Physical versus harvest based measures of capacity: the case of the UK vessel capacity unit system

Louisa Coglan[1], Sean Pascoe[2] and Simon Mardle[2]
1). Department of Economics and 2). CEMARE,
University of Portsmouth, Locksway Road, Southsea, PO4 8JF, UK.

Abstract: The FAO International Plan of Action on the management of fishing capacity calls for all member states to provide estimates of the total capacity of their fleets by 2001. In the UK, a "capacity" measurement system is currently in place, based on vessel size and engine power. An assumption is made that this measure is related to the harvesting ability of the fleet, and is the basis of the existing capacity reduction programs. In this paper, the harvesting capacity of a sample of UK otter trawls and netter-liners is estimated using data envelopment analysis (DEA). Estimates are made on a species by species basis for the key species harvested. These are compared to the existing measures of physical capacity. Implications for capacity management based on the physical measures, given the results, are drawn.

Keywords: Capacity, Capacity measurement, vessel capacity units, DEA.

1. INTRODUCTION

In the pursuit of effective fisheries management policies the measurement and reduction of fishing capacity is emerging as a major issue confronting fisheries managers in the new millennium.

In 1998, a technical working group (the La Jolla working group) was convened by the Food and Agricultural Organisation of the United Nations (FAO) to consider the management of fishing capacity (FAO 1998). Following this, the FAO produced an International Plan of Action for the Management of Fishing Capacity in 1999 (FAO 1999), which calls for all member states to achieve efficient, equitable and transparent management of fishing capacity by 2005 (preferably 2003). In addition, the International Plan of Action requires member states to provide estimates of the capacity of their fishing fleets by 2001. An international conference was subsequently held in Mexico in December 1999 to discuss unified methods for the measurement of fishing capacity.

Johansen (1968) defines capacity as "the maximum amount that can be produced per unit of time with existing plant and equipment, provided that the availability of variable factors of production is not restricted" (p. 57, cited in Färe *et al* 1994). The La Jolla working group adopted Johansen's definition, and defined fishing capacity in terms of the potential output of a fleet (FAO 1998). This definition was largely adopted by the Mexico conference, with the recognition that managers could only manage capacity through fleet adjustment, so an equivalent physical measure of capacity was also required (FAO 2000). Many nations have already developed measures of capacity based on the physical attributes of the fleet, and have implemented capacity reduction policies based on these capacity measures, such as gross tonnage (GT) or engine power.

In the UK, vessel capacity units (VCUs) are based on a combination of the physical features of the boats, which are assumed to be linearly related to the harvesting ability of each vessel (the latter being the La Jolla working group's definition of capacity). In the case of multi-gear and multi species fisheries, such as the UK Channel fleet, physical capacity measures imply that it does not matter which boats are removed from the fishery. An additional complication is that whilst total physical capacity may be constant, capacity units are able to be transfer between fleet segments. Hence, the relationship between physical capacity and harvesting capacity for individual species may actually vary.

VCUs can, therefore, only be an appropriate proxy for harvesting capacity given there are no differences between the level of input utilisation and technical efficiency between boats with the same VCUs. Since there is no *a priori* reason to assume that this is the case, harvesting capacity measures need to be estimated separately from physical capacity measures.

Measures of harvesting capacity can be estimated using data envelopment analysis (DEA). The advantage of this approach is that it explicitly takes account of the level of input utilisation and technical efficiency of different operating units.

In this paper, the harvesting capacity of a sample of UK otter trawls and netter-liners is estimated using data envelopment analysis (DEA). Estimates are made on a species by species basis for the key species harvested. These are compared to the existing measures of physical capacity. Implications for capacity management based on the physical measures, given the results, are drawn.

2. METHODOLOGY

DEA is a linear programming technique that was developed in the work of Charnes *et al* (1978). It is a nonparametric technique used in the estimation of production functions and has been used extensively to estimate measures of technical efficiency in a range of industries (Cooper, Seiford and Tone 2000).

Seiford and Thrall (1990) describes DEA in terms of floating a piece-wise linear surface to rest on top of the observations (i.e. envelop the data). More specifically, the key constructs of a DEA model are the envelopment surface and the efficient projection path to the envelopment surface (Charnes *et al* 1994). The envelopment surface will differ depending on the scale assumptions that underlie the model. The projection path to the envelope surface is determined by whether the model is output orientated or input orientated. The choice of input or output orientated models depends upon the optimisation production process characterising the firm.

Input orientated DEA configures the linear program so as to determine how much the input use of a firm could contract if used efficiently in order to achieve the same output level. Output orientated DEA configures the linear program to determine a firm's potential output given its inputs if it operated efficiently as firms along the best practice frontier. Output orientated models are 'very much in the spirit of neo-classical production functions defined as the maximum achievable output given input quantities' (Färe *et al* 1994 p. 95).

DEA can be used to estimate capacity. It is of particular relevance in determining capacity in fisheries where the unique characteristics of the industry do not preclude its application. For example, a heterogeneous capital stock and/or a multi-product output does not present an indeterminacy problem, since the DEA approach converts each into a single composite factor (Kirkley *et al* 1999a).

In this study, output orientated DEA is used to determine (i) capacity output given current use of inputs, where boats' potential output is estimated based on its fixed inputs e.g. boat length, engine power etc., and (ii) a technically efficient measure of output where boats' potential output is estimated also taking into consideration the efficient use of variable inputs (i.e. days fished).

Following Färe *et al* (1989, 1994) the output orientated DEA model of capacity output given current use of inputs is given as:

$$\begin{aligned}
&\mathit{Max}\ \Phi_1\\
&s.t\\
&\Phi_1 u_{j,m} \le \sum_j z_j u_{j,m} \quad \forall\ m\\
&\sum_j z_j x_{j,n} \le x_{j,n} \quad n \in \alpha \qquad\qquad (1)\\
&\sum_j z_j x_{j,n} = \lambda_{j,n} x_{j,n} \quad n \in \hat{\alpha}\\
&\sum_j z_j = 1\\
&\lambda_{j,n} \ge 0 \quad n \in \hat{\alpha}
\end{aligned}$$

where Φ_1 is a scalar showing by how much the production of each firm can increase outcome, $u_{j,m}$ is amount of output m by firm j, $x_{j,n}$ is amount of input n used by boat j and z_j are weighting factors. Inputs are divided into fixed factors, defined by the set α, and variable factors defined by the set $\hat{\alpha}$. To calculate Johansen's measure of capacity output, the bounds on the sub-vector of variable inputs, $x_{\hat{\alpha}}$, need to be relaxed. This is achieved by allowing these inputs to be unconstrained through introducing a measure of the input utilisation rate ($\lambda_{j,n}$), itself estimated in the model for each boat j and variable input n (Färe *et al* 1994). The restriction $\sum_j z_j = 1$ allows for variable returns to scale[1].

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

$$\begin{aligned}
&\mathit{Max}\ \Phi_2\\
&s.t.\\
&\Phi_2 u_{j,m} \le \sum_j z_j u_{j,m} \quad \forall\ m \qquad\qquad (2)\\
&\sum_j z_j x_{j,n} \le x_{j,n} \quad \forall\ n\\
&\sum_j z_j = 1
\end{aligned}$$

where Φ_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 (i.e. the equality constraint on the output orientated model of capacity has been relaxed). Again, the restriction $\sum_j z_j = 1$ is imposed to allow for variable returns to scale.

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1 In contrast, excluding this constraint implicitly imposes constant returns to scale while $\Sigma z_j \le 1$ imposes non-increasing returns to scale (Fare *et al* 1989).

Capacity output based on observed outputs (u^*) is defined as Φ_1 multiplied by observed output (u). From this, capacity utilisation (CU) based on observed output (u) is:

$$\frac{u}{u^*} = \frac{u}{\Phi_1 u} = \frac{1}{\Phi_1} \qquad (3)$$

The measure of capacity utilisation ranges from zero to 1, with 1 being full capacity utilisation (i.e. 100 per cent of capacity). Values less than 1 indicate that the firm is operating at less than full capacity given the set of fixed inputs.

Implicit in the above is a downwards bias because observed outputs are not necessarily being produced efficiently (Färe *et al* 1994). An unbiased measure of capacity utilisation is calculated as the ratio of technically efficient output (Φ_2 multiplied by observed output) to capacity output (u*). That is:

$$\frac{\Phi_2 u}{\Phi_1 u} = \frac{\Phi_2}{\Phi_1} \qquad (4)$$

The technically efficient measure of capacity utilisation again ranges from zero to 1. Values less than 1 indicating that, even if all current inputs (both variable and fixed) were used efficiently, output is less than potential output. That is, output could increase through increased variable input use.

In fisheries, the technique has been applied to the Malaysian purse seine fishery (Kirkley *et al* 1999a), US Northwest Atlantic sea scallop fishery (Kirkley *et al* 1999b), Atlantic inshore groundfish fishery (Hsu 1999), pacific salmon fishery (Hsu 1999), the Danish gillnet fleet (Vestergaards *et a*l 1999), and the total world capture fisheries (Hsu 1999).

3. THE WESTERN CHANNEL FISHERY – BACKGROUND AND DATA

The English Channel fishery consists of a wide variety of fishing activities that are aimed at targeting a variety of species. Approximately 4000 boats operate within the English Channel, over half of which are UK boats. UK boats broadly fall into 7 gear types: beam trawl, otter trawl, pelagic/mid-water trawl, dredge, line, nets and pots. In total 92 species are landed by boats operating in the English Channel. However, the majority of the landed weight and value are made up of less than 30 species. Much of the UK fishing activity takes place in the Western Channel.

Physical vessel capacity is currently measured in the fishery using vessel capacity units (VCUs). These are defined by:

$$VCU = l \times b + 0.45kW \qquad (5)$$

where l is length of the boat (in metres), b is the breadth (in metres), and kW is the engine power (in kilowatts). This formula was derived from an econometric analysis of the Scottish North Sea trawlers and was found to explain between 70 and 80 per cent of the differences in earnings between boats (UK Fisheries Department 1988)[2]. While derived on the basis of the North Sea trawlers, the formula has been applied to all UK registered boats.

A data set was constructed from log book records for all otter trawls and netter-liners greater than 10 meters in length[3], operating in the Western English Channel in 1995. The data set included observations for 60 otter trawlers and 17 netter-liners. Three netter-liners were excluded because of erroneous logbook data.

While all boats in the fishery use a range of gears, otter trawlers predominantly used the trawl gear over the period examined. In contrast, netter-liners tended to use both nets and long lines, often at the same time. Otter trawlers operate throughout the year, although the most intense period is during the summer. Otter trawling is slightly sensitive to climatic and tidal conditions. For many of the smaller otter trawlers fishing during the winter will therefore be irregular. Similarly, netter-liners operate throughout the year though specific gear types are particular sensitive to tides or times of the year. For example, gill nets are used only on a neap tide (which occur twice a month). In contrast, other gear types are used more during a specific periods (e.g. hand-liners operate in Western Channel mainly in August to mid-January) (Tétard *et al* 1995).

Both otter trawlers and netter-liners tend to be opportunistic (i.e. dependent on market conditions and stock availability), and consequently their catch composition is relatively varied. The Western Channel netter-liners catch a wide range of species, the main types

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[2] The original model was based on a Dutch study of North Sea beam trawlers. This model was applied to Scottish boats. However, the econometric analysis was undertaken in logarithmic form, i.e. *ln*(earnings) =f(*ln*[VCU]) (UK Fisheries Department 1988).

[3] Boats less than 10 metres were excluded as these tend to be highly opportunistic, switching gear regularly. As a result, they tend to undertake a wide range of fishing activities over a year (in some cases using 4 or more gear types). Larger boats tended to be more consistent in their gear use. For the purposes of analysis it was necessary to identify relatively homogenous boat types.

including hake, pollack, ling, cod, monk, and whiting. Otter trawlers catch a similar range of species as well as sole, cuttlefish and plaice (Tétard *et al* 1995).

This study considered the main target species (cod, cuttlefish, hake, ling, monk, plaice, sole and whiting) with all other species aggregated into an 'other' category. While the target species form the minority of the catch by weight, they generally form a significant part of the value of the total catch. Further, most of the target species are subject to quota control and are of main interest to fisheries managers (e.g. cod, hake, monk, plaice, sole and whiting).

The key inputs used in the analysis were days fished, length and breadth of boat and engine power (kW) (Table 1). Fixed inputs (length, breadth and engine power) correspond to what is used in the estimation of vessel capacity units. Variable inputs only included days fished. Whilst data was available on crew, only annual crew had been recorded (therefore crew did not vary through the sample period).

Inputs were relatively similar between otter trawlers and netter-liners. Netter-liners fished, on average, approximately 2 days less a month than otter trawlers. Otter trawlers tended to have, on average, physically bigger boats (in terms of length times breath), although netter-liner boats had on average larger engines. There is no *a priori* reason why this would be the case. Vessel capacity units are presented for information but were not used in the DEA model.

Table 1. Key inputs for otter trawlers and netter-liners

	Variable	Fixed			
	Days fished	Length	Width	Kw	VCU
Otter Trawlers					
• Average	14.0	13.27	4.66	157.7	133.9
• Maximum	34	23.16	6.34	373	303
• Minimum	1	10.33	3.62	28	52
Netters-liners					
• Average	11.9	12.29	4.34	171.2	131.5
• Maximum	31	23.82	5.79	442	244
• Minimum	1	10.4	3.5	55	69

4. ANALYSIS AND RESULTS

The DEA model was developed in GAMS (Brooke *et al* 1992).

Catch composition changes over the year due to different patterns of seasonal abundance (Pascoe 1988). However, information on the stock conditions in each month was not available, so a stock variable could not be included in the analysis. To allow for variations in availability, the DEA model was run categorically. That is, 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 abundance was relatively constant over the month so that the timing of fishing did not affect the catch composition. Spatial variations in catch composition are also not considered. The analysis is limited to one area of the Channel (the western half) and it is assumed that species abundance does not vary substantially across this area.

The model was also run separately for the two fleet segments such that otter trawlers were not directly compared to netter-liners. A combined analysis would have required the assumption of a common production process, which clearly is not realistic.

From the model output, capacity utilisation (CU) varied considerably by species and between the two fleet segments examined (Table 2). For most species, the otter trawlers were operating at less than 90 per cent capacity (e.g. cod, hake and ling) and for some species less than 80 per cent capacity (e.g. cuttlefish, plaice and whiting). 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 capacity utilisation (i.e. TE CU) for the target species would have been greater than 90 per cent.

Table 2. Estimated capacity output (tonnes) and capacity utilisation by species

	Observed output	Capacity output	TE output	CU $1/\theta_1$	TE CU θ_2/θ_1
Otter trawlers					
Cod	89.5	108.3	98.2	0.83	0.91
Cuttlefish	472.2	649.6	596.4	0.73	0.92
Hake	15.1	17.5	16.0	0.86	0.91
Ling	33.8	38.1	35.7	0.89	0.94
Monk	218.4	260.1	237.3	0.84	0.91
Plaice	121.7	158.0	144.6	0.77	0.91
Sole	15.2	18.6	17.1	0.82	0.92
Whiting	650.6	822.0	757.0	0.79	0.92
Other	2499.4	3550.4	3038.5	0.70	0.86
Net-liners					
Cod	38.0	41.2	40.4	0.92	0.98
Cuttlefish	25.3	26.7	25.7	0.95	0.96
Hake	3.8	3.9	3.8	0.98	0.99
Ling	84.6	88.2	86.9	0.96	0.99
Monk	57.5	59.3	58.8	0.97	0.99
Plaice	8.5	9.2	8.8	0.92	0.96
Sole	3.4	3.5	3.4	0.98	0.99
Whiting	59.3	66.1	63.0	0.90	0.95
Other	786.7	894.2	856.4	0.88	0.96

In contrast, the netter-liner fleet segment were generally operating at above 90 per cent capacity, and if inputs were used efficiently, would be operating at almost 100 per cent capacity for most of the target species.

The higher degree of capacity utilisation of the netter-liners is also reflected in the variable input utilisation rate (λ). Netter-liners were operating at their optimal number of days in over 80 per cent of observations (Figure 1). In contrast, only about 60 per cent of the otter trawler observations were at their optimal number of days fished.

Comparing average capacity output per VCU for each species between the two fleet segments suggests that the capacity output of the two groups differ (Table 3). On this basis, decreasing VCUs in the otter trawl fleet may result in a greater decrease in total capacity output of all of the quota species (with the exception of cod) than an equivalent decrease in VCUs in the netter-liner segment.

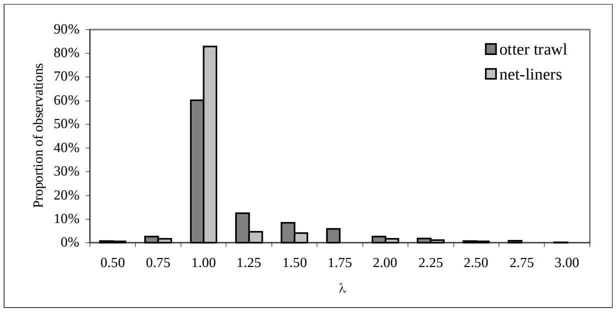

Figure 1. Variable input utilisation rate (λ)

Table 3. Average capacity output per VCU (kg/VCU)

	Otter trawlers	Netter-liners
Cod	13.5	18.4
Cuttlefish	80.8	11.9
Hake	2.2	1.7
Ling	4.7	39.4
Monk	32.3	26.5
Plaice	19.6	4.1
Sole	2.3	1.5
Whiting	102.2	29.5
Other	441.4	399.1
No. VCUs	8043	2240

Basing the expected impact of changes in fleet structure on average capacity output assumes that output is correlated to the number of units (the whole basis of the unitisation system). Correlation of the capacity output of individual boats with VCUs suggests that VCUs are reasonably correlated with the capacity output of otter trawlers for most species, particularly cod and sole (Table 4). As these two latter species are the main target species of trawlers in the North Sea (from which the VCU formula was derived), such a result is not surprising.

However, with the exception of monk, there is little correlation between VCUs and capacity output of the netter-liner boats (Table 4). Hence, while the expected impact on capacity output due to changes in VCUs in the fleet may be reasonably estimated for the otter trawl fleet, it is unlikely that any realistic impact of VCU change could be estimated for the netter-liner fleet.

Table 4. Correlation between output capacity (kg) and VCUs of individual boats

	Otter trawl	Netter-liner
Cod	0.60	0.06
Cuttlefish	0.09	-0.11
Hake	0.44	0.17
Ling	0.40	-0.12
Monk	0.44	0.52
Plaice	0.49	0.06
Sole	0.67	-0.19
Whiting	-0.03	0.05
Other	0.27	-0.01

5. DISCUSSION AND CONCLUSIONS

If operated efficiently, both fleets examined would be operating close to their capacity output level. On average, the netter-liner fleet appeared to be operating more efficiently than the otter trawl fleet. Coglan *et al* (1999) found that 70 per cent of the trawlers in the English Channel (including both beam and otter trawlers) were operating at less than 90 per cent efficiency while almost 40 per cent were operating at less than 75 per cent efficiency. Much of the difference in efficiency was thought to be due to differences in skipper skill (Coglan *et al* 1999). These results are consistent with the results presented in Table 2 for the otter trawlers. Previous studies of the technical efficiency of netter-liners have not been undertaken in the Channel.

As with any analysis, the results are limited by the quality of the data. A particular problem in fisheries analyses is mis-reporting. Fishers are not required to record their catches of non-quota species (i.e. ling, cuttlefish and 'other' species), although most do. However, there is no guarantee that all landings of these species are recorded, as it is likely that small catches would not be recorded. In this study, the non-quota species of interest were target species and generally caught in large quantities. It is assumed that recorded measures of catch of these species are reliable. While some catch may not have been recorded by these boats, it is likely that this is relatively small in comparison to the total landings of these species.

Incentives exist to mis-report landings of quota species, particularly if the aggregate quota is full or close to being filled[4]. The extent to which this affected the records is uncertain. A necessary assumption of the analysis is that the individual records of landing are correct. However, discarding of catch is likely to have taken place, and this may be manifesting itself in the form of inefficiencies and under-capacity. In such a case, fishing capacity may be a better indicator of actual fishing mortality than landings for quota species.

A further problem with the analysis – a problem common to any multi-species analysis – is that not all boats caught all species in every month. As a result, zero catches were recorded for some species in some months for nearly every boat in the data set. As a necessary condition for DEA is that all inputs and outputs are greater than zero, zero catches were replaced by a nominal 0.1kg. This is not expected to have distorted the capacity output substantially, and is likely to be a better approach to capacity measurement than excluding most of the observations in the data set.

The measure of capacity output is a technical measure only, and does not take into account the costs of fishing. While it may be technically feasible for boats to increase output, it may not be worth fishing more if the marginal cost exceeds the marginal benefits. Boats which are operating close to full capacity may not be economically efficient given the current stock level. Information is not available to make any assessment about this.

The results of the analysis are also only short term. In some cases, it may be economically efficient for boats to operate at less than full capacity if this is due to a resource constraint (i.e. stock abundance) and that this constraint is not (or less) binding in other years (i.e. "peak" years).

Despite these problems, the analysis provides an interesting insight into the potential effectiveness of the decommissioning schemes in the fishery based on VCUs. Capacity reductions are required in most EU member states under the European Union's Multi-Annual Guidance Programme (MAGP). In the UK, these have been implemented through a decommissioning program based on VCUs. Pascoe and Coglan (2000) demonstrated that the effectiveness of this programme may have been less than expected for beam and otter trawlers as a result of differences in efficiency of fishing vessels (such that the effective capacity removed is less than the nominal capacity). From this study, the lack of correlation between VCUs and capacity of the netter-liners further calls into question the effectiveness of the programme.

While a physical measure of capacity is essential for fisheries management (Hsu 1999, FAO 2000), this study also calls into question the desirability of applying a single measure of physical capacity to all fisheries. The formula currently used in the UK appears to be reasonable in representing the harvesting capacity of the otter trawlers, but unreasonable in representing the harvesting capacity of netter-liners. It is likely that this result could be extended to other fleet segments using static gear (e.g. potting boats). As a result, fishery specific measures may need to be developed (e.g. related to gear type or fishing activity).

This has wider implications than just deriving new measures of physical capacity. Under the current management system, licences are not defined in terms of gear types that can be used. However, in order to estimate physical capacity effectively, the fleet will need to be delineated into distinct segments, and licences applied to these individual segments.

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