{1}{R}\sum_r s^+_{rj_0} / x_{rj_0} \\ &s.t. \\ &\qquad x_0 = X\lambda + s^- \\ &\qquad y_0 = Y\lambda - s^+ \\ &\qquad \lambda, s^+, s^- \geq 0 \end{aligned} \qquad (4)$$

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[6] This is due to the introduction of new vessels in the fishery that are smaller in volume to agree with the regulations. Fishermen have tried to "compensate" the decrease in the volume with an increase in the engine power.

[7] This is work in progress

In this case the output mix inefficiency is given by:

$$\text{Output mix inefficiency (OMI)} = \theta\text{out} / \rho\text{out} \qquad (5)$$

This value is bounded by 0 and 1 and represents a measure of a wrong output composition.

Results showed an average value of the output mix inefficiency of 0.82, with a standard deviation of 0.21. More than 66% of the units were output mix inefficient. We got an interesting result as the percentage of the average slack variable associated to fish (60%) was higher than the slack variable associated to seafood (40%). This can be explained by the fact that even if shellfish is generally composed of higher price species (around 3 times more), probably other fish species can be obtained in bigger quantities when using the same effort levels (producing higher values). Hence, an appropriate output mix does not always has to be focused just on the higher price species.

4. CONCLUSIONS

In this paper we have analysed the input and output mix efficiency of the vessels that operated in the South Atlantic deep trawl fishery during the period 1993-1998. While this is a very useful technique it has hardly been applied in empirical analyses and it has never been applied in fisheries before.

Regulations on the fishery under analysis have traditionally been of high complexity. However, they just control two of the main physical inputs (time spent fishing and volume) whereas the engine power of the vessels is out of any control. As this was the only uncontrolled main input, the fleet seemed to turn to an increase of this input to compensate the lack of volume. However, as this input seemed to be under-utilised the increase in the volume brought about an increase in the efficiency of the vessel (Garcia-Hoyo and Herrero, 1998). While the intention of the regulations were the control of the already over-exploited fishing grounds, they got the reverse result, an increase in the vessels efficiency (and, as a consequence, an increase in the over-exploitation of the resource). However, years later, it seems that an over-dimension of the engine power of the vessels has been produced and it is currently being under-utilised.

Understanding the composition of the inputs and outputs of the production process is a key point for understanding the production process and for the optimal management system of the fishery. It seems important that fishery managers pay attention to the control of *every* main input involved in each fishery to avoid either a reverse effect (with vessels being more efficient and over-exploiting the fishing grounds) or to avoid the fleet over investing in some inputs that are useless to be expanded as they are not producing any increase in the benefits of the vessels.

A similar analysis has been carried out to analyse the mix efficiency regarding the different composition of the captures. Results show that the optimal species composition does not always has to result in increasing the higher price species.

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