

# Applicability of English Channel methodology to Mediterranean fisheries

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## Abstract

Data Envelopment Analysis (DEA) is applied to obtain a measure of the technical efficiency of Italian bottom trawl and mid-water pair trawl fleets of the Northern and Central Adriatic Sea. Both bottom and mid-water pair trawlers result to operate close to their capacity output level. Variable factors not considered in the analysis are discussed. Further comparison of DEA analysis with stochastic methods based on production function is suggested.

## 1. Introduction

In this study we have applied Data Envelopment Analysis (DEA) to some key fleet segments operating in Northern and Central Adriatic. The aim was to estimate a measure of technical efficiency of these segments using a quantitative approach. The methodology is similar to that employed for the analysis for English Channel fisheries (Pascoe *et al.*, this volume). This fishing area, as in the Northern and Central Adriatic, is characterised by multi-species and multi-gears fisheries. Following Pascoe's approach we have compared multi-output measures of capacity utilisation based on catches and on revenues.

## 2. Methodology

In simple terms, DEA is a non-parametric approach to frontier estimation because it assumes the production function of a firm is unknown. This method is a linear programming technique for considering optimum solutions relative to individual units rather than assuming, as in optimised regression, that a solution applies to each decision making unit (DMU).

The purpose of DEA is to construct a non-parametric envelopment frontier over the data points, such that all observed points lie on or below the production frontier. DEA measures efficiency by comparing each individual production unit against all other production units within its sample data. The efficiency of each unit is calculated by comparing output and input use with points on the production frontier (best observed practice). If the production unit is on the frontier (efficient point), it will be assigned an efficiency score of 1. On the contrary, if a unit is inside on the frontier (inefficient point) it will be assigned an efficiency score smaller than 1.

DEA can be input or output oriented: it depends upon the optimisation production process characterising the firm. The input oriented technical efficiency measure addresses the question: "By how much can input quantities be proportionally reduced without changing the

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<sup>1</sup> This study makes extensive use of studies undertaken on the subject by Sean Pascoe. However responsibility for the selection of material and its presentation in this document rests solely with the author.

output quantities produced?” The alternative output oriented measure asks the question: “By how much can output quantities be proportionally expanded without altering the input quantities used?”

In figure 1 the distance  $AA'$  represents technical inefficiency. That is, the amount by which outputs could be increased without requiring extra inputs. Hence a measure of output-orientated technical efficiency is the ratio:  $TE = OA/OA'$

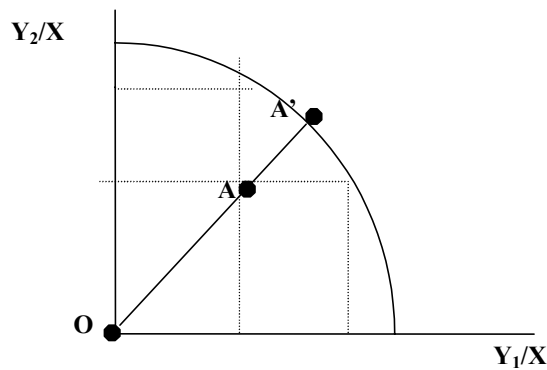


Figure 1. Technical Efficiency from an Output Orientation.

In synthesis DEA study provides:

- A best practice frontier represented by a piecewise linear empirical envelopment surface. The best practice units are those exhibiting the highest input/output relation.
- Specific targets or efficient projections onto the frontier for each inefficient DMU.
- An efficient reference set or peer group for each DMU defined by the efficient units closest to it. The peer DMU are observed to produce the same or highest level of outputs with the same or less inputs in relation to the inefficient DMU being compared.

In this study, output orientated DEA is used to determine:

- Capacity output** given current use of inputs, where potential vessel output is estimated based on its fixed inputs (i.e. gross tonnage and engine power)
- Technically efficient measure** of output where vessels' potential output is estimated also taking into consideration the efficient use of variable input (i.e. days fished)

The mathematical formulation of the DEA model of capacity output, given current use of inputs and with variable return to scale, is given as:

$$\text{Max } \theta_1$$

subject to

$$\begin{aligned}
\theta_1 u_{0,m} &\leq \sum_j z_j u_{j,m} \quad \forall m \\
\sum_j z_j x_{j,n} &\leq x_{0,n} \quad n \in \alpha \\
\sum_j z_j x_{j,n} &= \lambda_{0,n} x_{0,n} \quad n \in \hat{\alpha} \\
\sum_j z_j &= 1 \\
z_j &\geq 0, \quad \lambda_{j,n} \geq 0 \quad n \in \hat{\alpha}
\end{aligned} \tag{1}$$

where:

$\theta_1$  is a scalar showing by how much the output of each vessel can be increased,

$u_{j,m}$  is the output  $m$  produced by vessel  $j$ ,

$x_{j,n}$  is the amount of input  $n$  used by vessel  $j$

$z_j$  are weighting factors measuring the distance vessel  $j$  is from the frontier.

The value of  $\theta_1$  is estimated for each vessel separately, with the target vessel's outputs and inputs being denoted by  $u_{0,m}$  and  $x_{0,n}$  respectively.

Inputs are divided into fixed factors (i.e. set  $\alpha$ ) and variable factors (i.e. set  $\hat{\alpha}$ ).

The measure of capacity output is calculated by relaxing the bounds on the sub-vector of variable inputs,  $x_{\hat{\alpha}}$ . This is achieved by allowing these inputs to be unconstrained through introducing an input utilisation rate ( $\lambda_{j,n}$ ). This is estimated in the model for each boat  $j$  and variable input  $n$ .

The restriction  $\sum_j z_j = 1$  allows for variable returns to scale<sup>2</sup>.

Hence, capacity utilisation ( $CU$ ) is defined as:

$$CU = 1/\theta_1 \tag{2}$$

It estimates capacity utilisation as a function of fixed inputs only. The measure of  $CU$  ranges from zero to 1, with 1 being full capacity utilisation (i.e. 100 per cent of capacity).

The output oriented DEA model for technically efficient measure of output is given as:

$$Max \theta_2$$

subject to

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<sup>2</sup> In contrast, excluding this constraint implicitly imposes constant returns to scale, while  $\sum z_j \leq 1$  imposes non-increasing returns to scale (Färe *et al.*, 1989).

$$\begin{aligned}
\theta_2 u_{0,m} &\leq \sum_j z_j u_{j,m} \quad \forall m \\
\sum_j z_j x_{j,n} &\leq x_{0,n} \quad \forall n \\
\sum_j z_j &= 1 \\
z_j &\geq 0
\end{aligned} \tag{3}$$

where:

$\theta_2$  is a scalar outcome showing how much the production of each firm can increase by using inputs (both fixed and variable) in a technically efficient configuration.

In this case, both variable and fixed inputs are constrained to their current level and  $\theta_2$  represents the extent to which output can increase through using all inputs efficiently.

The technically efficient level of output ( $u_{TE}^*$ ) is defined as  $\theta_2$  multiplied by observed output ( $u$ ).

As the level of variable inputs is also constrained,  $\theta_2 \leq \theta_1$  and the technical efficient level of output is less than or equal to the capacity level of output (i.e.  $u_{TE}^* \leq u^*$ ).

The level of technical efficiency (TE) is estimated as:

$$TE = 1/\theta_2 \tag{4}$$

It estimates technical efficiency as a function of fixed and variable inputs.

Consequently, the unbiased estimate of capacity utilisation ( $CU^*$ ) is estimated by:

$$CU^* = \frac{CU}{TE} = \frac{1}{\theta_1} \bigg/ \frac{1}{\theta_2} = \frac{\theta_2}{\theta_1} \tag{5}$$

As  $\theta_1 \geq \theta_2$ , the unbiased estimate  $CU^* \geq CU$ .

### 3. The Mediterranean Case Study

The case study refers to bottom trawl and mid-water pair trawl of the Northern and Central Adriatic Sea. This area as most of fisheries in Mediterranean is characterised by a multi-species, multi-gears and artisanal-type fishery.

The Central and North and Adriatic Italian fleet is classified into the following six segments: bottom trawlers, mid-water pair trawlers, purse seiners, dredges, small scale fisheries and multi-purpose trawling vessels.

With respect to 2001, this area covered 820 bottom trawlers, with a total of 28,467 GRT and 177,302 Kw, about 18% of the Central and North Adriatic fleet in terms of number and 55% in terms of gross tonnage. There were 112 mid-water pair trawlers operating in this area, covering almost the entire Italian fleet segment (132) even if they account only for 2% of the local fleet. In 2001, catches from bottom trawlers are estimated around 36,132 tonnes, representing 26% of the Northern and Central Adriatic by weight and 40% by value. In the same period catches of mid-water pair trawl were around 33,300 tonnes, the 24% in terms of

weight and only 7% in terms of value. The low value of mid-water pair trawl landings is due to the low weight of high value species, such as marine crustaceans.

The landings of bottom trawl include a wide range of species. In 2001 the 48% of bottom trawl landings refer to the groups of finfishes and demersal fishes. For mid-water pair trawl about 90% of total volume of landings are composed by anchovies and pilchards.

The data set was constructed from the Irepa Observatory. It included monthly observations for 95 bottom trawlers and 21 mid-water pair trawlers, operating from 2000 to 2001. DEA was also run separately for bottom trawlers with greater overall length than 18 meters and bottom trawlers less than 18 meters in length (Table 1). In fact the differences between these vessels under physical and output points of view could influence the analysis (Table 2).

Table 1. Consolidated data sets used in the analyses.

<b>Gear</b>	<b>Boats</b>	<b>Number of Obs.</b>
Bottom trawl (total)	95	1,157
Bottom trawl (overall length <=18m)	39	374
Bottom trawl (overall length >18m)	56	783
Mid-water pair trawl	21	279

Source: Irepa Observatory

The key inputs used in the analysis were days fished as variable input, gross tonnage and engine power as fixed inputs. CU was estimated using multiple output (Table 2). For the multiple output measures, the top species were used individually, with the other species aggregated into a composite “other” category<sup>3</sup>. The “other” catch category (in weight terms) was derived using revenue shares while the revenues of 2000 were inflated to 2001 values using a Fisher price index. A different price index was estimated for each fleet segment, representing the different combination of species in the catch.

Table 2. Outputs and Inputs used in the analyses (Average per boat per month).

<b>Gear</b>	<b>Catch (Kg)</b>	<b>Revenue (€)</b>	<b>Days fished</b>	<b>Gross tonnage (GRT)</b>	<b>Engine power (KW)</b>
Bottom trawl (total)	3,692	16,479	14	43	238
Bottom trawl (overall length <=18m)	2,097	9,110	13	15	158
Bottom trawl (overall length >18m)	4,877	22,102	15	64	298
Mid-water pair trawl	28,704	29,408	16	66	334

Source: Irepa Observatory

<sup>3</sup> The main target species of bottom trawl are hake, red mullet, octopus, cuttlefish, Norway lobster and spottail mantis.

The main target species of mid-water pair trawl are anchovy, pilchard, mackerel, grey mullet and jack and horse mackerel.

The results were produced using a linear programming model developed in GAMS<sup>4</sup> by Sean Pascoe. This program has four main characteristics:

- i) It considers unbalanced panel data because the number of boats varied from 2000 to 2001. In addition mid water pair trawlers did not operate in August.
- ii) It runs the model with all outputs together (main species and “other” category) because it estimates multi-output measures of CU. This has the effect of reducing the influence of random fluctuations on the comparative process, so providing more accurate results<sup>5</sup>. In fact a boat may catch more of one species than another. If in the DEA analysis we use a single output measure (running the model for separate species), the CU results of lower species will appear under-utilised, while the boat is fully utilised when all the activity is considered.
- iii) It was also run separately for four fleets (total otter trawlers, otter trawlers desegregated by two vessel length categories and mid-water pair trawlers).
- iv) As data on stock abundance were not available, the model was run separately for each month so that only boats that fished in the same month would be compared. It is assumed that stock levels were relatively constant over the month; hence a stock variable cannot be included in the analysis. Spatial variations in catch composition are also not included. It is assumed that species abundance does not vary substantially across this area.

The CU biased and unbiased average scores of fleets considered are shown in Table 3. It is interesting to note the similarity between the catch and revenue based measures.

The results show that capacity utilisation (CU) varied between bottom trawlers and mid-water pair trawlers for both measures. Between bottom trawlers CU scores for vessel equal or less than 18m in overall length were inferior to CU scores of vessels greater than 18m. However, much of this under-utilisation of capacity arose out of using the inputs inefficiently rather than not using enough variable inputs. If the inputs had been used efficiently, then unbiased capacity utilisation (TE CU) for both medium-sized vessels and large vessels have been greater than 94%.

For mid-water pair trawlers capacity utilisation levels (unbiased) are always over 94%: in particular both unbiased catch and revenue-based measures of capacity utilisation (TE CU) are close to 100%.

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<sup>4</sup> GAMS 2.0 (General Algebraic Modeling System). GAMS Development Corporation.

<sup>5</sup> S. Mardle, S. Pascoe, D. Tingley. ”*Trends in capacity utilisation in the English Channel*”. XII Conference of the European Association of Fisheries Economists, Salerno, Italy.

Table 3. Estimated capacity output and capacity utilisation.

Gear	Observed output	Capacity output	CU (1/01)	TE (1/02)	TE CU (01/02)
<b>Multiple outputs based on weights (tonnes)</b>					
Bottom trawl (total)	4552	5840	0.78	0.81	0.96
Bottom trawl (overall length <=18m)	784	953	0.82	0.86	0.94
Bottom trawl (overall length >18m)	3766	4480	0.84	0.87	0.96
<i>Mid-water pair trawl</i>	8073	8522	0.95	0.96	0.98
<b>Multiple outputs based on revenues (€'000)</b>					
Bottom trawl (total)	21219	25610	0.83	0.86	0.96
Bottom trawl (overall length <=18m)	3853	4453	0.87	0.90	0.95
Bottom trawl (overall length >18m)	17356	19656	0.88	0.90	0.97
Mid-water pair trawl	8551	9130	0.94	0.95	0.99

The degree of capacity utilisation is also reflected in the variable input utilisation rate ( $\lambda$ ), which says how much variable inputs need to increase in order to operate at full capacity. Mid-water pair trawlers were operating at their optimal number of days in over 80% of observation (Figure 2). In contrast, about 60% of bottom trawlers observations were at their optimal number of days fished.

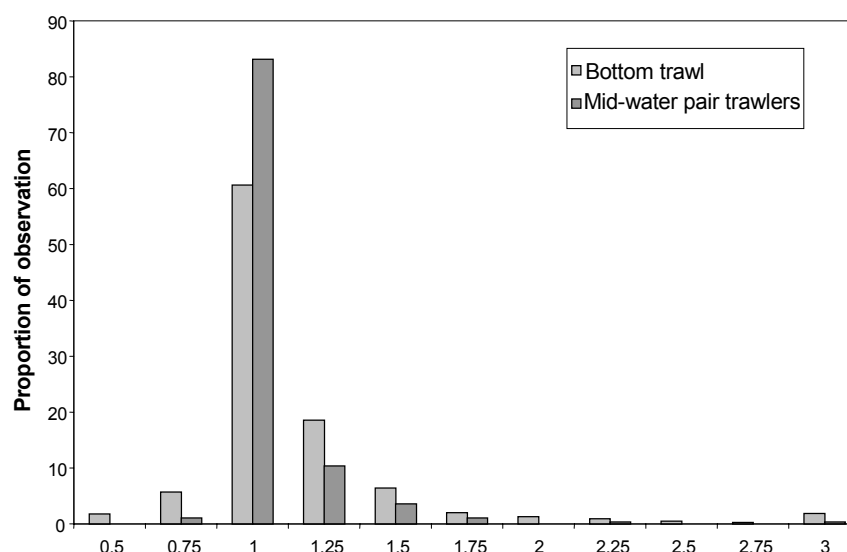


Figure 2. Variable input utilisation rate ( $\lambda$ ).

Finally, it is interesting to observe the trend of average CU scores throughout the period considered. The average CU results tend to decrease between 2000 and 2001 for all bottom trawlers and for bottom trawlers less than 18m in overall length whilst large bottom trawlers (greater than 18m in overall length) appear to have constant scores. In average, only CU unbiased scores based on revenue of mid-water pair trawl tend to increase from 98% to 99% over the period considered.

Table 4. Average CU results by year.

Gear	CU (1/01)		TE CU (01/02)	
	2000	2001	2000	2001
<b>Multiple outputs based on weights</b>				
Bottom trawl (total)	0.80	0.77	0.97	0.95
Bottom trawl (overall length≤18m)	0.91	0.78	0.97	0.93
Bottom trawl (overall length>18m)	0.85	0.84	0.96	0.96
Mid-water pair trawl	0.95	0.95	0.98	0.98
<b>Multiple outputs based on revenues</b>				
Bottom trawl (total)	0.86	0.81	0.97	0.95
Bottom trawl (overall length≤18m)	0.92	0.84	0.99	0.93
Bottom trawl (overall length>18m)	0.90	0.87	0.97	0.97
Mid-water pair trawl	0.93	0.94	0.98	0.99

#### 4. Conclusions

In this empirical analysis we have evaluated the efficiency of multi-output or multi-species fisheries using a non-parametric method such as Data Envelopment Analysis (DEA). Results indicate that both bottom trawlers and mid water pair trawlers operate close to their capacity output level. On average, the unbiased capacity utilisation levels of all fleet segments examined are over 94% for both catches and revenues measures. Mid-water pair trawlers appear to be operating more efficiently than bottom trawlers and between bottom trawlers larger boats have higher capacity utilisation scores than the smaller boats.

In these applications, the DEA methodology doesn't seem to give additional information about the economic performance of fleets examined because the results of the empirical analysis appear very similar. Almost all vessels sampled appear efficient. There are few differences between boats with different fishing gears and between bottom trawlers with different physical features. Probably the results are limited by the quality of variables included in the analysis and all these considerations suggest that other important factors have been ignored.

The DEA technique evaluates capacity establishing deviations from “best practice” performance, taking all types of fishing effort inputs into account, and comparing the resulting measures to those considering only the use of capital inputs, unconstrained by the availability of variable factors. The problem with the application to the Mediterranean case arises from the structure of fleet segments analysed, which is very homogenous. For example, if we observe the variable input, we can notice that days fished are very similar for both fleet segments considered because they are regulated by the same temporal withdrawal.

In our case it could be more interesting to analyse the characteristics of fishing activity of the vessels. For example, bottom trawlers usually follow the same fishing routes and for this reason their productivity is more influenced by the fishing area rather than by their capacity. This suggests the need to include a variable related to the fishing area in the model.

Finally the fundamentally random nature of the fishing processes under consideration suggests that stochastic methods could be preferable for estimation of efficiency. Hence future works shall compare DEA analysis with stochastic methods based on production functions.

## 5. References consulted

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