Measuring Capacity in Fishing Industries using the Data Envelopment Analysis (DEA) Approach

Final Report

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1. Summary and Conclusions

The overall purpose of the project has been twofold: methodological and empirical. The application of the Data Envelopment Analysis (DEA) method to analyse fishing capacity is very recent and still not fully developed towards fishery applications. Therefore during the work several methodological issues were treated, issues that have not been handled before in the literature. Empirically, the DEA method has been applied to many EU fisheries, all of very different nature. The results from the various stages of the analyses provide a useful insight into capacity utilisation and levels of excess capacity. Two different approaches were undertaken, the firm level and the industry level approach. The individual vessel analysis provides information about the capacity utilization, while the industry analysis shows possible reduction in the fleets. The data requirements of DEA analysis are not very high because the analysis can be done with a minimal dataset; however, the main barrier is that the data needs to be at firm level.

Generally, the analyses have been privileged by the comprehensive and detailed amount of data available. The DEA analyses have provided realistic and reliable results, which highlight interesting and usable characteristics of the capacity utilization of the considered fleet segments. The second stage and the industry level analyses moreover yield interesting results, and seem to have considerable potential for further development. It is thus the general belief that the DEA analysis, and related analyses, may be a valuable tool in future management of EU fisheries.

United Kingdom

The results from the various stages of the analyses present the capacity utilisation scores in English Channel fisheries, and their levels of excess capacity. From the individual vessel analyses, it appears that the fleet is utilising, on average, around 80 percent of its capacity. From the industry analysis, full capacity utilisation may require a reduction of around 25 per cent of the fleet, at least for the vessels targeting quota species.

The factors that affect the level of capacity utilisation were less clear than anticipated. While prices and fuel costs were expected to be important factors, these did not appear to affect the level of capacity utilisation in the manner expected. The main ‘drivers’ of capacity utilisation appear to be relative stock abundance, which in turn affects catch rates. With inflexible prices, as is the case with most species in the Channel for which demand relationships have been examined, the revenue per unit of effort will be directly related to stock abundance. As a result, it is likely that capacity utilisation is related to economic incentives.

The above analysis of capacity utilisation and the ‘optimal’ fleet size is based purely on technological measures of output rather than on economic measures. The analysis ignores the costs of fleet reduction if a policy such as a decommissioning scheme is imposed. Further, it does not relate to the economically optimal fleet size. Despite this, the DEA technique can provide useful information to fisheries managers in terms of potential excess capacity in the industry. The study identified a number of potential problems and methods for dealing with these problems. In particular, the problem of multi-species multi-métier fisheries was addressed. The study demonstrated that ignoring other activities could result in a biased estimate of capacity utilisation. Similarly, the problem of degrees of freedom was also examined. This was found to be less of a problem than expected, but caution should nevertheless be taken when the analysis is applied to small data sets.

France

Beyond the DEA analysis of capacity utilisation according to the common methodology, we have focused on the question of the scale efficiency of the vessels and on the inclusion of a stock index in the DEA approach. We conclude that there are increasing returns to scale in the seaweed fishery and that this situation could explain the dynamics of the fleet, which is now composed of a larger share of bigger vessels. Secondly, the integration of stock index may explain difference in CU scores and in efficient and capacity output levels. Despite the inherent difficulties of including resource influences in the measures of vessel efficiency, this approach could be generalised.

The analysis of CU scores concludes that there is large difference between vessels even if it depends on the fisheries studied. The indicators provided by the model – observed CU or unbiased CU – give measures of the necessary shifts in fixed or variable inputs to reach efficient or capacity output. At a large scale – for example of the Channels fisheries – the potential for an increase in variable input, which is malleable on a short-term basis is high. All things equals, the capacity output of the fleet is high compared to the current level and this is of interest from a management perspective. However, it is difficult to identify the factors explaining the variability of CU scores. Based on the available information and a preliminary statistical analysis, the study shows that CU depends on the other activities practiced elsewhere in the fishery sector or in other sectors. However, the main sources of deviation are the length of the vessels and the use of gears or combination of gears. The bigger the vessels are, the higher is their CU scores.

Finally, the study gives an assessment of the total engine power or other physical indexes that should be excluded from the fishery to reach optimal fleet size. Parallel to this approach, we valued the (private) cost of upgrading the observed fixed input to the capacity input level and the (public) cost of decommissioning schemes required to reach the optimal fleet size according to regulations.

Belgian Beam Trawl Fleet

Concerning the individual vessel analysis for the sample fleet for the period 1996 – 2000 the capacity utilisation score based on the observed output is 0.88 on average. The technical efficiency for the entire fleet sample is calculated at 0.97. Hence in general the sample fleet is operating in a relative efficiently way. This is reflected by an unbiased efficiency capacity utilization score for the entire fleet sample of 0.91. If one regards the projected output based on the calculated capacity utilisation scores as indicative for production under unrestricted circumstances, on average output could be increased by 17%. Concerning factors that influence the capacity utilisation of vessels it is regarded that prices play an important role. Also an annual fluctuation of efficiency scores is reflected in the analysis.

From the sector analysis and the composition of the fleet, based on the used sample of vessels, the results indicate a similar trend. Present magnitude of output under efficient conditions could be achieved on average with 75% of fixed inputs and 82% of variable inputs.

In general, the conclusion must be that since the effort data (not available) were being estimated based on the operations of a similar, though different, fleet with a distinctly different deployment of the variable input, the analysis can only be regarded as being indicative.

German Beam Trawl Fleet

Concerning the individual vessel analysis for the sample fleet for the period 1996 – 2000 the capacity utilisation score based on the observed output is 0.34 on average. The technical efficiency for the entire fleet sample is calculated at 0.75. This rather large difference between the two entities can be attributed to the fact that the sample fleet is a rather heterogeneous amalgamation of vessels operating in a wide variety of modes of production (metiers). An analysis taking into account production realised in an adjacent fishing activity should provide a more general efficiency score per vessel for the totality of fishing activities undertaken. This is partly reflected by an unbiased efficiency capacity score for the entire fleet sample of 0.54. Stock- and quota data influence the capacity utilisation of individual vessels. If one focuses on technical efficiency as a measure of projected increase in output as a result of increased efficiency, the projected unrestricted output would be in the order of 14% higher than observed output.

From the sector analysis and the composition of the fleet, based on the used sample of vessels, the results indicate a similar trend. Present magnitude of output under efficient conditions could be achieved on average with 34% of fixed inputs and 99% of variable inputs, which corresponds with the production of 38% of the sample fleet at fully efficient modes of operation.

In general the conclusion is that based on the present sample of vessels and the available data, it is problematic to draw general conclusions as to the efficiency of the fishing operation. Compared to the capacity output, the technically efficient output scores show a relatively noteworthy degree of efficiency.

Dutch Beam Trawl Fleet: Plaice and Sole Fisheries

Concerning the individual vessel analysis for the sample fleet for the period 1992 – 1999 the capacity utilisation score based on the observed output is 0.84 on average. Hence the entire fleet can be characterised as being relatively efficient. Concerning the two segments of the beam trawl fleet, the capacity utilisation score of the segment with an engine capacity of less than 1500 HP is slightly below the total average (0.82) whereas for the group of 1500 Hp and over the average capacity utilisation score is 0.84. If one regards the projected output based on the calculated capacity utilisation scores as indicative for production under unrestricted circumstances, on average output could be increased by 33%.

Concerning factors that influence the capacity utilisation of vessels, there is a significant difference between vessels operating form the northern ports and those operating from the southern ports. This would indicate that along with distinguishing vessel size and related mode of production (metier; especially as a reflection of output realised in a different mode of production), home port plays a significant role in constructing reference groups in calculating capacity utilisation scores, and hence in determining the efficiency of operations. As was expected the set of price developments and stock- and quota data influence the capacity utilisation of individual vessels.

The technical efficiency score for the entire fleet sample is calculated at 0.91 with the smaller vessel being more efficient (0.94) than the larger vessel segment (0.90). Still the technical efficiency of the entire fleet sample is high. The systematic difference of capacity utilisation scores between the two fleet segments would suggest the use of two separate analyses with each focusing on a more homogeneous group of vessels. This is in line with the fleet characterisation in which the vessels of 1500 Hp and over operate in a much more homogenous way then the smaller vessels.

From the sector analysis and the composition of the fleet, based on the used sample of vessels, the results indicate a similar trend. The present magnitude of output under completely efficient conditions could be achieved on average with 80% of fixed inputs and 97% of variable inputs, which corresponds with the production of 88% of the sample fleet at fully efficient mode of operation. Hence, taking into account adverse conditions of operation the number of sea days used at present is at par with efficient production conditions. When taking variances in production and efficiency into consideration[1] the fleet size is operating relatively efficient.

The general conclusion is that, on average, the vessels are operating in a relatively efficient manner. However the level of efficiency is determined by both environmental factors and by the composition of the reference group. In a further analysis focus should be on the study of a constant group of similar vessels over a time period. This reference group then could provide the information useful to perform analyses with different restrictions and assumptions.

Dutch Beam Trawl Fleet: Shrimp Fisheries

The analysis of the shrimp fleet has been based on observations by gear type and not on vessel observations at metier level. As a result capacity scores relate to efficiency of the gear and not necessarily to the vessel itself since the vessel could operate a number of gears consecutively in any given year. Concerning the individual gear for the sample fleet for the period 1992 – 1999, the capacity utilisation score based on the observed output is 0.46 on average. The technical efficiency score for the entire fleet and gear sample is calculated at 0.62, ranging from 0.53 to 0.94. The unbiased efficiency score for the entire fleet and gear sample is 0.68.

Concerning factors that influence the capacity utilisation of gears by vessels there is a significant difference between the consecutive years. In addition spawning stocks and quota influence the efficiency of the operation.

Denmark

The Danish analysis is based on data obtained from the Danish Directorate of Fisheries. The dataset covers selected segments of the Danish fishing fleet in the period 1991 to 1998. Fishing areas considered are the Skagerrak, the Kattegat, the Sound, Belt Sea and Baltic Sea, the North Sea and other fishing areas. Vessel types are Gill netters and liners, Multi-purpose vessels, Purse seiners, Danish seiners and Trawlers. Catch has been classified into 9 categories: Cod, Other Cod fish, Plaice, Sole, Herring and Mackerel, Norway Lobster, Shrimps, Other consumption species and Industrial species. Only landed weight has been considered. Data has generally been aggregated on a yearly level.

The individual vessel capacity utilisation analysis has examined as observed and efficient capacity utilization at the individual vessel level for selected fleets. Observed capacity utilisation allows variable inputs to be readjusted optimally, while efficient capacity utilisation corrects the observed ca-

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[1] The average ratio between projected output based on technical efficiency and observed output is 112.3% with a variance of 377.9.

pacity for technical efficiency bias, i.e. assumes that observed fixed inputs are used optimally before capacity is measured. Observed and efficient capacity utilisation scores at the individual vessel level have been obtained using DEA analysis, and the distributions of these scores described for each fleet considered. Fleets have been characterised by vessel type, sea area and operating year. Trawlers and netters in the North Sea and in the Skagerrak in all years 1991-1998 have been analysed. The individual vessel analysis has firstly shown that 20-30 % of trawlers and netters in the North Sea and in the Skagerrak are observed to operate near to full capacity. Secondly it has been shown that if the vessels had used their observed inputs optimally more than half of the considered fleets would be operating very near to full capacity, and thus much may be gained simply by reallocation of already existing inputs.

The second stage comparative analysis covers comparison of observed capacity utilization of selected fleets using two different methods, between-type comparison and regression analysis. In the between-type analysis, optimal observed capacity utilisation frontiers are compared for the different fleets two by two by the Wilcoxon-Mann-Whitney rank sum test. Fleets considered are trawlers and netters in the North Sea and in the Skagerrak in the two years 1991 and 1998. Observed capacity utilisation frontiers are firstly obtained for each individual fleet by separate DEA analysis. Secondly non-efficient vessels are projected onto these individual frontiers. Thirdly the resulting frontiers of the two fleets that are compared are merged and a joint DEA analysis performed for this merged set. Finally the difference in location of the hereby obtained capacity utilization scores of the two fleets is investigated with the rank sum test. By this procedure it is analysed whether the frontiers of the two fleets are equally located or whether one frontier is located below or above the other, and thus whether the two fleets operate at similar or different levels of capacity. The analysis has firstly shown that netters have generally become less efficient during the period 1991-1998, while trawlers on the contrary have become more efficient. Secondly it has been observed that netters have been more efficient than trawlers in both areas in 1991 while trawlers have been more efficient than netters in both areas in 1998. Thirdly trawlers shift in the period from being most efficient in the Skagerrak to being most efficient in the North Sea, while the netters are most efficient in the Skagerrak in both years.

The regression analysis is based on the observation that vessels might operate in different external environments and hence the CU scores obtained might be biased. By regressing the CU scores on external factors the influence of these can be assessed and the CU scores adjusted. The analysis shows that a higher share of cod catch has a negative impact on the CU score and that vessels fishing in the Kattegat and the North Sea have a higher CU than vessels fishing in The Skagerrak.

The industry analysis focuses on the fleet structure and the use of vessels (i.e. fixed inputs in the fishery). The CU scores obtained in the individual analysis are used as inputs in an aggregated model, the objective is to minimise the use of fixed inputs while at the same time catching the TAC for each species. The results show re-allocation of inputs and outputs between vessels and the optimal configuration of vessels and fleets. In the case of the Danish fishery in 1998 it is shown that the Danish fleet can be reduced by 35%-47% depending on the chosen objective. The method also gives information on the resulting fleet structure and hence the manager can target a fleet reduction program towards the relevant vessels-groups.

2. Introduction and background

There has been a long history of recognizing the need to control excess harvesting capacity in fisheries. Fishery researchers have, in fact, strongly argued that the major problem confronting fishery managers is overcapitalisation and excess capacity (Mace 1997). Warming (1911) and Gordon (1954) were the first to show that unregulated entry into a fishery would lead to severe capitalization and hence both biological and economic overfishing, i.e. sub-optimal levels of harvest capacity, capital and harvest. Since then, there have been many reports and conferences addressing the need to control excess harvesting capacity in fisheries. However, there is no universally accepted definition or measurement of capacity and capacity utilisation. Within the fishery, capacity-related concepts are defined and employed by biologists, resource managers, and economists. They all define capacity in terms that are useful for addressing their own particular concerns. Also fishery scientists and managers have had a tendency to define capacity and related concepts relative to information available. See Kirkley and Squires (1999) for a detailed overview.

Capacity and capacity utilization is therefore important concerns for fisheries management. In the European Union (EU), a Multi-Annual Guidance Program (MAGP) has been in force since 1983. The primary function of the MAGP is to recommend adjustments to the size and operation of fishing fleets commensurate with the potential harvest levels of the available resources. Since 1987, the main instrument to achieve this objective has been to withdraw vessels from the fleets. Several reports have pointed out that the reduction in the size of the fleet, on average, must be at least 40% in order to match the fleet capacity to the availability of the resource. However, these suggestions were based on only biological considerations.

Although economic theory offers numerous procedures for developing measures of capacity and capacity utilization (CU), most of the theoretical approaches cannot actually be used to assess capacity and capacity utilization in fisheries, because in most cases the data are inadequate. In economic theory and used for conventional industries, capacity and CU are defined in terms of output-based measures.

The nature of fisheries is such that problems related to externalities, excess capacity, and overcapitalisation dictate final policy recommendations in terms of the levels of inputs. If resource managers or administrators desire to resolve the problems associated with excess capacity, it is necessary first to assess the current level of capacity and second, to determine an optimal level of harvesting capacity, and finally, the level by which the current level of capacity must be reduced. A solution is driven by the fact that in a fishery, the critical concerns are economic waste (e.g., production is not least cost) and excess harvesting capacity.

Of the various approaches, the Data Envelopment Analysis (DEA) approach perhaps is the easiest and offers the most promising method to determine harvesting capacity. With the DEA approach, it is possible to determine the characteristics of the firms, which maximize output, minimize input, or optimise relative to revenue, costs, or profits. In the case of fisheries, managers may want to determine how many vessels should be in a fishery and their characteristics (the respective level of input utilization and the gear type) and the level of output which is allocatively or technically efficient. The DEA approach allows the determination of such variables.

A FAO technical working group (FAO 1998) and a FAO technical concultation (FAO 1999), suggested both the use of the DEA approach as a common method to measure capacity and capacity utilisation. However, the groups also recognized that practical case studies were needed. The groups proposed a definition of capacity based on potential output, which was been adopted by the FAO Committee of Fisheries at the Twenty-third session in February 1999 (see internet www.fao.org).

DEA is a nonparametric or mathematical programming approach. DEA has been widely applied to problems in which answers about optimum input levels or output level and their characteristics were desired. A comprehensive discussion and introduction to DEA may be found in Charnes et al. (1995) and Färe et al. (1994). There are two primary orientations of the DEA approach. Frontiers and technical efficiency may be assessed from an output or input-orientation. These two orientations, however, are quite different than the input and output orientation considered for assessing capacity. With DEA, and input-based measure indicates the level by which inputs may be changed to best harvest a given output level; the input-based capacity measure focuses on determining the maximum level of input usage. The output-based efficiency measure in DEA determines by how much output can be expanded or changed given the available level of inputs. Relative to assessing capacity and capacity utilization in fisheries, both approaches may provide useful information. The input-based measure would allow the determination of the optimal fleet configuration and actual vessels, which should be in a fishery given a Total Allowable Catch. Alternatively, the output-based measure would allow managers to identify the level of output and subsequent vessels, which would maximize output subject to given input levels and resource constraints. Thus, by knowing the TAC, managers can determine the number of vessels and actual vessels, which yield maximum harvesting efficiency subject to a TAC constraint.

In the case of assessing capacity and capacity utilization in fisheries, the framework of Färe et al. (1994) is utilized. By appropriately specifying a DEA problem, the vessel capacity utilization rates and the ith input utilization rate might be determined. Given the capacity utilization rate, the capacity output is easily estimated. The determination of capacity and capacity utilization may be done at the individual firm level, sub-fleet level or relative to fleet performance. Relative to fisheries and the needs of resource managers, the preferred solution should probably be an integrated analysis where both the capacity level is determined at the individual vessel level and at the fleet level.

After stating the objective of the work in the next chapter, the methodology and used methods are reviewed in chapter 4. The chapters 5 to 8 cover a summery of each country case studies, while the report is finalised by the conclusions. In the appendix, complete reports of the country case studies are provide together with the GAMS code of the used DEA models.

3. Objective of the work

The objective with the project was to use the DEA approach to measure the capacity and capacity utilization of selected EU fishing fleets. In particularly, the following questions were put forward as the main research and policy questions:

- What is the maximum amount of output and fishing mortality a vessel, operating unit, or fleet can produce given available input stocks?

- Which external factors explain the variation in the capacity utilisation between vessels and vessel gear-types?

- What portion of total fishing effort is redundant or unnecessary relative to present levels and biological and economic Total Allowable Catches (TACs) ensuring sustainable fisheries?

- What is the "balanced" or target structure of industry and the utilization of inputs?

All the questions have been addressed in different magnitude in this report. The expected outcome of the project was three fold:

- Development of the DEA approach to measure capacity and capacity utilization in multi-product and multi-input industries, here the fishing industry

- Application of the approach on the EU fishing industry

- To provide estimates of the excess capacity of the fleets and in fisheries involved in the study

Since the application of the DEA approach is very recent to fisheries, some novel applications have been developed and applied in the report. The second stage analysis, where the influence of external factors on the variation in the capacity utilisation between vessels and vessel gear-types is determined and capacity frontiers of different fisheries are compared, has not been applied to fisheries before. Further, the integrated assessment of the industry capacity using the DEA approach is among the first applications.

4. Methodology and methods used

4.1. Definitions of Capacity

Capacity has been defined in many ways. Figure 4.1 below graphically depicts some of the various economic and physical capacity definitions that have been suggested. Klein (1960) stated that the output level associated with optimal capacity was at the tangency point between the short-run average cost (SRAC) and long-run average cost (LRAC) curves, point A in figure 4.1. Berndt and Morrison (1981) suggested that the minimum point of the SRAC curve should represent optimal capacity, point B. In physical terms, 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 are not limited”, point D. Coelli et al. (2001), however, stress that these three capacity measures suggest that firms operate at a point where short-run profit is foregone. Hence, they suggest that the point of short-run profit maximisation be used as the preferred measure of capacity, point C.

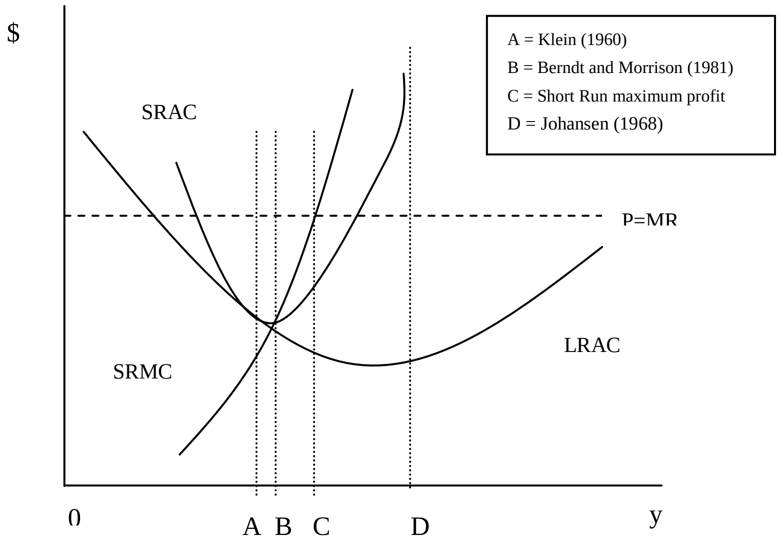

Figure 4.1. Measurement of Capacity (Coelli et al. 2001)

In 1999, the Food and Agricultural Organisation of the United Nations (FAO) agreed on an International Plan of Action for the Management of Fishing Capacity. The plan calls for all member states to achieve efficient, equitable and transparent management of fishing capacity by 2005, and to provide estimates of capacity of their fishing fleets by 2001. In this regard it has been concluded that the Johansen (1968) definition of capacity, with slight modification, can be shown to provide a suitable measure of capacity. Guidelines laid down by the FAO Technical Working Group on the Management of Fishing Capacity (FAO 1998), hence proposed that capacity should be viewed as a physical (technical) output, where:

> *"Fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilised, given the biomass and age structure of the fish stock and the present state of the technology".*

4.2. Measuring Efficiency and Capacity

Farrell (1957) proposed that the efficiency of a firm consists of two components: technical efficiency and allocative efficiency. Technical efficiency in this context reflects the ability of a firm to obtain maximal output from a given set of inputs, whereas allocative efficiency refers to the firm's ability to use inputs in optimal proportions, given the production technology and input prices. The two measures in combination provide a measure of total economic efficiency (Coelli et al. 1999).

In the simplest terms, technical efficiency (TE) is an indicator of how close actual production is to the maximal production that could be produced given the available fixed and variable factors of production. TE may also be an indicator of the minimum levels of inputs or factors of production necessary to produce a given level of output relative to the levels of inputs actually used to produce that same level of output (Kirkley et al. 1999). In the case of fisheries, this interpretation is consistent with the FAO definition of fishing capacity described above.

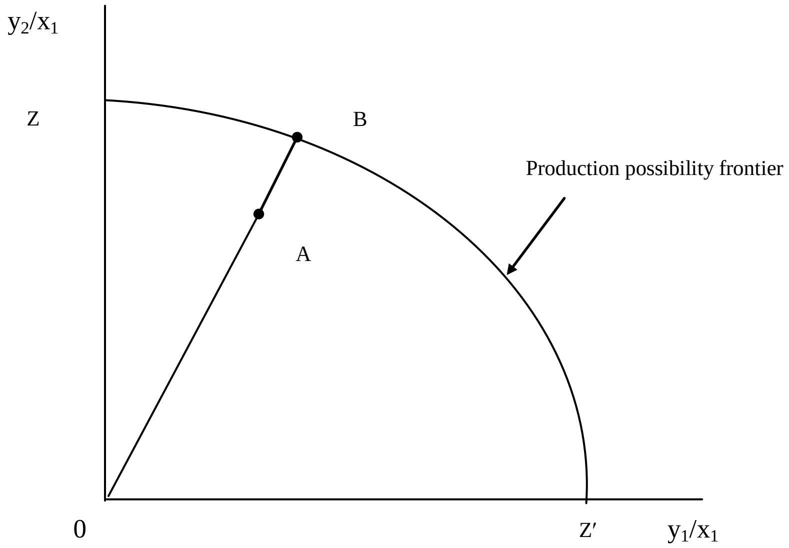

Figure 4.2. Technical Efficiencies from an Output Orientation (Coelli et al. 1999)

Coelli et al. (1999) illustrate output-orientated measures by considering the case where production involves two outputs (y_1 and y_2) and a single input (x_1). If we hold the input quantity fixed at a particular level, we can represent the technology by a production possibility frontier (PPF) in two dimensions.

In figure 4.2 we can see how the line *ZZ′* represents the PPF, the upper bound of production possibilities, and point *A* lies below the PPF and corresponds to an inefficient firm. Point *B*, however, represents an efficient firm situated on the PPF. The distance defined by *AB* represents technical inefficiency, and represents the amount by which outputs can be increased without requiring extra input. Coelli et al. (1999) hence define the measure of output-orientated TE as the ray measure ratio *0A/0B*.

Färe et al. (1985, 1994), however, define technical efficiency in terms of *0B/0A* which indicates the total efficient production level for each output. Subtracting 1.0 from the Färe et al. (1985, 1994) output-orientated measure indicates the proportion by which outputs may be expanded relative to their observed levels (Kirkley et al. 1999).

4.3. Measuring Capacity using DEA

An extension of the single input, single output efficiency analysis by Farrell (1957) was undertaken by Charnes et al. (1978), who first applied Data Envelopment Analysis (DEA) to multiple input, multiple output processes. Since then, DEA has been used to assess efficiency in many different areas, ranging from the public sector to the fishing industry. It has also been applied to estimate optimal input utilisation, productivity, identify strategic groups, determine benchmarks and total quality programmes, and to estimate social and private costs of regulating undesirable outputs and capacity (Kirkley et al. 2000).

Färe et al. (1989) proposed that the DEA framework could be modified in order to estimate capacity as defined by Johansen (1968). Here, the capacity estimate refers to the maximum potential or frontier level of output that could be produced given the fixed factors and full utilisation of the variable factors. The DEA technique allow us to asses the capacity output scores (CO) of an existing technology relative to an ideal, ‘best practice’, frontier technology (Coelli et al. 1999). The frontier technology in this case resembles the most technical efficient combination of inputs and outputs. That is, the output is as large as possible given input and technology levels, or the input levels are as small as possible given the output levels (Färe et al. 2000a).

The production frontier, as depicted in figure 4.2, is formed as a non-parametric, piece-wise linear combination of observed ‘best practice’ activities. Data points of all firms are enveloped with linear segments, and CO scores are calculated relative to the frontier. That is, CO scores of each firm are provided, representing their radial distance from the frontier. To be on the frontier, a firm must thus be producing the maximal level of output for a given level of fixed inputs, and must be both efficient and fully utilising variable inputs (Ward 2000). Firms that are not on the frontier can either be below it, either because they are using inputs inefficiently or because they are using lower levels of variable inputs relative to firms on the frontier.

When measuring capacity an output-oriented DEA approach is used. Output-orientation holds the current input levels fixed and assesses the extent to which outputs could be proportionally expanded. A CO score of 1.20, for example, would potentially allow the output level to be increased by 20% given the current level of fixed inputs. A CO score of 1.0 represents a firm that is producing at full capacity and is on the frontier.

Figure 4.3 shows a graphical representation of an output-orientated DEA model with a single input for nine firms. The frontier is traced through the points representing the maximum level of output for a given input; any points below the frontier are deemed inefficient (Walden and Kirkley 2000a). For example, the firm at point (*8,8*) is the deemed to be inefficient compared to the firm at point (*8,14*), as the firm produces six less units of output with the same amount of input. Inefficiency for any firm is thus determined either through direct comparison of other firms, or by comparing to a convex combination of other firms on the frontier, which utilise the same level of input and produce the same or higher level of output (Walden and Kirkley 2000a). The analysis is accomplished by requiring solutions that can increase some outputs without worsening the other inputs or outputs (Charnes et al. 1994).

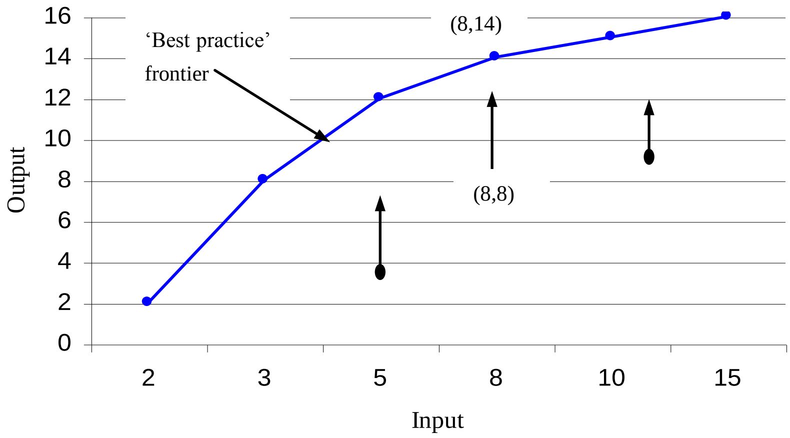

Figure 4.3. Output-orientated DEA model (adapted from Walden and Kirkley 2000a)

DEA is a non-parametric mathematical programming approach that uses the optimisation of an objective function given a series of constraints. The approach being non-parametric refers to the fact that it does not have to assume a particular functional relationship between the inputs and outputs. That is, the approach does not have to assume any statistical distribution and no parameters have to be estimated on the basis of statistical distributions (Färe et al. 2000a).

One of the advantages of using this approach in fisheries is that it explicitly takes account of the level of input utilisation and technical efficiency of different operating units (Kirkley and Squires, 1999), helping to identify those operating units that are underutilising their array of inputs. Furthermore, DEA is particularly well suited for estimating capacity in multi-species fisheries, as it can readily accommodate both multiple inputs (capital and labour) and multiple outputs (Ward 2000). It is also a usable method even in cases where data are relatively limited, and may be run on basic data that include catch levels, vessel number, and number of trips. However, the existence of more complete data helps to improve the analysis.

One of the drawbacks of DEA is that it is unable to account for the stochastic nature of data. With DEA, all random deviations from the frontier are deterministically attributed to inefficiency, and do not account for data noise (e.g. catch rate fluctuations) or measurement error. The position of the frontier may hence be impacted by such an assumption, as the model assumes that the highest observed catch rates could always be duplicated (Ward 2000). This may not always be the case (e.g. outliers).

A further restriction is that efficiency scores cannot be ranked or compared directly to other analyses, as the scores are only relative to the best firms in the sample concerned. Also, capacity output is based on observed practices and the economic and environmental conditions at the time observations were made. Current capacity may thus differ from long-term capacity, or indeed historical capacity, particularly if the resource is currently depleted and the management strategy seeks to rebuild the depleted resource.

4.4. Specifications of the DEA Model

As mentioned, Färe et al. (1989) proposed a modified version of an output-orientated technical efficiency model to measure capacity consistent with the Johansen (1968) definition. The model holds fixed inputs constant and determines the maximal output that can be produced for any given level of fixed input. The approach provides a scalar measure or efficiency score, θ^*_1, that indicates the percentage by which the production of each output of each firm may be increased. That is, the score measures the distance between the observed output and the 'best-practice' frontier. For example, if the solution is 1.10, the capacity output is 1.10 times the observed output. Hence, capacity utilisation can then simply be calculated as 1/1.10 = 0.90.

4.4.1. DEA Framework

Consider j producers that use n inputs and m outputs. We let u_{jm} equal the quantity of the m^{th} output produced by the j^{th} firm, and x_{jn} the level of the n^{th} input used by the j^{th} firm. Outputs and inputs are assumed to satisfy the following:

$$u_{jm} \geq 0, x_{jn} \geq 0 \tag{4.1}$$

$$\sum_{j=1}^{J} u_{jm} > 0, m = 1,2,....M \tag{4.2}$$

which can also be written as:

$$\sum_{j=1}^{J} u_{jm} > 0, \forall m \tag{4.3}$$

$$\sum_{n=1}^{N} x_{jn} > 0, \forall j \tag{4.4}$$

$$\sum_{j=1}^{J} x_{jn} > 0, \forall n \tag{4.5}$$

$$\sum_{m=1}^{M} u_{jm} > 0, \forall j \tag{4.6}$$

Equation (4.1) imposes the assumption that each producer uses non-negative amounts of each input to produce non-negative amounts of each output. Equations (4.3) and (4.4) require aggregate production of positive amounts of every output, and aggregate employment of positive amounts of each input. Equations (4.4) and (4.6) require each firm to employ a positive amount of at least one input to produce a positive amount of at least one output. Zero levels are permitted for some inputs and outputs.

4.4.2. Capacity Output

The estimation of capacity output can be obtained by solving a linear programming model. We designate the vector of outputs by *u* and the vector of inputs by *x*, with *m* outputs, *n* inputs, and *j* firms or observations. Inputs are divided into fixed factors, defined by the set F_x, and variable factors defined by the set V_x. Capacity output and the optimum or full input utilisation values require us to solve the following problem:

$$\underset{\theta, z, \lambda}{Max} \theta_1 \tag{4.7}$$

subject to:

$$\theta_1 u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, \forall m \tag{4.8}$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, n \in F_x \tag{4.9}$$

$$\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, n \in V_x \tag{4.10}$$

$$z_j \geq 0, \forall j \tag{4.11}$$

$$\lambda_{jn} \geq 0, n \in V_x \tag{4.12}$$

where:

θ_1 is the capacity score,
u_{jm} is the amount of output *m* produced by firm *j*,
x_{jn} is the quantity of input *n* used by firm *j*,
z_j is the intensity variable for firm *j*,
λ_{jn} is the input utilisation rate by firm *j* of variable input *n*.

Equation (4.8) represents one constraint for each output, while equation (4.9) constrains the set of fixed factors. Equation (4.10) sets constraints for the variable inputs, allowing them to vary so as not to constrain the model. Equation (4.11) is the non-negativity condition on the *z* variable. The *z* vector allows us to decrease or increase observed production activities (input and output levels) in order to construct unobserved but feasible activities. The vector also provides weights that are used to construct the linear segments of the piece-wise, linear frontier technology constructed by DEA.

The model is run once for each firm in the data set. Capacity output is then determined by multiplying θ_1^* by observed output. This is consistent with the Johansen (1968) definition of capacity because only fixed factors constrain production (Walden and Kirkley 2000b).

The problem imposes constant returns to scale, but it is a simple matter to impose variable returns to scale by imposing the following constraint:

$$\sum_{j=1}^{J} z_j = 1 \tag{4.13}$$

The practical implication of imposing variable returns to scale is that it is easier for some observations to be deemed efficient and placed on the frontier, because imposition of the convexity constraint means that the supporting hyperplane does not have to pass through the origin (Charnes et al. 1994). The effect is that the firm is only compared to firms of similar size.

4.4.3. CU Observed

Capacity utilisation (CU) can be calculated using the observed output as follows:

$$CU(observed) = \frac{u}{\theta_1^* u} = \frac{1}{\theta_1^*} \tag{4.14}$$

This measure provides a ray measure of capacity output and CU in which the multiple outputs are expanded in fixed proportions relative to their observed values (Segerson and Squires 1990). This corresponds to a Farrell (1957) measure of output-orientated technical efficiency due to the radial expansion of outputs, as the ray measure converts the multiple-output problem to a single-product problem by keeping all outputs in fixed proportions. The CU scores range from 0 to 1, with 1 representing full capacity utilisation. Values of less than 1 indicate that the firm is operating at less than full capacity given the set of fixed inputs.

4.4.4. *CU Efficient*

The CU observed measure might be downwards biased because the numerator in the measure, the observed outputs, may not necessarily be produced in a technically efficient manner (Färe et al. 1994). A technically efficient measure of outputs can be obtained by solving a problem where both the variable and fixed inputs are constrained to their current levels. The outcome (θ^*_2) shows the amount by which production can be increased if production is technically efficient. Färe et al. (1994) indicate that this can be determined by solving another linear programming problem, which is similar to the capacity problem:

$$\underset{\theta,z}{Max}\,\theta_2 \tag{4.15}$$

subject to:

$$\theta_2 u_{jm} \le \sum_{j=1}^{J} z_j u_{jm}, \forall m \tag{4.16}$$

$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn}, n \in F_x \tag{4.17}$$

$$\sum_{j=1}^{J} z_j x_{jn} \le \lambda_{jn} x_{jn}, n \in V_x \tag{4.18}$$

$$z_j \ge 0, \forall j \tag{4.19}$$

Again, equation (4.13) can be imposed as a constraint to allow for variable returns to scale. The CU efficient measure is then calculated as the ratio of the technically efficient output (θ^*_2 multiplied by the observed production for each output) and capacity output. That is:

$$CU(efficient) = \frac{\theta^*_2 u}{\theta^*_1 u} = \frac{\theta^*_2}{\theta^*_1} \tag{4.20}$$

The technically efficient CU measure[2] again ranges from 0 to 1. Values less than 1 indicate that CU is less than full CU, even if all current inputs (variable and fixed) were used efficiently.

4.4.5. *Variable Input Utilisation*

Färe et al. (1989, 1994) also introduced the concept of using the DEA approach to provide information on the optimal utilisation rate of variable inputs, λ^{*}_{jn}, or the utilisation of the variable inputs required to produce at full capacity output. For example, if the ratio of the optimal variable input level and the observed variable input level exceeds 1.0 in value, then there is a shortage of the i^{th} variable input currently employed and the firm should expand the use of that input.

Based on the capacity problem using DEA, we can thus obtain a measure of observed input to optimum input, or the input level corresponding to full capacity utilisation or capacity output, as follows:

$$\lambda^{*}_{jn} = \frac{\sum_{j=1}^{J} z^{*} x_{jn}}{x_{n}} \tag{4.21}$$

where n pertains to variable inputs of the j^{th} producer and z is the intensity score. This measure hence indicates the percentage at which the current level of input is used relative to the full capacity output level of input utilisation.

4.4.6. *Discussion*

Walden and Kirkley (2000a, 2000b) highlight that one general drawback of DEA is that the measured capacity output (θ) is radial, which means that all outputs produced by the firm are expanded proportionally. However, in multiple-output production as in fisheries, radial expansion may not yield the highest level of production because of slacks in the linear programming model. Walden and Kirkley (2000a, 2000b) draw on work by Intrilligator (1971) to show that the capacity output model can be modified to account for slacks by converting the inequality constraints to equality constraints and adding slack variables.

4.5. Comparing the Capacity utilisation scores of firms producing under different circumstances: A second Stage Analysis

Clearly, factors that are not accounted for in the DEA model may impact the capacity output and

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[2] Also called the CU Färe measure.

CU scores. Also comparing firms operating in different circumstances is not straightforward. Coelli et al. (1999) suggest several different approaches to make a comparison feasible. Two of these approaches are applied in the project, namely regression analysis in order the assess variables that may be influencing the scores and a between-type comparison where optimal frontiers of two different types are compared using the Wilcoxon-Mann-Whitney rank sum test (see also Cooper et.al. 2000).

4.5.1. Regression analysis

The capacity scores obtained using DEA do not explicitly control for external factors (i.e. nondiscretionary variables) not under control of the firms. The scores will therefore be biased, because the capacity frontier will consist of firms producing under the "best circumstances". The presence of nondiscretionary factors leads to different frontiers. It is therefore necessary to modify the standard DEA model to properly control for these external factors.

The capacity scores attained in the first stage of the analysis are regressed against a range of variables, such as season, homeport and perhaps most important socio-economic factors, so the influence of these variables on the scores can be assessed. In an analysis of the Danish gill-net fleet, Vestergaard et al. (2000) consider the impact of homeport on capacity and CU scores, which in turn may reflect differences in institutional practices, resource availability, and market conditions. Vestergaard et al. (2000) suggest that variations in CU scores can be evaluated using a Tobit analysis, because the scores are restricted to be between 0 and 1.

Formally the framework is the following; see also Ray (1991). Assume that the frontier capacity production function *F* is a separable function of conventional fixed inputs *x* and external factors *w*. Let *q* represents capacity output. The production function is

$$q = F(x,w) \quad \text{and let} \quad F(x,w) = g(x)\cdot h(w), \quad \text{with}\, 0 \le h \le 1 \tag{4.22}$$

Let *y* be the observed production and hence the unbiased capacity score *CO* is:

$$CO = {}^{q}\!/_{y} \quad \text{or} \quad y = \frac{1}{CO}\cdot q = \frac{1}{CO}\cdot g(x)\cdot h(w) \tag{4.23}$$

Applying DEA only with conventional fixed inputs will give the biased capacity scores *CO/h(w)* or the biased CU score, *CU=h(w)/CO*. If the production is at full capacity given the external factors w, *CO = 1* and *CU = h(w)*. If production is less than full capacity then *CU < h(w)*. Therefore the regression model is specified as:

$$CU = h(w) + \varepsilon, \varepsilon \leq 0 \tag{4.24}$$

This will provide the predicted value of *CU*, $\overline{CU}$. However, the error term has zero mean and hence the residuals are not always nonpositive as required. However, by adding to the intercept term the largest positive residual ε_L and subtracting this value from each residual, the adjusted residuals will all be nonpositive. The adjusted predicted value of *CU* ($\overline{CU_A}$) for each firm is $\overline{CU_A} = \overline{CU} + \varepsilon_L \leq 1$. The unbiased CU score for each firm is $1/CO = CU/\overline{CU_A}$. The unbiased CU score measures the extent of less than full CU that is due to managerial inefficiency.

Different variables measuring characteristics of the fisheries will be included as nondiscretionary inputs in the second-stage regression model. A positive external factor will have a positive coefficient indicating that increases in this factor will contribute to a higher Capacity utilisation. A negative external factor will have a negative coefficient indicating that increases in this factor will contribute to a lower Capacity utilisation.

4.5.2. Between-type comparison

The second stage analysis of between-type comparison covers the following steps:

i) Determination of the optimal capacity frontiers of the two groups by running separate DEA analyses for each group and projecting non-efficient vessels onto these frontiers.
ii) Merging the two optimal frontiers into one dataset and performing a common DEA analysis for the joined set. This results in capacity scores of each individual vessel in the two groups relative to the common frontier for the two individual frontiers.
iii) Rank sum test of the location relative to each other of the resulting two sets of capacity scores for the two different groups.

These steps will be described in detail below.

Determination of capacity frontiers

The optimal capacity frontier for an individual vessel group is determined by running a DEA analysis for the group and projecting inefficient observations onto the frontier determined by the fully operating vessels. Hence, the firstly the DEA capacity problem (7)-(13) is solved for the individual group. And secondly vessels operating below full capacity ($\theta>1$) are projected onto the frontier (determined by the vessels with $\theta=1$) using the estimated weights:

$$
\begin{aligned}
u_m^{*k} &= \sum_{j=1}^{N} z_j^{*k} \cdot u_{m,j}, \forall m \\
x_n^{*k} &= \sum_{j=1}^{N} z_j^{*k} \cdot x_{n,j}, \forall n
\end{aligned}
\qquad (4.25)
$$

Thus the outputs are increased, the fixed inputs decreased, and the variable inputs either increased or decreased depending on which operation makes the vessel fully efficient, thus placing each non-efficient vessel on the frontier as a linear combination of one or more of the originally efficient vessels.

Determination of the common frontier
Next the two individual frontiers determined by the procedure described above are merged into one dataset, and a mutual DEA analysis, corresponding to model (7)-(13), is performed for this joined dataset. This procedure determines the optimal frontiers of the merged set, i.e. measures which parts of the two individual frontiers that are above relatively below each other.

The θ_k^* values resulting from the pooled DEA analysis gives the observed capacity utilization values

$$
CU_k = \frac{1}{\theta_k^*} \qquad (4.26)
$$

of the two frontiers relative to each other.

Rank Sum test
The relative location of the frontiers relatively to each other is finally estimated by the Wilcoxon-Mann-Whitney rank sum test, which will be performed for the *CU* scores.

The null hypothesis of this test is that the two frontiers have the same location, i.e. that the one is not located significantly above the other. The test is performed by first ranking the *CU* values obtained by the DEA analysis for the pooled sample (using midrange for ties), and second, calculating the sum *W* of the ranks from the *i*’th sample. If the null hypothesis is true, these sums will not be significantly different from the expected mean ranks given by:

$$
\mu_i = \frac{n_i(n_i + n_j + 1)}{2} \qquad (4.27)
$$

Whether the rank sums are equal to or different from the expected means are tested by calculating the test variable:

$$z = \frac{W - \mu}{s} \tag{4.28}$$

where s is the standard deviation given by:

$$s = \sqrt{\frac{n_i n_j (n_i + n_j + 1)}{12}} \tag{4.29}$$

The test variable z has been shown to be standard normally distributed, and must thus lie within the range [-1.64;1.64] for the null hypothesis to be accepted on a 5% level. For more details on the Wilcoxon rank sum test see Cooper et. al., 2000.

Example

An example with one (fixed) input and one output has been constructed to illustrate the method described above. Two samples have been constructed, both of which are presented in table 4.1a and figure 4.4a. The figure indicates that it may be expected that the sample I data is generally more efficient than the sample II data.

Table 4.1a and figure 4.4b furthermore shows the optimised data for the two samples, i.e. the data obtained by running separate DEA analysis for the two samples and projecting non-efficient observations onto the two frontiers. Figure 4.4b confirms the belief that sample I is generally more efficient than sample II.

The two optimised samples have next been merged into one sample and a DEA analysis run for this dataset. The common optimal frontier is comprised of the observations connected by a solid line in figure 4.4b. Figure 4.4c shows the corresponding efficiency scores.

These scores are finally ranked (from lowest to highest value), with ties used for equal values, and the sums of the ranks of the two samples calculated. These sums are $W_I=521$ for sample I and $W_{II}=299$ for sample II.

The mean rank sums expected for the two samples are equal, as the samples have an equal number of observations. These means are given by $\mu=20(20+20+1)/2=410$ (using equation 4.27). The variance of the ranks of the two samples are given by $s^2=20\,/20(20+20+1)/12=1366.667$ (using equation 4.29), giving the standard deviation $s=36.7$.

The test value z given by equation 4.28 thus becomes $z=3.01$. The null hypothesis is therefore easily rejected on a 5% as well as on a 1% level.

It is thus concluded that the sample I frontier is located significantly higher than the sample II frontier, i.e. that sample I is on the whole more efficient than sample II.

Table 4.1a. Example data

Raw data				**Optimised data**			
Sample I		**Sample II**		**Sample I**		**Sample II**	
$\mathbf{x_1}$	$\mathbf{y_1}$	$\mathbf{x_2}$	$\mathbf{y_2}$	$\mathbf{x_1}$	$\mathbf{y_1}$	$\mathbf{x_2}$	$\mathbf{y_2}$
1.0	1.0	1.0	1.5	1.0	1.00	1.0	1.50
1.5	1.0	1.5	1.2	1.5	1.35	1.5	1.75
2.0	1.7	2.0	2.0	2.0	1.70	2.0	2.00
2.5	1.5	2.5	1.3	2.5	1.90	2.5	2.05
3.0	2.1	3.0	2.1	3.0	2.10	3.0	2.10
3.5	1.0	3.5	2.0	3.5	2.25	3.5	2.15
4.0	2.4	4.0	2.2	4.0	2.40	4.0	2.20
4.5	2.0	4.5	1.9	4.5	2.50	4.5	2.25
5.0	2.6	5.0	2.3	5.0	2.60	5.0	2.30
5.5	2.5	5.5	2.0	5.5	2.70	5.5	2.35
6.0	2.8	6.0	2.4	6.0	2.80	6.0	2.40
6.5	2.0	6.5	2.3	6.5	2.88	6.5	2.45
7.0	2.9	7.0	2.5	7.0	2.95	7.0	2.50
7.5	2.7	7.5	2.0	7.5	3.03	7.5	2.55
8.0	3.1	8.0	2.6	8.0	3.10	8.0	2.60
8.5	2.0	8.5	2.5	8.5	3.15	8.5	2.65
9.0	3.2	9.0	2.7	9.0	3.20	9.0	2.70
9.5	2.5	9.5	2.6	9.5	3.25	9.5	2.75
10.0	3.3	10.0	2.8	10	3.30	10.0	2.80
10.5	3.0	10.5	2.5	10.5	3.30	10.5	2.80

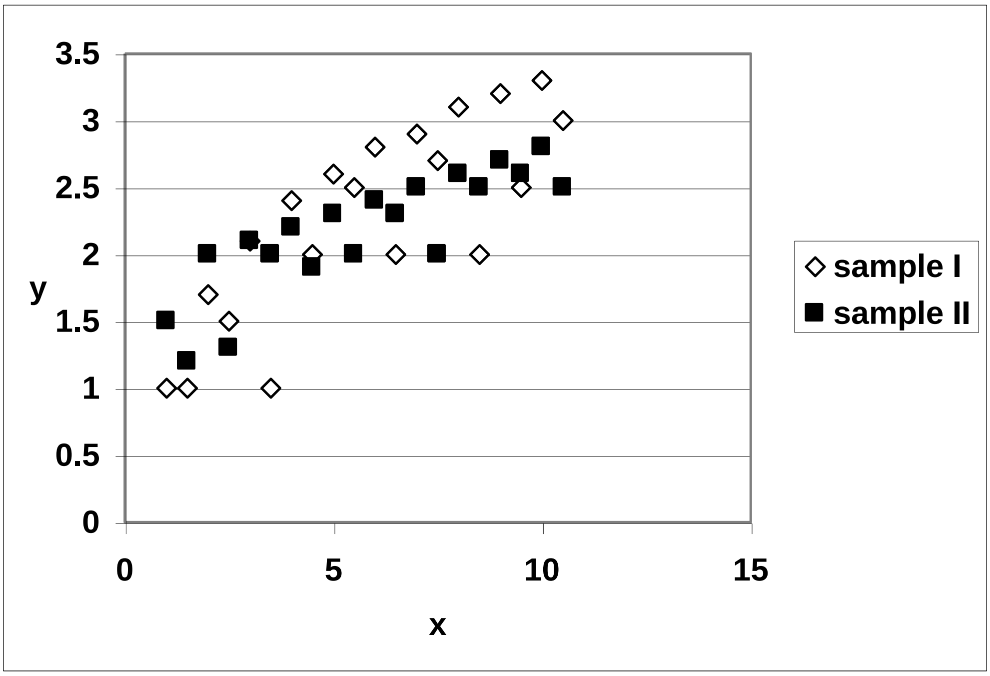

Figure 4.4a. Raw data for the example

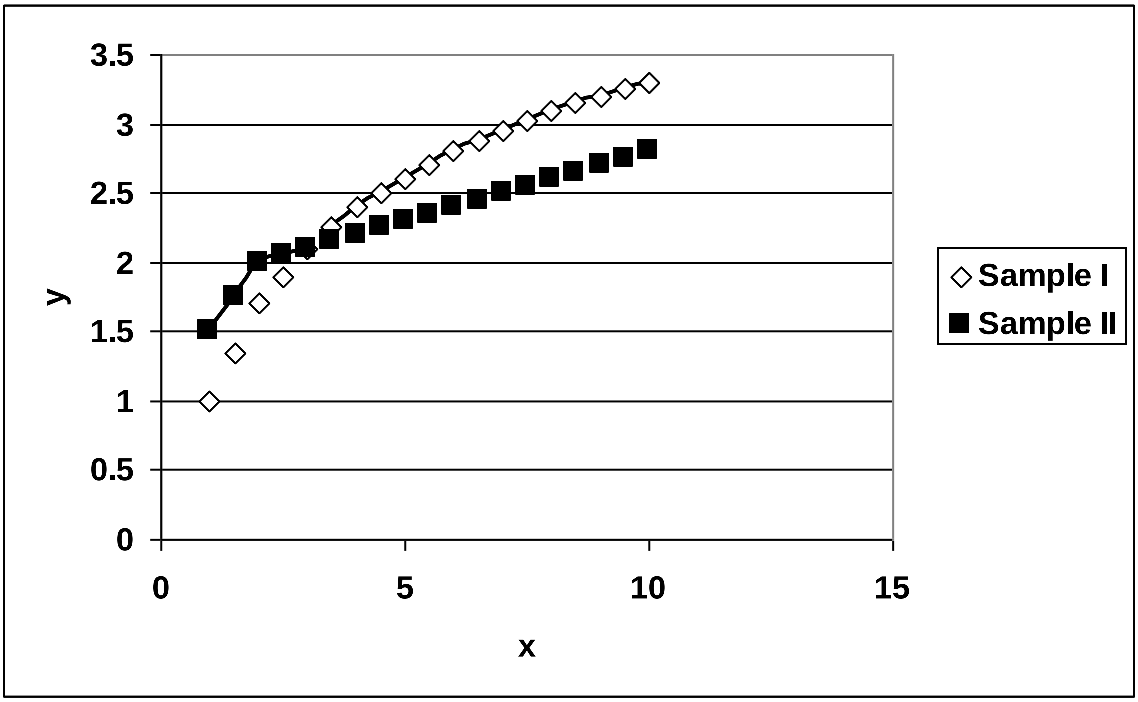

Figure 4.4b. Optimised data for the example. The common optimal frontier is connected by the solid line.

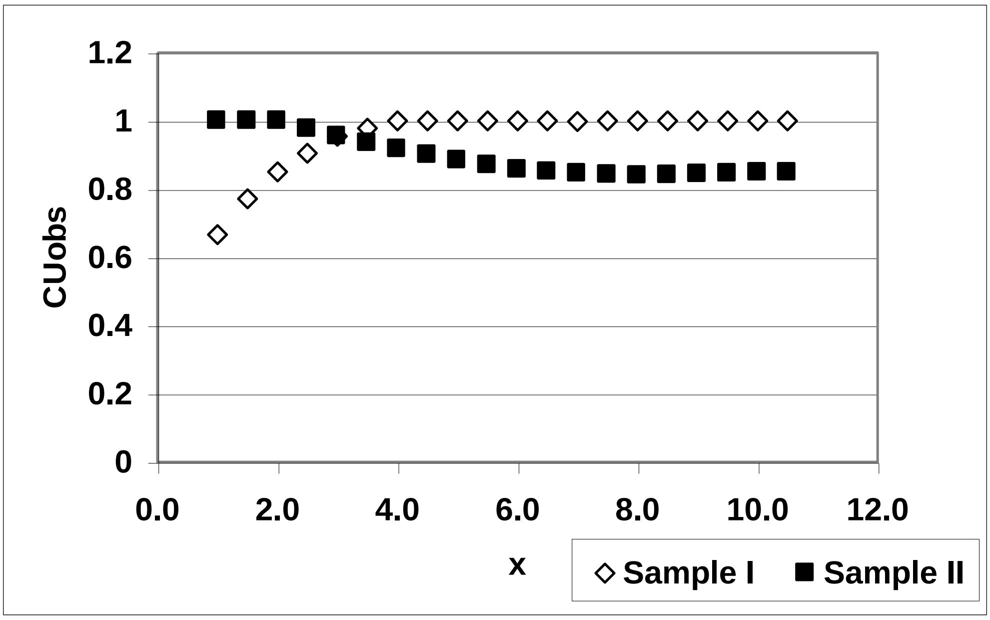

Figure 4.4c. Efficiency scores obtained for the pooled sample

4.6. Industry Allocation Model

Setting up an Industry Allocation model seeks to address a range of issues concerning capacity analysis. For example, fisheries managers generally wish to know the level of capacity on a fishery, regional or national level. There is also a need to assess reallocations of capital, labour, and other productive resources in relation to an objective on fleet capacity adjustment. However, only one study (Färe *et. al.* 2000) has been on the capacity at the industry level, all others have been at the individual level. One of the main reasons for this discrepancy is that the main methods to assess capacity and capacity utilisation operate at the level of the decision-making unit. Färe et al. (2000b) consider that assessing capacity at an aggregate, or industry, level is considerably more complicated than determining firm-level capacity.

Färe, Grosskopf and Li (1992) provide theoretical models of industry performance using firm level data. The models are output-oriented, meaning that output is maximized given current level of inputs. Further, reallocation of inputs across firms is allowed in order to maximize aggregate output. It is shown that models with allocation of all inputs forms one extreme, while in contrast, models, where no allocation of inputs is allowed, form the other extreme. The last models represent firm level models in which the “best practice” technology available to the industry is constructed and for each firm a maximum potential output level is found[3]. An estimate of aggregate industry output is then the sum of each firm’s maximum potential output. When on the other hand reallocation of all inputs is allowed, the maximum aggregate output is found in a (one model) industry model. Färe, Grosskopf and Li (1992) further shows that between these extremes are models for which only some of the inputs are reallocatable across firms while the other inputs are not. In all the models the inputs are constrained at the industry or firm level (depending on the model) to their current use. Comparing maximum potential industry output with current aggregate output provides a measure of the industry efficiency performance.

Färe, Grosskopf and Li (1992) did not, however, address the issue of capacity limitations in their models; hence the models are long run models. Building on the work of Johansen (1972), Färe (1984) showed the existence of plant capacity and Färe, Grosskopf and Kokkelenberg (1989) formalized further the concept so that firm level capacity levels can be calculated. Basically, it is assumed that firms cannot exceed their use of the fixed factors, but that the use of variable factors is not constrained. Again, as in the firm level model of efficiency measure, a best practice technology is provided and the current output of each firm is evaluated against the maximum potential output at full capacity utilization, called capacity output. Summing these firm level capacity output gives an estimate of aggregate industry capacity output, which can then be compared to current industry output. This will provide a measure of the overcapacity of the industry.

However, this measure allows no reallocation of inputs and outputs across firms, so no insight into the optimal restructuring and configuration of the industry is obtained. The measure and the Färe, Grosskopf and Li (1992) measures implicitly assume that production of capacity output is feasible and that the necessary variable input is available. In fisheries, this is normally not the case, since the total production of the sector is constrained by the productivity of the fish stocks. In order to protect the fish stocks from overexploitation constraints are implemented on the activities of the firms, i.e. the sector is regulated with the purpose to sustain the fish stock biomass above a certain level. In EU, for example, the main tool is formulation of TAC (Total Allowable Catch) for the main species. The TAC is divided between the involved countries as country shares of TAC. Each country implements regulation, so production is less than the provided share. Hence, the production of the industry is constrained by the current industry production (=TAC).

Following the approach by Dervaux, Kerstens and Lelue (2000) the industry configuration and optimal structure can be found by minimization of the total use of fixed inputs given that each firm cannot increase their use of fixed inputs and the production of the industry is at least at the TAC level. As output level of each firm is used capacity output obtained from the firm level capacity model. That is, frontier capacity production is identified at the firm level and used as input in the

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[3] In the literature this model is called the output based efficiency measure. Each firm's performance can be judged by comparing current output to the maximum potential output.

industry model; thereby the excess capacity at the firm level is explicitly taken into account. The capacity measure is a short run measure since it assumes no change in the existing capacity.

4.6.1. Empirical methodology

In one of the industry models in Färe, R., S. Grosskopf and S-K. Li (1992) the total industry output was simply found by aggregating the technically efficient output production $\theta_2^{*k} u_k$ of each firm, see model (15)-(19). Likewise, the aggregate industry capacity output could be found as the sum of firm level capacity output, $\theta_1^{*k} u_k$, see model (7)-(13).

The focus is now on reallocation of production between vessels by explicitly allowing improvements in technical efficiency and capacity utilization rates. The model is specified as follows. From model (7)-(13) an optimal activity vector z^{*k} is provided for firm k and hence capacity output and use of fixed and variable inputs can be computed:

$$u_{km}^{*} = \sum_j z_j^{*k} u_{jm}; \quad x_{kf}^{*} = \sum_j z_j^{*k} x_{jf}; \quad x_{kv}^{*} = \sum_j z_j^{*k} x_{jv}; \tag{4.30}$$

These “optimal” frontier figures (capacity output and capacity variable and fixed inputs) are used as parameters in the industry model. The industry model minimizes the industry use of fixed inputs such that the total production is at least at the current total level by reallocation of the production between firms. Reallocation is allowed based on frontier production and input use of each firm. In the short run it is assumed that current capacities cannot be exceeded both at the firm and industry level. Defined U_m as the m’th industry output level and X_f as the aggregate fixed inputs available to the sector of factor f, i.e.:

$$U_m = \sum_j u_{jm} \text{ and } X_f = \sum_j x_{jf}. \tag{4.31}$$

The formulation of the short run industry model is:

$$\begin{aligned}
&\underset{\theta,z,X_v}{Min}\ \theta \\
&\sum_j u_{jm}^{*} z_j \geq U_m, m = 1,..,M, \\
&\sum_j x_{jf}^{*} z_j \leq \theta\ X_f, f = 1,...,F, \\
&-X_v + \sum_j x_{jv}^{*} z_j \leq 0, v = 1,...,V, \\
&0 \leq z_j \leq 1, \theta \geq 0, j = 1,..., J.
\end{aligned} \tag{4.32}$$

where X_v is the industry use of variable input. The solution gives the combination of firms that can produce the same or more outputs with less or the same amount of fixed inputs in aggregate. Remark, that the components of activity vector, z_j, cannot be greater than 1, so current capacities cannot be exceeded. In the long run version of the industry model, the capacity can be scaled up, i.e. no restriction on z_j. The long run model is therefore model (32) without the upper limit on the activity vector.

The method offers information on the resulting fleet structure and hence the manager can target a fleet reduction program towards the relevant vessel groups. This basic model can be adjusted towards the specific study. For example, different gear types are present and hence the model can minimize the use of fixed inputs for each gear type separately. Also if the industry operates in different areas, the model can be changed accordingly. This is an advance of the DEA approach, because changes in the constraints and objective function are straightforward.

4.7. The GAMS Software

The DEA programmes for this project are written in the General Algebraic Modeling System (GAMS) language, a mathematical programming language used in a variety of linear, nonlinear, and mixed integer programming models, general equilibrium models, and network models. The DEA programmes are based on a model written in GAMS by Olesen and Petersen (1996), who argue that GAMS is preferable to many specialised DEA software packages currently available because of the flexibility that it offers. For example, it can easily incorporate slack variables and is able to directly estimate the value of λ (Walden and Kirkley 2000b). The user can also exert greater control to modify codes that account for changes to the standard DEA model. This is especially important in fisheries where production problems generally differ from the standard model (Walden and Kirkley 2000a).

5. Measuring capacity in United Kingdom fleets

5.1. Introduction

This chapter summarises the main findings and conclusions of the UK analysis of capacity. A full description of the methodology used, results and discussion is presented in the UK Country Annex of this report.

The diversity of fishing activities in the English Channel are largely representative of all UK activities, with the exception of nephrops fisheries. As a consequence, the Channel is well suited for examining the appropriateness of the DEA technique in assessing capacity and capacity utilisation in the UK and was the focus for the Individual Vessel and Second-stage analyses. The Industry-level analysis focused on all UK fisheries that are subject to quotas.

5.2. Individual Vessel Analysis

The objective of the individual vessel analysis was to calculate unbiased capacity utilisation (CU*) scores for vessel operating in discrete fleet segments in the English Channel. Capacity utilisation (CU) and technical efficiency (TE) scores were therefore estimated to generate the CU* scores.

5.2.1. Data

Fishing activity in the Channel is generally based upon six major gear types (otter trawl, beam trawl, scallop dredge, nets, pots and handline) which have been further classified into a number of métiers based on gear use, target species and area fished (Tétard *et al.*, 1995). The smaller vessels are generally multi-purpose, operating with different gears over the year and, in some cases, using different gears in the same month. Large vessels tend to use the same gear over time but change métier by altering fishing grounds (Dunn, 1999). Many of the 2000 plus British vessels operating in the Channel work part-time.

An extensive database of trip level log-book data in the English Channel covering the period 1993-1998 was disaggregated into different fleet segments and métiers based on recorded fishing activity. Trip level data were aggregated to provide monthly levels of output and effort by vessel over the period examined. The data set was then refined to filter out part-time fishers by only including vessels that fished for at least four months a year and in at least half of the six years.

5.2.2. Techniques employed

The output oriented DEA models presented in the main body of the report were used to estimate the degree of CU and TE in each métier, and from these, estimates of CU* were derived. In the models, non-increasing returns to scale were imposed as there are generally *a priori* reasons to assume that fishing would be subject to non-constant, and in particular non-increasing, returns to scale.

As data on stock abundance were not available the model was run separately for each time period, i.e. one month. It was assumed that stock levels would not have varied significantly during this period, hence the lack of stock abundance data was not perceived to be a significant problem.

The key inputs used in the individual vessel analysis were days fished, vessel 'deck area' and engine power. The CU* scores were estimated using both single and multiple composite outputs and also using both weight and revenue-based measures. As the Channel is characterised by multi-purpose multi-métier fleets CU*scores were re-estimated including an extra input and output reflecting any activity in other métiers in each time period.

As DEA is a comparative process, when there are a small number of observations proportionately more vessels will lie on the production frontier, hence results will be biased upwards. A 'rule of thumb' suggested by Cooper et al (2000) was used to avoid such problems relating to insufficient degrees of freedom.

5.2.3. Results

The 'best' estimates of CU* (i.e. based on the multi-output measures with the addition of the other activities) suggest that most fleet segments in the English Channel are, on average, operating at between 80 and 90 per cent of their capacity, with some fleet segments (e.g. potters) operating at around 95 per cent of their capacity. A meaningful comparison of scores between gear types is not appropriate given that scores were calculated separately for each métier and month.

The mobile gear segments appear to have the lowest levels of CU (e.g. otter and beam trawl). Many larger boats in these segments also operate outside of the Channel, and this may be reflected in the lower CU rates. However, it also suggests that, at least within the Channel, there is excess harvesting capacity in the fleet as a smaller fleet could have taken the same level of catch if fully utilised.

The incorporation of an extra input and output representing other fishing activities, in the same time period, outside the métier being analysed had a substantial effect on CU* scores, particularly for highly mobile beam trawlers fishing in several areas in the Channel in a given month, and also for netter-liners that frequently change gear types and hence metiers in the month.

CU* was not significantly different between revenue and weight-based measures however scores increased by an average of 7% across all metiers when multi-outputs were used instead of single outputs.

Given the regional variations in stock abundance and catch composition, it was decided to undertake the analysis of CU* at a very disaggregated level. As a result, many Channel fisheries analyses experienced ‘degrees of freedom’ problems based on the Cooper et al (2000) rule of thumb. A key result of this study, however, is that the measures of unbiased CU are less sensitive to degrees of freedom problems than initially anticipated. This result was consistent for a range of different fleet segments undertaking different activities.

5.3. Second-stage analyses

The objective of this second-stage analysis was to determine which factors affect CU* scores. CU* scores for the key metiers in each of the four main English Channel fleet segments (otter trawl, beam trawl, scallop dredge and gill nets) were regressed over a range of variables thought to be of influence.

A number of stochastic elements will always affect fisheries and are nearly impossible to capture in data format, e.g. luck, weather, disease outbreaks, breakdowns and unpredictable stock biomass changes. Despite this, it is assumed that planned output, and CU*, would generally be based on expected yield, prices and costs.

5.3.1. Data

CU* scores for the key metiers were calculated for this Second-stage analysis by comparing observations for all vessels over the entire 1993 to 1998 time period, as opposed to discrete monthly comparisons carried out in the Individual Vessel Analysis. The inputs and outputs used to recalculate these CU* scores were the same as those used in the Individual Vessel Analysis and included an extra input and output representing activity in other metiers.

Additional information was required for the regression analysis of the CU* scores. A range of continuous and dummy variables were compiled. Continuous variables included average real fish prices for each metier, average national marine diesel prices, boat size, engine size and total fishing activity (represented by the number of boats recorded in the data in each time period). Dummy variables included year (to capture specific events or annual changes), month (representing seasonal changes in stock abundance), home port (representing main fishing locations) and change in home port over the period examined (representing a change in key fishing location). These data were derived from logbook information.

5.3.2. Techniques employed

The CU* scores were re-calculated for the key metiers using DEA. There were sufficient degrees of freedom in each analysis owing to the fact that all observations for a métier during the period 1993 to 1998 were compared with each other. It was expected that comparison of inputs and output over the entire six-year period would yield better regression results, particularly for the year and seasonal variables. Linear and log-linear tobit regression analysis was carried out for each metier. Tobit was chosen over Ordinary Least Squares regression due to the limited nature of the dependent variable, i.e. CU* scores range between 0 and 1.

5.3.3. Results

Average CU* scores for each métier over the 1993-98 period ranged between 67 and 88 per cent, for beam trawl and otter trawl respectively. The linear tobit regression models appeared to be marginally more appropriate than the log-linear models across all metiers. In general, the overall statistical quality of the models was found to be poor.

The results generally supported the assumption that fishers respond to seasonal changes in fish stocks and conditions. However they do not provide support to general theories relating to standard responses to economic incentives. Generally, CU* did not increase with fish prices and did not decrease with fuel prices. Results were often contradictory between linear and log-linear forms of each model. Counter-intuitive results were thought largely to reflect influences that could not be factored into the analysis rather than evidence to refute the above key assumption underlying fisher behaviour. In particular, the counter-intuitive result with respect to prices may be due to an inability in the model to separate the incentives created by increased revenues related to stock abundance which more than offset the reduction in prices.

Seasonality and location results were reasonably consistent with expected theory, however they only explained a relatively small portion of the variation in CU*. While random events such as breakdowns would affect the CU* of a vessel in a given time period, it is unlikely that these events would explain the extent of variation found in the study. Pascoe and Coglan (2000) also found considerable variation in TE in the fishery and concluded that the effectiveness of any fleet reduction scheme will be influenced by which particular vessel is removed as their impact on the stock is not homogeneous. Similarly, this study indicates that removal of boats operating at below average CU* will have a less than proportional impact on the harvesting capacity of the fleet.

The results suggest that an increase in the number of vessels fishing in a particular métier causes CU* to increase. However, this finding is probably spurious, due to the multi-purpose nature of the fishery, i.e. vessels will switch between different métiers when it is expected that catches will be better than in the current activity resulting in a positive relationship between vessel numbers operating in a métier and improved CU*. It was expected that the permanent removal of vessels from fleet segments may result in an increase in CU* in the longer term, however results did not reflect this assumption.

5.4. Industry analysis

The objective of the industry analysis was to determine the minimum fleet size necessary to take the overall harvest. Many vessels operating in the Channel also operate in adjacent fisheries (and vice versa), therefore a model was developed for UK fisheries as a whole.

5.4.1. Data

Similar data to that available for English Channel fisheries were not available to the project team for other UK fisheries. However, information on the fixed quota allocations (FQAs) to the over-10m fleet were available for all UK fisheries. Given that quota species represent the majority of output by value, the use of these data provided a useful proxy for the total capacity output of the UK industry. Vessel characteristic information similar to that used in the other analyses were also available at the industry level.

5.4.2. Techniques employed

A key assumption of the industry analysis was that total capacity output can be defined in terms of total quota holdings, and that a reallocation of UK Fixed Quota Allocations (FQAs) between vessels could result in a smaller fleet operating at full capacity. The reallocation of FQA between vessels was assumed to flow from vessels operating at lower levels of CU* to those operating at greater, near full, levels of CU* (CU* in defined in terms of the relationship between current and potential FQA holdings).

Using DEA, CU* scores were estimated for the section of the UK fleet that held quota. Therefore, the under 10m fleet was not included in the analysis as they have no FQAs; nor were any over 10m boats that target only non-quota species. Data on physical input use (e.g. engine power, boat size) and outputs (in the form of FQA holdings in 2001 limiting the catch of the quota species) were used in the analysis.

The second part of the industry analysis utilised an allocation model which estimated the minimum fleet size required to catch the quota of each and every species, with all vessels operating at, or close to, full capacity. The model was specified such that the vessels that have the lowest CU* were the first to exit the industry, with their quota being reallocated to boats operating closer to full capacity.

A number of separate quota trade scenarios were examined, resulting in different measures of CU* for each vessel as a result of the comparative nature of the DEA analysis. The scenarios considered were (i) complete transferability between all boats; (ii) transferability between boats in the same fleet segment; and (iii) transferability between boats in the same region. Four regions were defined as the English Channel, Irish Sea, West of Scotland and North Sea. Vessels were allocated to one of these regions based on their home port.

5.4.3. Results

The estimated average CU* of the existing fleet varied substantially between fleet segments: pelagic boats (trawlers and purse seiners) were estimated to average between 90 and 95 per cent, depending on the degree of transferability, while shellfish boats were estimated to average between 20 and 50 per cent. Pelagic boats would therefore need to increase their quota holdings by about 5 to 10 per cent on average to operate at full capacity. On the face of it shellfish boats would need to more than double their quota holding to operate at full capacity however this is most likely an overestimate, as it does not take into account the non-quota species that make up a large proportion of a shellfish vessels' catch.

The second stage of the analysis involved the use of the industry adjustment model to estimate the minimum fleet size necessary to take the quota. The reduction in fleet size estimated using the model may overstate actual reductions experienced in the fishing fleet if quota could be traded easily in reality. Many boats that have relatively small FQAs may concentrate their effort on the non-quota species, for example shellfish fishermen, rather than exit the fishery. Low levels of profitability and difficulties in raising finance may also act as a constraint on adjustment, at least in the short to medium-term. The lack of alternative uses of the vessels may also act as a short run impediment to boats selling their quota and exiting the fishery.

The estimated reduction in the fleet after all potential reallocation of quota was undertaken was estimated by segment and region. In 2001, 1554 vessels held FQAs. Depending on the assumptions regarding the transferability of the quota, the fleet operating at full capacity may vary between 930 and 1100 vessels (as a minimum). If FQA trade was allowed between all vessels, regardless of region or fleet segment, a reduction in beam trawl vessel numbers of 17% was estimated. However if FQA trade was restricted to being only amongst the beam trawl fleet a reduction of 11% was estimated. The full set of results based on a range of scenarios can be seen in the UK Country Annex.

Generally, the greater the degree of transferability permitted in the system, the greater the level of adjustment and the smaller the overall resulting fleet size. The fleet segments least likely to be reduced are the pelagic, beam trawl and distant water as these were found to have a high degree of CU* on average. In contrast, the shellfish boats are likely to be the most susceptible to reduction, however as noted above, the analysis does not take into consideration the non-quota activity which is particularly important in the shellfish, net and line segments.

At the regional level, the impact is likely to be fairly evenly distributed between the English Channel and Irish and North Seas, although the West of Scotland may experience a greater proportional decrease in fleet size. The overall results suggest that the fleet size could be reduced by between 25 and 36 per cent in the English Channel depending on the assumptions of how quota is reallocated across the remainder of the UK fleet.

5.5. Conclusion

The results from the various stages of the analyses provide a useful insight into CU and the level of excess capacity in the English Channel. From the individual vessel analyses, it appears that the fleet are utilising, on average, around 80 percent of their capacity. From the industry analysis, full CU may require a reduction of around 25 per cent of the fleet, at least for the vessels targeting quota species.

The factors that affect the level of CU were less clear than anticipated. While prices and fuel costs were expected to be important factors, these did not appear to affect the level of CU in the manner expected. The main ‘drivers’ of CU appear to be relative stock abundance, which in turn affects catch rates. With inflexible prices, as is the case with most species in the Channel for which demand relationships have been examined, then revenue per unit of effort will be directly related to stock abundance. As a result, it is likely that CU is related to economic incentives.

The above analysis of CU and the ‘optimal’ fleet size is based purely on technological measures of output rather than economic measures. The analysis ignores the costs of fleet reduction if a policy such as a decommissioning scheme is imposed. Further, it does not relate to the economically optimal fleet size. A bioeconomic modelling analysis of the fishery (Pascoe and Mardle 2001) suggests that economic profits in the fishery would be maximised by a lower fleet size than suggested by the industry analysis, which aimed at maximising CU. It could be argued that the full capacity fleet is the upper bound required for an efficient fishery.

Despite this, the DEA technique can provide useful information to fisheries managers in terms of potential excess capacity in the industry. The study identified a number of potential problems and methods for dealing with these problems. In particular, the problem of mult-species multi-métier fisheries was addressed. The study demonstrated that ignoring other activities can result in a biased estimate of CU. Similarly, the problem of degrees of freedom was also examined. This was found to be less of a problem that expected, but caution should nevertheless be taken when the analysis is applied to small data sets.

6. Measuring capacity in the fleets of The Netherlands, Belgium and Germany

6.1. Introduction

In order to investigate the merit of using the DEA-method for capacity-determination the focus of the study is next to launching an analysis of a specific fleet segment to compare analyses of different fleet segments across a selection of countries[4]. Aim of the study is, among others, to compare and aggregate maximum allowable capacity and capacity-utilisation given the limited fish stocks, technical productivity of ships and fleets, over-capacity, sustainable balance between sector-structure and available inputs. As part of the project LEI has been commissioned to analyse data for the Dutch Beam Trawl fishing fleet both the fisheries for sole and plaice and the shrimp fisheries, and the German Beam Trawl fishing fleet and the Belgian Beam Trawl Fishing Fleet fishing for sole and plaice.

6.2. Dutch Beam Trawl fleet: sole and plaice fisheries

The cutter fleet is the main branch of the Dutch sea- and coastal fisheries, consisting of about 400 vessels by the end of 2000, producing total gross revenues of € 290 million in that year and providing employment to about 1830 fishermen.

It's main activity is beam trawling for flatfish: nearly 90% of the fishing effort measured in kW-days is spent in this fishery, yielding more than 80% of total revenues and providing for more than 70% of employment. Boats with main engines of more than 1100 kW are almost exclusively engaged in this fishery. In addition, a number of 'Euro Cutters' – boats with engines up to 221 kW – are beam trawling for flatfish, a few full time or nearly full time, but mostly seasonally.

6.2.1. Data set

In the Netherlands systematic studies of costs and earnings of fishing vessels were started in 1948. The studies are implemented by the department of Fisheries of the Agricultural Economics Research Institute (LEI). The figures are obtained from voluntary participation by vessel owners; LEI visits vessel owners and their accountants to collect data directly from the accounts.

Data for the DEA analyses were derived from the LEI panel for costs and earnings studies. This panel is composed of 25 to 30% of the cutter fleet in the various size-groups (defined by main engine power) and make up a representative sample of the fleet. Out of the total panel a group of

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[4] Denmark, France, United Kingdom, the Netherlands, Germany and Belgium.

beam-trawling vessels has been selected that had beam trawling as the main activity in the period 1992 - 1999.

To facilitate the analysis of differences in outcome of the DEA analysis based on input data the base data set comprises all beam trawl vessels within the used selection criteria of level of activity in the given period. After the analysis of the entire selected fleet panel data the data set was split into two segments: vessels of 1500 HP and over and vessels of less than 1500 HP which consists mainly of vessels of 300 HP and less. The smaller vessels can both be engaged in flat fish fisheries as in shrimp fisheries

For the total period a number of 474 observations were obtained; 106 observations in the segment of vessels with an engine capacity of less than 1500 HP and 378 in the larger segment of over 1500 HP engine capacity.

The variables used in the analysis are:

- Engine capacity in HP
- Vessel size in GT
- Variable inputs in days at sea
- Catch of sole in kg
- Catch of plaice in kg
- Aggregated catch of other flatfish species
- Aggregated catch of other species.

6.2.2. Conclusions

Concerning the individual vessel analysis on average for the sample fleet for the period 1992 – 1999 the capacity utilisation score based on the observed output is 0.84. Hence, on average, the fleet can be characterised as being relatively efficient. Concerning the two segments of the beam trawl fleet the capacity utilisation score of the segment with an engine capacity of less than 1500 HP is slightly below the total average (0.82) whereas for the group of 1500 HP and over the average capacity utilisation score is 0.84.

Concerning the analysis of the technical efficiency (TE) score for the entire fleet sample is calculated at 0.91 with the smaller vessel being more efficient (TE of 0.94) than the larger segment (TE of 0.90). Still the technical efficiency of the entire fleet sample is high.

Combining the two capacity scores one can conclude that concerning the number of sea days in theory efficiency could be improved, however sea days are regulated hence the individual fishing unit has no free choice in optimising effort, but the general technical capabilities of the vessels are well utilised. This is reflected by an unbiased efficiency score (Cu*fare*) for the entire fleet sample of 0.92. However, here we find a large difference between the score for the smaller fleet segment (Cu*fare* 0.88) and the sample of larger vessels (Cu*fare* 0.93).

The systematic difference of capacity utilisation scores between the two fleet segments along engine size would suggest the use of two separate analyses each focusing on a more homogenous groups of vessels. This is in line with the fleet characterisation in which the vessels of 1500Hp and over operate in a much more homogenous way then the smaller vessels. It also points out the fact that the analysis of efficiency should include the joint activity-pallet of a fishing unit.

The projected output calculated on the basis of the capacity utilisation scores is of course in line with the found capacity utilisation scores. If one regards the projected output based on the calculated capacity utilisation scores as indicative for production under unrestricted circumstances, on average output could be increased by 33%. Related to technical efficiency this projected unrestricted output would be in the order of 4%.

From the sector analysis and the composition of the fleet, based on the used sample of vessels, the results indicate a similar direction. Present magnitude of output under complete efficient conditions could be achieved on average with 80% of fixed inputs and 97% of variable inputs, which corresponds with the production of 88% of the sample fleet at fully efficient mode of operation. Hence, taking into account adverse conditions of operation the number of sea days used at present is at par with efficient production conditions. When taking variances in production and efficiency into consideration[5] also the fleet size is in line with efficient operation.

Concerning factors that influence the capacity utilisation of vessels next to noting a difference according to vessel engine capacity (and hence vessel size) there is a significant difference between vessels operating from the northern ports and those operating from the southern ports. This would indicate that next to distinguishing vessel size and related mode of production (métier; especially as reflection of output realised in a different mode of production), home port plays a significant role in constructing reference groups in calculating capacity utilisation scores and hence in determining efficiency of operations.

As was expected the set of stock-, quota data and price developments influence the capacity utilisation of the individual vessels. Also the size of the fleet influences the efficiency of the individual vessels.

In general the conclusion is that on average the vessels are operating in an efficient manner. However the level of efficiency is determined by both environmental factors and by the composition of the reference group. In a further analysis focus should be on the study of a constant group of similar vessels over a time period. This reference group then could provide the information useful to perform analysis with different restrictions and assumptions.

The fact that the fleet has been working with restricted ITQ's that were strictly enforced throughout the period considered might have influenced the efficiency. The extent of this could be subject of further study.

6.3. Dutch Beam Trawl fleet: shrimp fisheries

The cutter fleet is the main branch of the Dutch sea- and coastal fisheries, consisting of about 400 vessels by the end of 2000, producing total gross revenues of € 290 million in that year and providing employment to about 1830 fishermen.

About 55% of the cutter fleet in numbers have main engines of 221 kW or less, with a little more than 10% of total fishing effort in kW-days, producing nearly 25% of total revenues and providing for 35% of employment on the fleet. The main activity of this segment of the cutter fleet is beam trawling for shrimp, taking up nearly 60% of their effort in kW-days and 55% of the man-years, and providing for more than 50% of their revenues.

6.3.1. Data set[6]

The DEA analyses of the Dutch cutter fleet for shrimp fisheries was concentrated on the smaller cutters, up to 300 HP (≤ 221kW), mostly fishing for shrimp (*Crangon crangon*) but in many cases doing a seasonal succession of other fisheries as well. Data of the boats were derived from DAFIST[7], a simplified and user friendly excerpt of the official Dutch logbook database VIRIS.

For the period 1995 – 2000 2726 observation were used, divide over six different gear types.
The variables used in the analysis are:

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[5] The average ratio between projected output based on technical efficiency and observed output is 112.3% with a variance of 377.9.

[6] OTB= otter trawl bottom; OTM = otter trawl mid-water; PTB = pair trawl bottom; PTM = pair trawl mid-water; TBB = twin beam trawl bottom ;TBS = Twin beam trawl shrimp.

[7] DA(tabase of) FI(shery) ST(atistics) was developed with support from the European Commission: Ref.: Beek, F.A. van, J.W. deWilde, W. Dol & W.C. Blom, 'Creation of a Database of fishery Statistics of the Dutch fleet (DAFIST)', RIVO Report CO14/98, IJmuiden, 1998.

- Engine capacity in HP
- Vessel size in GT
- Variable inputs in days at sea
- Catch of sole in kg
- Catch of plaice in kg
- Catch of shrimp in kg
- Aggregated catch of other species.

6.3.2. Conclusions

The analysis of the shrimp fleet has been implemented on observation by gear type basis and not on a vessel by métier level. As a result capacity scores relate to efficiency of the gear and not necessarily to the vessel itself since the vessel could operate a number of gears consecutively in any given year.

Concerning the individual gear on average for the sample fleet for the period 1992 – 1999 the capacity utilisation score based on the observed output (Cu*obs*) is 0.46. This varies from the relatively efficient use of PTM (Cu*obs* = 0.96) to the relatively less efficient use of OTB (Cu*obs* = 0.30).

Concerning the analysis of the technical efficiency score (TE) for the entire fleet and gear sample is calculated at 0.62, ranging from 0.53 for TBB to 0.94 for OTM.

The unbiased efficiency score (Cu*fare*) for the entire fleet and gear sample is 0.68. However, here we find a large difference between the score for the OTB (Cu*fare* 0.44) and the sample of PTM (Cu*fare* 1.0).

If we take the requirements for degrees of freedom in consideration we have the following results for respectively the capacity utilisation score based on the observed output (Cu*obs*), the technical efficient score (TE) and the unbiased efficiency score (Cu*fare*)

	Cu*obs*		**TE**		**Cu*fare***	
GEAR	*Mean*	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*
OTB	0.30	0.11	0.57	0.11	0.44	0.11
PTB	0.30	0.13	0.59	0.16	0.44	0.14
TBB	0.39	0.11	0.53	0.12	0.66	0.10
TBS	0.53	0.06	0.67	0.04	0.78	0.07
Average	0.45	0.10	0.61	0.08	0.68	0.10

The projected output calculated on the basis of the capacity utilisation scores is, due to the fact that the analysis was implemented on a gear by gear manner in stead of a fishing unit analysis, not to be considered realistic. Part time operations of a particular gear are compared to full time utilisation of the gear. Hence dramatic increases are calculated whereas in reality the total output and input per fishing unit should be considered. This fact is echoed by the results of the industry analysis.

Concerning factors that influence the capacity utilisation of gears by vessels there is a significant difference between the consecutive years. In addition spawning stocks and quota influence the efficiency of the operation.

In general the conclusion of the analysis of the beam trawl fleet shrimp fisheries is that an integrated fisheries analysis should be implemented and not a partial activity analysis.

6.4. German Beam Trawl fleet: sole and plaice fisheries

The German fishing fleet counts two segments of beam trawlers, both operating in the North Sea only. Specialised beam trawlers for flatfish are the smallest segment in the fleet, contributing only 0.3% to the fleet in numbers, 2.5% to total tonnage and 3.8% to aggregate engine power at the start of 2000.

In addition to these flatfish beamers there is a sizeable segment of boats that are allowed to beam trawl in the 12-mile zone and the plaice box. They contributed 13% to the fleet in numbers, 18% to total tonnage and 30% to aggregate engine power at the end of 2000. Most of these boats are primarily engaged in fishing for shrimp (as appears from the statistics in the 1996 BMELF report), often combining this with seasonal fishing for flatfish. Those having flatfish as their main target species probably in most cases combine this fishery with seasonal shrimping.

6.4.1. Data set

On request the *Bundesanstalt fur Landwirtschaft und Ernahrung* has made available for the research data on the German fishing fleet and landings by port, by gear and by species. The data are based on the logbook sheets and focus on the flatfish fishery with the beam trawl gear with mesh size of over 80 mm. The data set contains the 1996 – 2000 period and provides figures on individual vessel level including data on engine capacity in kW, vessel size in GT mesh size of the gear in mm, date and time of leaving port and return data, time spent at sea and actual hours spend fishing and catch data by species in kg landed weight.

A total of 147 observations for the period 1996 – 2000 were obtained. The variables used in the analyses were:

- Engine capacity in kW
- Vessel size in GT
- Variable inputs in Fishing hours
- Catch of sole in kg
- Catch of plaice in kg
- Aggregated catch of other species.

6.4.2. Conclusions

Concerning the individual vessel analysis on average for the sample fleet for the period 1996 – 2000 the capacity utilisation score based on the observed output is 0.34. Concerning the analysis of the technical efficiency score (TE) for the entire fleet sample is calculated at 0.75.

This rather large difference between the two entities can be attributed to the fact that the sample fleet is a rather heterogeneous amalgamation of vessels operating in a wide variety of modes of production (métiers). An analysis taking into account production realised in an adjacent fishing activity should provide a more general efficiency score per vessel for the totality of fishing activities undertaken. This is partly being reflected by an unbiased CU score (Cu*fare*) for the entire fleet sample of 0.54.

The projected output calculated on the basis of the capacity utilisation scores is of course in line with the found capacity utilisation scores. As a result of the sample fleet composition and the fact that catches realised in an other mode of production have not been included in the analysis the projected output based on the calculated capacity utilisation scores vary dramatically between vessels based on the relative effort allocated to a specific métier. If one focuses on the technical efficiency as a measure of projected increase in output as a result of increased efficiency the projected unrestricted output would be in the order of 14% higher than observed output.

From the sector analysis and the composition of the fleet, based on the used sample of vessels, the results indicate a similar direction. Present magnitude of output under efficient conditions could be achieved on average with 34% of fixed inputs and 99% of variable inputs, which corresponds with the production of 38% of the sample fleet at fully efficient mode of operation.

Concerning factors that influence the capacity utilisation of vessels, stock- and quota data influence the capacity utilisation of the individual vessels. Also the size of the fleet influences the efficiency of the individual vessels.

In general the conclusion is that based on the present sample of vessels and the available data it is problematic to draw general conclusions as to the efficiency of the fishing operation. Compared to the capacity output the technical efficient output scores show a relative noteworthy degree of efficiency. In general the conclusion is that an integrated fisheries analysis should be implemented.

6.5. Belgian Beam Trawl fleet: sole and plaice fisheries

The sea-going Belgian fishing fleet at the end of 2000 was composed of 127 boats with an aggregate engine power of 63 355 kW and an aggregate tonnage of 23 054 GT. Beam trawling for flatfish is the main activity of the Belgian fleet, contributing around 75% to the fishing effort expressed in days at sea. Beam trawler landings in 1999 and 2000 of about 22 500 t at a value of around € 75 million contributed between 85 and 90% to the total landed weight and value.

6.5.1. Data set

On request the *Dienst Visserij* has made available for the research data on the Belgian Beam Trawl fleet and landings by species. The data are based on the logbook sheets and focus on the flatfish fishery with the beam trawl gear of vessels involved in the operation for a minimum of 150 days per annum. The data set contains the 1997 – 2000 period and provides figures on individual vessel level including data on engine capacity in kW, vessel size in GT and catch data by species in kg catch weight.

In the Belgian setting the effort data of the fleet are not available for research. In order to facilitate a DEA analysis, in which variable inputs play a key role, effort data have been estimated based on catch and effort data of the Dutch beam trawl vessels for the period 1996 –2000 and average number of sea days per HP group as reported by the Belgian government. Since the above procedure only provides a rough estimate of effort the presented analysis must be considered as being indicative a no judgement can be provided based upon the analysis.

For the period 1997 – 2000 a total of 218 observations were available. The variables used in the analysis are:

- Engine capacity in HP
- Vessel size in GT
- Variable inputs in days at sea
- Catch of sole in kg
- Catch of plaice in kg
- Aggregated catch of other flatfish species
- Aggregated catch of other species.

6.5.2. Conclusions

As a result of the unavailability of firm level effort data the analysis presented here can only be regarded as indicative.

Concerning the individual vessel analysis on average for the sample fleet for the period 1996 – 2000 the capacity utilisation score based on the observed output is 0.88. Concerning the analysis of the technical efficiency score (TE) for the entire fleet sample is calculated at 0.97. Hence in general the sample fleet is operating in an efficient way. This is being reflected by an unbiased efficiency score (Cu*fare*) for the entire fleet sample of 0.91

The projected output calculated on the basis of the capacity utilisation scores is of course in line with the found capacity utilisation scores. If one regards the projected output based on the calculated capacity utilisation scores as indicative for production under unrestricted circumstances, on average output could be increased by 17%. Related to technical efficiency this projected unrestricted output would be in the order of 12%.

From the sector analysis and the composition of the fleet, based on the used sample of vessels, the results indicate a similar direction. Present magnitude of output under efficient conditions could be achieved on average with 75% of fixed inputs and 82% of variable inputs, which corresponds with the production of 83% of the sample fleet at fully efficient mode of operation.

Concerning factors that influence the capacity utilisation of vessels prices play an important role. Also an annual fluctuation of efficiency scores is reflected in the analysis. In addition, the size of the fleet influences the efficiency of the individual vessels.

In general the conclusion must be that since the effort data were being estimated based on the operations of a similar though different fleet with a distinctly different deployment of the variable input, the analysis can only be regarded as being indicative. However, the present analysis shows a sample fleet that is operating in a relative efficient manner.

7. Measuring capacity in the fleets of France

The application of the Data Envelopment Analysis in the French context is based on a selection of three case studies. Heterogeneous in nature and scale, these case studies were chosen to represent the diversity of the fleets in terms of technology used and activity practised. The first case study concerns the coastal seaweed fleet harvesting only one species –kelp - and located into the Brittany region. The fishery is seasonal, mainly regulated on input side. The second case study is the bottom trawl fleet targeting Norway Lobster in ICES area VIIIa,b. The landings are not only composed of this last output but of other species like anglerfish, sole and hake. Capacity related problems into this fishery are exacerbated by the required sharp reduction of the TAC levels of these main species. The third fleet studied is a sample of the French fleet harvesting into the English Channel.

The first section describes the fisheries and focus on the capacity related problems encountered. The main differences in data set used concerns:

- The physical and monetary variables included in the DEA analysis to capture outputs or inputs variables
- The factors that might explain the differences in capacity utilisation (CU) scores
- The length of the data set, time series or cross sectional data.

The second section discusses the main results of the DEA models in terms of CU scores, efficient and capacity output levels. Deviation from the common methodology mainly concerns the inclusion of a stock index as a fixed input and the test of scale efficiency in the seaweed model.

The third section gives some results about the factors explaining the individual differences in CU scores. The fourth section presents some results about the industry model in order to estimate the optimal fleet size for different level of the TAC. In the Norway lobster case, a preliminary assessment of the cost needed to scrap the excess capacity is provided.

7.1. Selected fisheries and data

In this chapter are presented the three French case studies selected for the implementation of the DEA approach. The main French seaweed fishery is located in the Brittany region and most of the fields harvested are situated in the western part of this area. The fishery is seasonal - from May to October - and exploited by small vessels. In 1999, the fleet was composed of 57 vessels. Average size was less than 10 meters for an average horse power of 67 kW.

Table 7.1. Main characteristics of the seaweed fleet in 1999 (average figures)

Year	Number of vessels	kW	Length (m)	GRT	Hold capacity (m3)	Total landings (MT)
1999	57	66.59	9.58	10.25	15.70	50.8

Source : Ifremer.

The only species targeted is called kelp (*laminara digitata*) and the vessels are fitted out with a specific gear - an hydraulic crane with a hook - to catch it. As a consequence, the technology of this fleet with one output and one gear can be considered as relatively easy to represent and study. The fleet is managed by an individual licence system (*numerus clausus*) with regulations on the vessels characteristics especially maximum length authorised to enter the fishery. The number of trips per day was also limited to one in 1987. Despite a reduction in the number of vessels, capital stuffing occurred in this fishery especially through the mechanisation of the vessels and the increase in the hold capacity of the fishing units.

The second study focus on the bottom trawl fleet targeting Norway lobster in the ICES area VIII. In 2000, this fleet was composed of 229 vessels and yields a turnover of 74.96 M.Euros. The share of Norway lobster in the total turnover of the fleet is about 39%. The average vessel is 15 meters long with an average horse power of 235 kW, but the fleet is mainly composed of less than 16 meters fishing units (76% of the fleet).

Table 7.2. Main characteristics of the Bottom trawl fleet in 1999 (average figures)

	Number of vessels	Length (m)	Age	Invested Capital
Total	229	14.74	19	542.6

The gear used to catch Norway lobster is the bottom trawl and the use of twin trawl became general in the beginning of the 90's. The fleet is subject to the implementation of Common fisheries policy measures, especially national quotas derived from the Total Allowable Catches levels. Because of the composition of the landings, the fleet is actually subject to sharp reduction in the level of the TAC.

The third case study concerns an economic sample of the French fleets belonging to the English Channel areas. These fleets mainly harvest in the ICES area VIIe and VIId even if they target species in other areas. For this case study, 255 vessels were selected and this sample represents more than 15% of the population of the vessels linked to the Channel regions. The average vessel is 11 meters long and the average engine power is 141kW. However, the dispersion of the vessel characteristics is very high.

Table 7.3. Main characteristics of an economic sample of the French fleet in the English Channel (average figures)

	Number of vessels	Length (m.)	GRT	kW	Age
Total	255	10.9	17.3	141	20

Capacity related problems in the channels fisheries have been underlined by different studies that points out the over-capacity of the English Channels fleets from a global point of view. Even specific stocks are autonomous, most of the fleets requires a reduction in capacity. A significant number of coastal fleets are regulated by licence systems.

Different type of data were used in this study: log-books on a trip level basis that give output per species, indicators on the intensity of the activity (days at sea …) and a data base on vessels sales at the auction market in value and quantities. National MAGP files give the characteristics of the vessels and some information on the vessel owner. Biological survey from Ifremer was also used for one case study. Conversely to this type of data, monetary variables were also used. For example, the variables included in this analysis are the annual gross turnover of each individual vessel (output value), the invested capital in the fishing units measured by the insurance value, the annual total gear cost, the fuel costs and the average crew size over the year (fixed and variable input values). The project dedicated a significant part of time to the validation of the data sets.

7.2. Firm level studies

In this section were analysed the main results of the DEA common methodology applied to the different case studies in terms of capacity utilisation scores, observed and unbiased values of CU's. We have also tried to give measures of the dispersion of CU and indicators of efficient and capacity output of each fishery. We focus especially on the sensitivity of the results to the inclusion of an increasing number inputs or observations. The question of the scale efficiency of the fishing units was also tested and the stock indexes were included in the seaweed case study.

In all the case studies, the necessary degrees of freedom according to Cooper index were reached. The CU scores can be considered as accurate. According to the sensitivity analysis on the number of fixed inputs, we conclude that it is useful to include many measures of inputs in order to give unbiased results for the technical efficient frontier and then capacity utilisation scores.

The seaweed fishery

In this case study, different types of analysis in term of scale and time series were developed: Intra-annual analysis with and without stock index (1998), Inter-annual analysis (years 1985 to 1997).

First, it is an interesting question to investigate the sources of inefficiency that individuals might have. The problem is to assess if the inefficiency is caused by the individual itself or by the disadvantageous conditions under which the vessels is operating. This study only presents preliminary results in this area. From a DEA model perspective, this requires a shift in the common methodology in order to include either constant or variable return to scale to the model structure. Within the sample of 45 individuals, nine vessels operate at or near the optimal scale size and the most scale efficient units are the biggest vessels in size. The conclusion is that there are increasing returns to scale into this fishery. This may explain why, the fishermen were incited to build or purchase vessels with increasing capacity.

Secondly, the study has considered a monthly analysis with and without stock index for the year 1998 so that the consequences in terms of sensitivity on CU scores could be assessed. In the first case, the model was applied for each month from May to September. In the second case, a single model for all the months was carried out.

Table 7.4.   Average statistics on CU scores

Year	May	June	July	August	September
Number of obs.	44	45	45	45	43
CU Fare without stock index	0.89	0.87	0.82	0.91	0.65
CU Fare with stock index	*0.84*	*0.86*	*0.82*	*0.67*	*0.59*
Obs. CU without stock index	0.76	0.74	0.67	0.72	0.48
Obs CU with stock index	*0.41*	*0.73*	*0.67*	*0.59*	*0.50*

Observed CU Fare or optimal CU.

The results in terms of unbiased values of CU are different: it ranges from 0.84 to 0.89 in May and from 0.59 to 0.65 in September. The difference between the CU Fare scores is not statistically different in June and July and the gap in August (0.91-0.67) is mainly due to change in efficiency explained by the stock situation. In fact, the efficient output should be higher considering the current stock level than the efficient output without consideration of the stock size. The conclusion is that the inclusion of a new variable as the stock index is interesting because it characterises efficiency gains due to stock increase.

The further step in the analysis is to focus on the impact of stock variation on the efficiency of the vessels and the fleet as a whole.

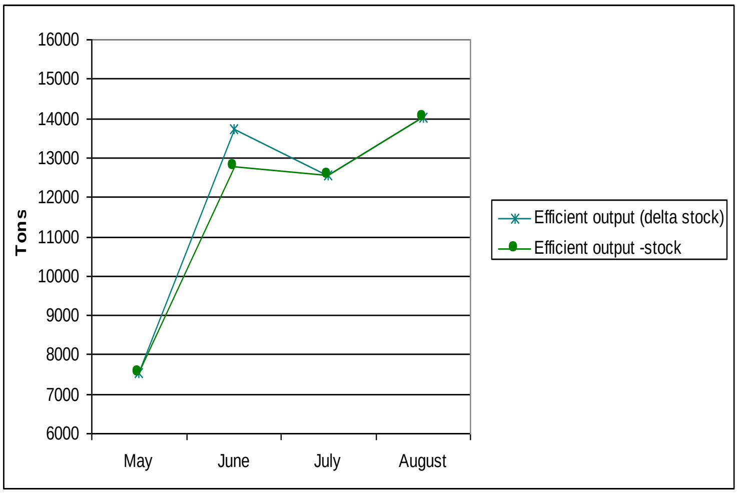

Figure 7.1. Efficient output with a June increase in stock abundance (scenario 1 and 2)

This increase in the June stock indexes (scenario 1) compared to scenario 2 with a respective 17% and 56% increase give rise to a 7% increase in the efficient output (see previous figure). Consequently, the optimisation process generated by the GAMS-DEA model expands the production possibility set with this new stock situation. This result is interesting because of the potential link with the model at the industry level allowing the assessment of the consequences of TAC reduction in terms of firm efficiency.

The bottom trawl fleet targeting Norway lobster

The selected sample concerns the vessels with an activity of more or equal to 9 months with a degree of freedom that give accurate measures of CU scores. Calculation of observed capacity utilisation shows that average CU is similar whatever the size with a relative low dispersion. The observed CU can be considered as high (0.862).

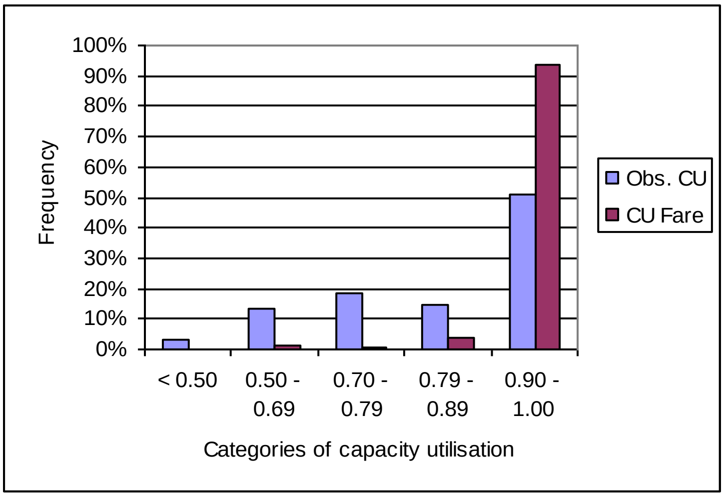

Figure 7.2. Bottom trawl fleet. Distribution of CU scores

About 50% of the vessels are the near the optimal level of capacity utilisation, between 0.90 and 1. The re-configuration of the fleet through change in input of each non-optimal vessel leads to a significant increase capacity utilization scores. More than 90% of the vessels become efficient in terms of unbiased level of CU. It is then useful to study the influence of inputs changes on the efficient level landings and landings composition.

*Table 7.5. Observed, efficient and capacity level for the outputs**

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Total
Observed level	372	2072	1080	563	339	936	4648	10009
Efficient level	422	2403	1190	633	382	1075	5236	11342
Capacity level	432	2441	1214	644	386	1095	5342	11553

Q1 : Index of shellfish, Q2 - Norway Lobster - Q3: Index of sharks, tuna, rays- Q4 : Index of Flatfish - Q5 : Anglerfish - Q6 Hake - Q7 Others (mainly rounfish).

The increase in total landings at efficient level is 13.9% higher than the observed level of landings. The rate of growth is the highest for the Norway lobster catch (16.0%) and the lowest (10.2%) for the output index that includes sharks, tunas, rays. The potential for an increase in landings due to an increase of the intensity of the activity can be considered as low for this sample compared to other fleets. However, a change of all the fixed inputs is required to reach capacity output level: 21% for the length, 22% for the kW index and 20% for the crew sire of the fleet as a whole.

The economic sample of the French channel fleets

The observed rate of capacity utilization is low with an average value of 0.584 with a standard deviation of 0.254 for the total sample. The scattering of values is not too high even if the range of values from 0.017 to 1.

Table 7.6. Observed, efficient and capacity value of landings for the sample

	Value of landings (in Million Euros)	Total C.U.
Observed value of landings	47.06	0.62*
Efficient value of landings	66.22	0.87**
Capacity value of landings	76.38	

* for observed CU. ** for Fare CU.

All things equal, the potential for an increase of the current turnover of the fleet is quite high with a CU at 62% (see Table 7.6). This rate of increase between actual production in value and “capacity production” in value is of course highest for the small categories of vessels than the biggest vessels.

For the overall fleet, the unbiased measure of capacity utilization (CU Fare) reaches a value of 0.867 with few differences between the fleet categories. As can be seen in the above table “capacity production” in value could be increased of about 15% with an increase of the variable factors (fuel consumption). The difference between 0.853 and 0.584 measures the potential of capacity production due to an optimal configuration of the fixed factors (value of the capital, gears cost, crew size).

7.3. Second-stage analysis

The objective of this section is to explain the individual variation in CU scores, especially on the economic sample of the French channel fleets. We focus on this study because the economic survey includes different information about the vessel-owner situation regarding the others activities elsewhere in the economy, his age, sociological factors like the reason of entry in the industry, etc. All these information were used to establish a table of correlation - and not described here a logit regression - between these variables and the optimal or the observed measures of capacity utilisation.

Table 7.7. Correlation test for capacity ratios

Correlated variable	CU Fare	CU Fare	Obs. CU.	Obs CU
	Pearson correlation	Bilateral signification	Pearson correlation	Bilateral signification
Other activities	-0.221**	0.000	-0.177**	0.005
Age of entry in the industry	-0.145*	0.023	-0.167**	0.009
Reason of entry (Father)			0.131*	0.036
Vessel length	0.224**	0.000	0.291**	0.000
Dredge	0.215**	0.001		
Gillnet	-0.143*	0.023		
H	0.316**	0.000	0.132*	0.035
Bottom trawl	0.316**	0.000	0.126*	0.035
Pelagic trawl	0.135*	0.031	0.126*	0.045
Line-hook	-0.148*	0.018		
Sifter gear	0.197*	0.022		
Seaweed gear			-0.176**	0.005

** significant at 1% level, * significant at 5%.

The level of significance is high, 99% for most of the Pearson coefficients. The coefficient gears like Bottom trawl, pelagic trawl and other trawls gears are always significant and positive, for example 0.316 and 0.132 for the bottom trawl coefficient. These gears variables are also correlated with the vessel length. The correlation with passive gears, especially gillnet which is significant at 99% and negative (-0.143). This can be explained by the specific hydrodynamic situation of the Channel fisheries. In fact, the tide is very high in the area, so the use of gillnet and passive gears is limited in duration. The other factor influencing negatively the level of capacity utilisation is the practice of other activities (e.g. revenues from retirement, revenues from shellfish-farming, processing of sea products). The age of entry is also a factor reducing the rate of capacity utilisation.

7.4. Sector level studies

In this chapter were applied the common methodology at the industry level. Based on the previous results of the CU scores, capacity output and efficient output, the model aims at assessing the optimal fleet size considering a defined level of landings and eventually other constraints on the inputs. Only the first and second case studies were used to assess the impact of the level of the constraints. We finally focus on the potential cost of decommissioning programs necessary to rationalize the fleet size.

The seaweed fishery

In the case of the seaweed fishery, the objective is to assess the consequence of a TAC implementation at a monthly level basis. In practice, the tool is required to control the fishing mortality at the beginning of the season in order to benefit from the stock growth capacity. Even we do not have, at this stage, any accurate model on the dynamic of the resource, different scenarios are nevertheless studied in order to value the results in terms of DEA approach combined with an industry analysis. We have based our analysis on two months (May and June) and the next tables indicates the main results in terms of fleet size for different level of the TAC’s. In May 1998, the observed level of the landings was 6,345 tons and required 44 vessels. In June, 11,077 tons were produced by the same fleet but with an increasing level of activity.

Table 7.8. Observed and capacity level of fixed and variable inputs for different scenarios of TAC

May	Length (m.)	GRT	KW	Cranes	Trips	Fleet size
(1) Observed level (6,345 tons)	418	432	2916	49	346	44
(2) Capacity level (6,345 tons)	345	356	2408	39	278	34
(2-1) in%	-17%	-18%	-17%	-20%	-20%	-23%
(3) Capacity level (5,000 tons)	255	264	1782	30	212	27
(3-1) in %	-39%	-39%	-39%	-39%	-39%	-39%
June						
(1) Observed level (11,077tons)	418	432	2916	49	690	44
(2) Capacity level (11,077tons)	339	346	2334	38	549	33
(2-1) in%	-19%	-20%	-20%	-22%	-20%	-25%
(3) Capacity level (15,000 tons or + 35%)	498	514	3495	56	754	44
(3-1) in %	19%	19%	20%	14%	9%	0%

The excess capacity composed of the less efficient vessels represent around 23% of the fleet in terms of variable or fixed inputs. The optimal fleet size at current level of landings is composed of 34 individuals. The scenario leading to a reduction of the landings to 5,000 tons need a 39% reduction in the fleet size. The negative impact of such a reduction could be compensated by an increase in the stock size for the month of June. If the stock size is big enough to reach a capacity output of 15,000 tons, the reduction in the fleet becomes nil with a slight progression in the intensity of the activity (+9%).

The bottom trawl fleet targeting Norway Lobster

The industry analysis is of interest in the case of the bottom trawl fleet targeting Norway Lobster in order to assess the consequence on the fleet structure of a reduction in total allowable landings. The next table presents the results of the optimisation procedure applied to the sample set (130 individuals). At the current levels of landings, the rationalisation of the fleet to its optimal size needs a 15% reduction in fleet size (from 130 vessels to 110 vessels). The table also presents the results of the implementation of the 2002 recommended TAC by the ACFM.

Table 7.9. Observed and capacity level of fixed and variable inputs

	Length (m.)	GRT (/100)	KW	Crew	Activity	Fleet size
(1) Observed level	184,962	356,875	27,547,0	416	1,469	130
(2) Status quo*	175,595	342,831	26,462	399	1193	110
(2-1) in%	***-5%***	***-4%***	***-4%***	***-4%***	***-19%***	***-15%***
(3) Recommended TAC	163,396	324,417	25,041	377	1,101	101
(3-1) in %	***-12%***	***-9%***	***-9%***	***-9%***	***-25%***	***-22%***

Table 7.10. Scenarios: 2002 TAC in percentage of TAC in 2001

	Shellfish	Norway lobster	Pelagic species, sharks,…	Flatfish	Anglerfish	Hake	Others
Scenario 6	100%	50%	100%	33%	20%	84%	100%

However, the implementation of the recommended TAC including not only a 50% decrease in Norway lobster TAC, but a reduction for the other species supposes a 22% decrease in the fleet size. The reduction of the fleet has an impact on the fleet structure per area. The biggest maritime district numbers suffer with a large decrease in terms of vessel number even if the reduction in percentage is not so high.

The results presented gives only physical indexes, especially the level of inputs at capacity level, compared to observed level and a valuation of total engine power that should be excluded from the fishery to reach optimal fleet size. Parallel to this assessment, it could be useful to value the cost of upgrading the observed fixed input to the capacity input level. Even if the economic incentives to exit vary from a fishermen to another, it is possible to provide an rough assessment of the cost of upgrading and decommissioning vessels. The assumption is that the minimum willingness to accept to leave the fishery is equal to the price of the capital. With a fleet of 130 vessels, the investment cost required to reach capacity level is around 66MF and the cost of scrapping the vessels is valued at 147MF. This cost is less important (102MF) if the fishermen have not simultaneously increased their capacity.

7.5. Conclusion

The main results of this study can be underlined from different point of views: methodological and empirical. Beyond the classical analysis of capacity utilisation according to the common methodology, we have focused on the question of the scale efficiency of the vessels and on the inclusion of stock index in the DEA approach. We conclude that there is increasing return to scale in the seaweed fishery and that this situation could explain the dynamics of the fleet which is now composed of a larger share of bigger vessels. Secondly, the integration of stock index may explain difference in CU scores and in efficient and capacity output levels. Despite the inherent difficulties to include resource influence in the measures of vessel efficiency, this approach could be generalised.

From an empirical point of view, the analysis of CU scores concludes that there is large difference between vessels even if it depends on the fisheries studied. The indicators provided by the model – observed CU or unbiased CU – gives measures of the necessary shifts in fixed or variable inputs to reach efficient or capacity output. At a large scale - example of the Channels fisheries – the potential for an increase in variable input, which is malleable on a short-term basis, is high. All things equals, the capacity output of the fleet is high compared to the current level and this is of interest from a management perspective. On another side, it is difficult to identify the factors explaining the variability of CU scores. Based on the available information and a preliminary statistical analysis, the study shows that CU depends on the other activities practised elsewhere in the economy. However, the main sources of deviation are the length of the vessels and the use of gears of combination of gears. The bigger the vessels are, the higher are their CU scores.

The DEA method gives efficient level of inputs (fixed and variable) compared to the observed levels. However, the shift of the fixed input configuration from the observed level to efficient level is not self-evident because it needs time to occur. Moreover, Regulation like the Multi Annual Guidance Programs and specific national policy on fishing permits restrict these possibilities. The degree of freedom to achieve the new configuration is then considerably limited by these regulation factors. The main opportunity to change vessel is to buy another one on the second hand market. Consequently, capacity output is rationed by public policy on a short-term basis. Last but not least, inputs like the type of gears and electronic equipment are not measured in the physical indexes even if it can be viewed as a crucial factor influencing vessel efficiency. Only the third case study gives a monetary index of the investment and the gears cost. Consequently, these CU scores can be considered as more accurate.

Finally, the study gives an assessment of the total engine power or other physical index that should be excluded from the fishery to reach optimal fleet size. Parallel to this approach, we valued the (private) cost of upgrading the observed fixed input to the capacity input level and the (public) cost of decommissioning schemes required to reach the optimal fleet size according to regulations.

8. Measuring capacity in the fleets of Denmark

8.1. Data

The Danish data has been obtained from the Danish Directorate of Fisheries. The dataset covers the Danish fishing fleet in the period 1991 to 1998. The following vessels have been filtered out:

- Vessels below 12 metres.
- Vessels primarily fishing mussels.
- Vessels primarily fishing horse mackerel.
- Vessels primarily fishing after deepwater shrimps in the waters around Greenland.
- Vessels fishing in an unknown fishing area more than two times during one year.

Fishing areas covered are (i) the Skagerrak, (ii) the Kattegat, (iii) the Sound, Belt Sea and Baltic Sea, (iv) the North Sea and (v) other fishing areas.
Vessel types are (a) Gill netters and liners, (b) Multi-purpose vessels, (c) Purse seiners, (d) Danish seiners and (e) Trawlers.
Catch has been classified into the following 9 categories: (1) Cod, (2) Other Cod fish, (3) Plaice, (4) Sole, (5) Herring and Mackerel, (6) Norway Lobster, (7) Shrimps, (8) Other consumption species, and (9) Industrial species. Only landed weight has been considered in the present analysis.
Effort is limited to (E1) Tonnage, (E2) Maximum horsepower, (E3) Crew size and (E4) numbers of days at sea. Of these E1 and E2 are fixed inputs, while E3 and E4 are variable inputs.

Data has been aggregated on a yearly level, resulting in a dataset that contains yearly aggregates on the vessel level of landed weight of the individual species, yearly aggregated levels of the number of days at sea, together with the values of tonnage, maximum horsepower and crew. The output of each species for the individual vessel is presented as aggregated landed weight divided by aggregated number of days at sea, i.e. as the mean landed weight per day at sea.

The resulting dataset contains yearly aggregated information for the years 1991 to 1998 for the vessel types (a) to (e) in the seas (i) to (v). As the measurement of capacity utilization and efficiency requires the analysed vessels to be identical concerning type, activity and conditions, the data has been divided into different area and type subsets. As information on stock has not been included in the analysis, the area-type subsets have been further divided into single year subsets, thus assuming that the stock will not change much during a one year period.

8.2. Analyses performed

Three types of analyses have been performed, Individual vessel capacity utilization analysis, Second Stage comparative analysis, and Industry capacity analysis.

The individual vessel capacity utilization analysis examines observed and efficient capacity utilization scores at the individual vessel level for selected fleets. Observed and efficient capacity utilization distributions for the individual fleets are described by the fraction of fully operating vessels together with distribution characteristics, such as mean, median and quantiles, for the distributions of the observed and efficient capacity utilization scores for the vessels that do not operate at full capacity. Fleets are characterised by vessel type, sea and operating year. The selected fleets are trawl and netters in the North Sea and in the Skagerrak in all years 1991-1998.

The second stage analysis covers comparison of optimal capacity utilization of different fleets. Optimal capacity utilization frontiers are compared for the different fleets two by two by the Wilcoxon-Mann-Whitney rank sum test. Fleets compared are trawlers and netters in the North Sea and in the Skagerrak in the two years 1991 and 1998.

The industry analysis provides a capacity measure at the sector level. The analysis is based on the 1998 situation and provides the optimal fleet structure necessary to fill the quota of each species. Three different scenarios are analysed, depending on the objective of the fleet structure.

8.3. Individual vessel analysis

Four separate scenarios have been examined in the Individual Vessel Analysis, (I) Trawlers in the North Sea in 1991 to 1998, (II) Trawlers in the Skagerrak in 1991 to 1998, (III) Netters in the North Sea in 1991 to 1998 and (IV) Netters in the Skagerrak in 1991 to 1998. In each different scenario a separate analysis has been performed for each year, and thus 32 different analyses have been performed in all.

Each year contains 307 to 398 individual vessel observations in scenario I, 338 to 298 individual vessel observations in scenario II, 153 to 190 individual vessel observations in scenario III and 69 to 157 individual vessel observations in scenario IV. With $n=4$ inputs (E1 to E4 described above) and $m=9$ outputs (1 to 9 described above) the degrees of freedom measure (Cooper et al. 2000) becomes $max\{m \times n, 3(m+n)\}=39$, which must be less than the number of individual vessel observations for the DEA analysis not to be biased. It is seen that the minimum number of observations employed is well above this measure, so no bias should be expected.
For each year in each scenario observed capacity utilization scores CU as well as technical efficient capacity utilization scores CU^{eff} have been obtained for each individual vessel. For the CU distribu-

tions, it has been observed that a fraction of ≈10 % to ≈25 % of the vessels in each different scenario in each year have $CU=1$ (are fully operating), while the *CU* values for the remaining vessels, i.e. vessels with $CU<1$, generally approximate a normal distribution. The *CU* distributions have thus been described by the fraction of fully operating vessels, together with the mean, medians and standard deviation of the *CU's* of the remaining vessels.

It has on the contrary been observed that a relatively larger fraction (≈30-70%) of the vessels in each different scenario in each year have CU^{eff} equal to 1 and that the CU^{eff} values for the remaining vessels ($CU^{eff}<1$) do not follow anything resembling a normal distribution. The CU^{eff} distributions have therefore been described by the fraction equal to 1, together with the 25 %, 50% (median) and 75% quantiles of the distribution of the remaining values.

Table 8.1 and 8.2 summarize the results of the individual vessel analysis. Table 8.1 shows the results for the *CU* distributions while table 8.2 shows the results for the CU^{eff} distributions. Figure 8.1 to 8.8 show boxplots of the *CU* and CU^{eff} distributions.

Table 8.1. CU distributions for the individual vessel analysis

Vessel	**Area**	**N**	**% fully operating**	**Mean CU**	**Median CU**	**St. Dev. CU**
Trawl	North Sea	307 - 398	10 – 18	0.61 – 0.71	0.60 – 0.73	0.17 – 0.20
	Skagerrak	338 - 398	8 – 14	0.44 – 0.55	0.41 – 0.57	0.21 – 0.23
Net	North Sea	153 - 198	11 – 25	0.47 – 0.69	0.44 – 0.72	0.17 - 0.22
	Skagerrak	69 – 157	15 – 29	0.48 – 0.61	0.44 – 0.59	0.19 – 0.24

Table 8.2. CU^{eff} distributions for the individual vessel analysis

Vessel	**Area**	**N**	**% fully operating**	**Q1**	**Median**	**Q3**
Trawl	North Sea	307 - 398	40 – 65	0.83 – 0.88	0.93 – 0.96	0.98 – 0.99
	Skagerrak	338 - 398	41 – 57	0.79 – 0.87	0.91 – 0.97	0.98 – 0.995
Net	North Sea	153 - 198	57 – 74	0.65 – 0.84	0.91 – 0.95	0.96 – 0.99
	Skagerrak	69 - 157	32 – 70	0.62 – 0.86	0.80 – 0.94	0.90 – 0.99

Table 8.1 and 8.2 firstly show that the fraction of fully operating vessels ($CU=1, CU^{eff}=1$) is generally higher for the netters than for the trawlers, reflecting a lower number of observations for netters than for trawlers.

Table 8.2 shows that 50% of the vessels with CU^{eff}<1 is generally operating very close to full technical capacity, i.e. have CU^{eff} values very close to unity. This is seen by examining the quantiles presented in the CU^{eff} tables. The Median is generally larger than 0.8 – 0.9, indicating that at least 50% of the non-efficient fleet is close to being operated at full technical capacity. When these are combined with the vessels having $CU^{eff}=1$ it may be concluded that more than one half of the fleet would be operating at near to full capacity, if the inputs were used technically efficient.

Figure 8.1, 8.3, 8.5 and 8.7 show the *CU* distributions for the vessels with $CU<1$. It is seen that for the netters in both seas and for the trawlers in the Skagerrak there does not seem to be a trend in the development of the *CU* distributions of the vessels from 1991 to 1998. For these segments there does only seem to be a stochastic variation of the distributions, with no real trending change.
For trawlers in the North Sea there does seem to be a slight movement of the *CU* distribution towards unity from 1991 to 1998, especially from 1996 to 1998. I.e. there seems to be an indication that the overall observed capacity of the trawlers in the North Sea increases slightly towards 1998.

Figure 8.2, 8.4, 8.6 and 8.8 shows the CU^{eff} distributions for the vessels with $CU^{eff}<1$. For trawlers in both seas and for netters in the North Sea there does not seem to be a trend in the development of the distributions from 1991 to 1998. For trawlers there does not even seem to be severe stochastic variation in the CU^{eff} distributions. For netters in the Skagerrak there might be a slight movement of the CU^{eff} distributions away from unity towards 1998, i.e. the overall efficient capacity utilization may decrease a bit towards 1998 for netters in the Skagerrak.

The analysis thus generally indicates that no big changes in capacity utilization takes place for the four fleets in the considered period, and that a rather large fraction of vessels in all four fleets would be operating near full capacity if they utilized their inputs optimally.

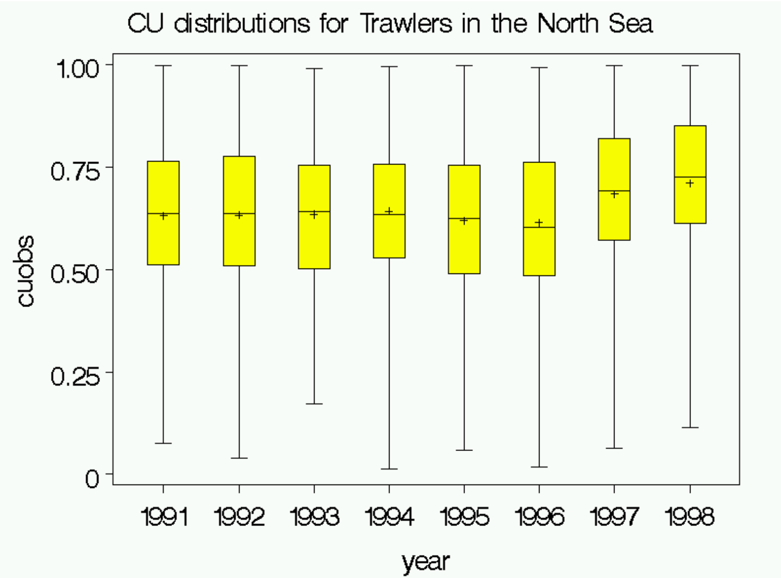

Figure 8.1. Box Plots of the CU distributions for trawlers with CU<1 in the North Sea in the years 1991-1998

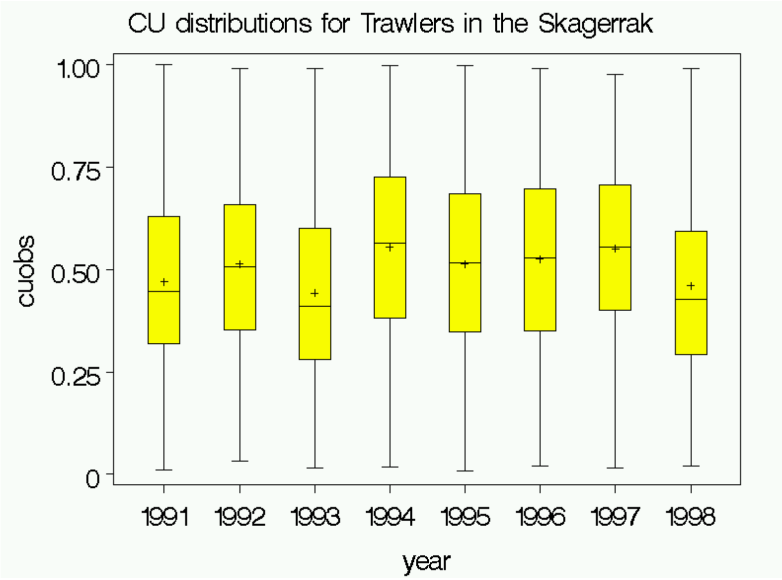

Figure 8.3. Box Plots of the CU distributions for trawlers with CU<1 in the Skagerrak in the years 1991-1998

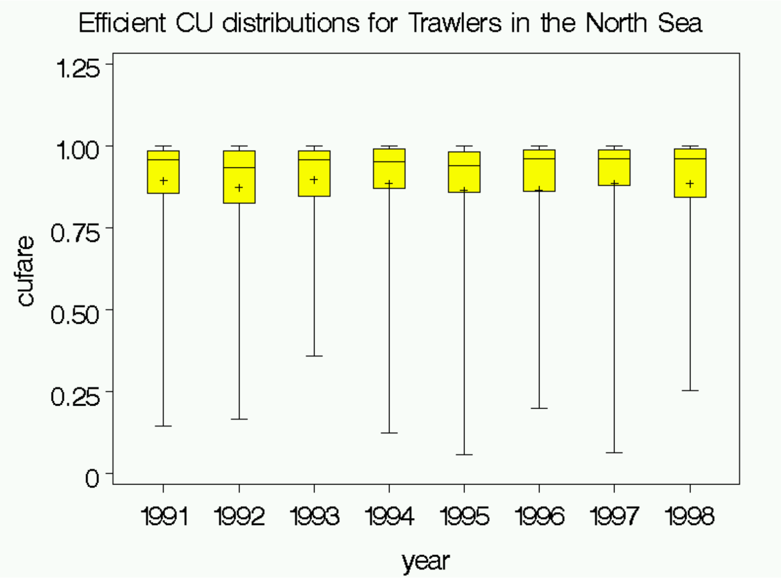

Figure 8.2. Box plots of the CU^{eff} *distributions for trawlers with* $CU^{eff}<1$ *in the North Sea in the years 1991-1998*

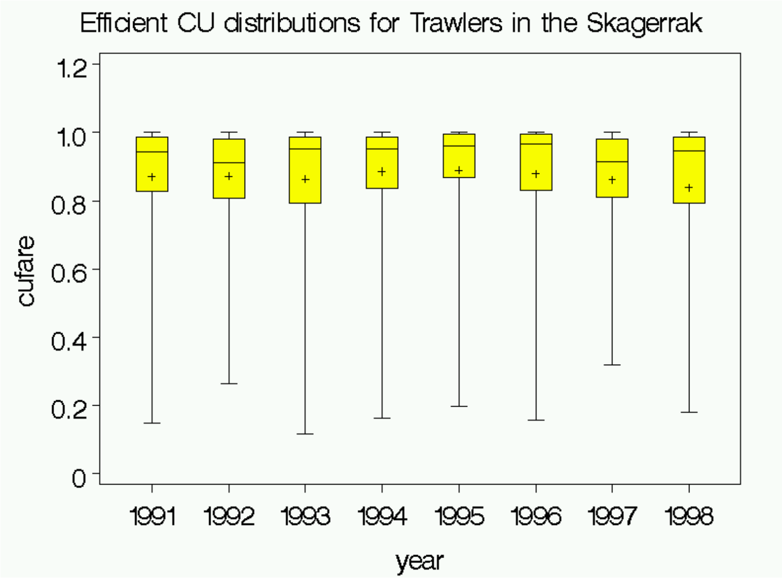

Figure 8.4. Box Plots of the CU^{eff} *distributions for trawlers with* $CU^{eff}<1$ *in the Skagerrak in the years 1991-1998*

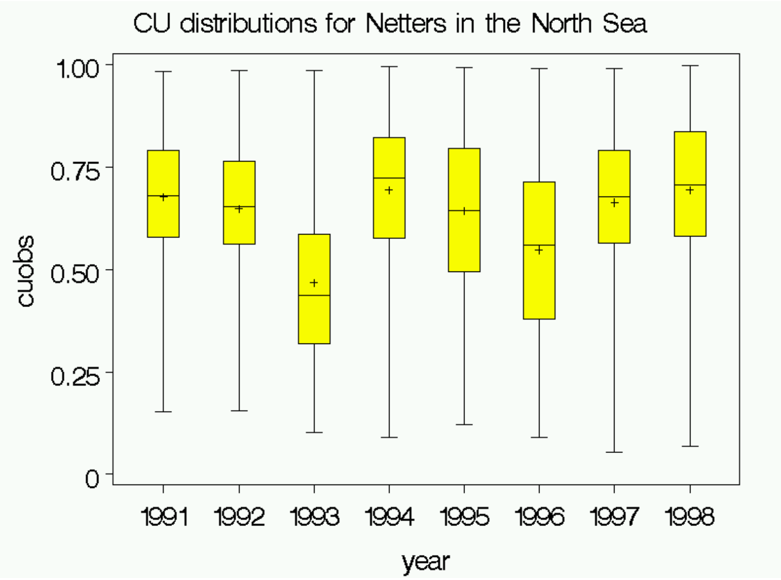

Figure 8.5. Box Plots of the CU distributions for netters with CU<1 in the North Sea in the years 1991-1998

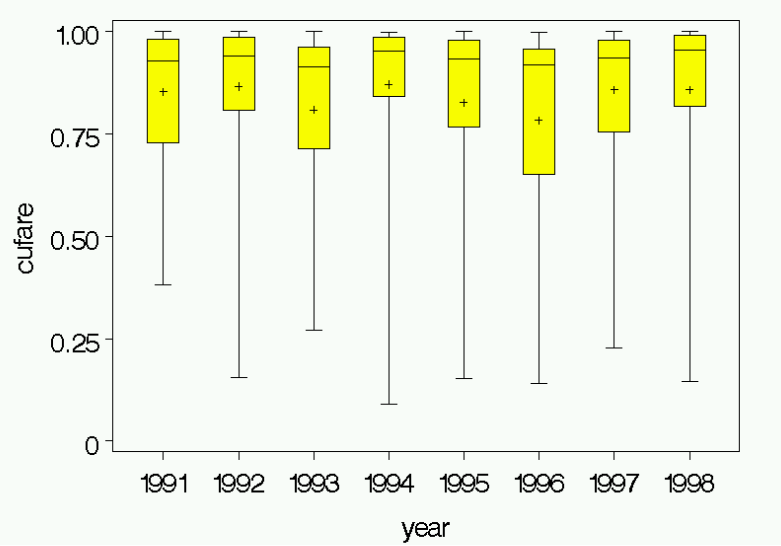

Figure 8.6. Box plots of the CU^{eff} *distributions for netters with* $CU^{eff}<1$ *in the North Sea in the years 1991-1998*

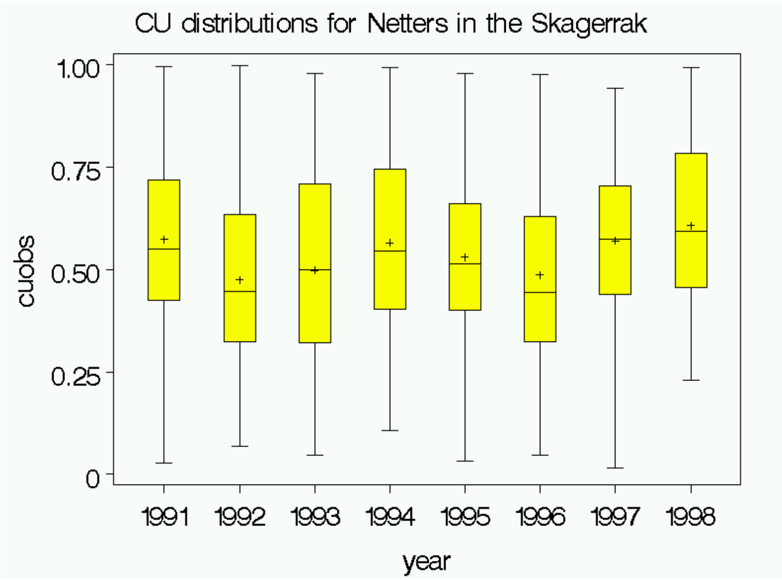

Figure 8.7. Box Plots of the CU distributions for netters with CU<1 in the Skagerrak in the years 1991-1998

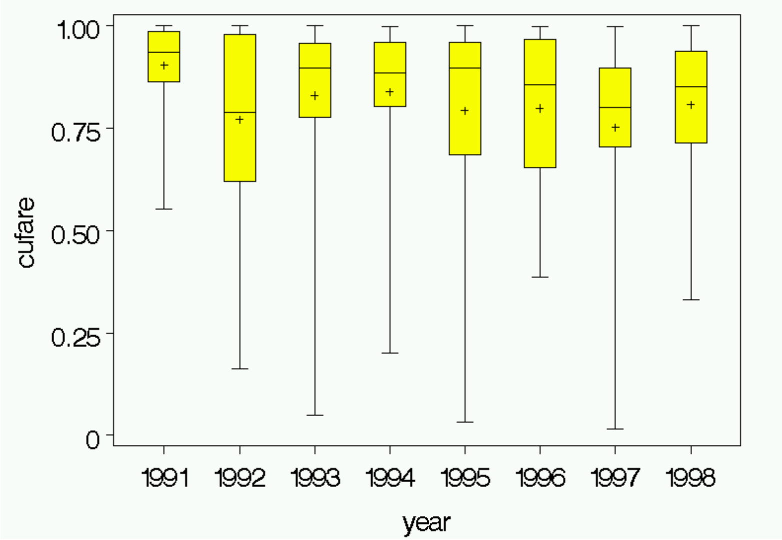

Figure 8.8. Box Plots of the CU^{eff} *distributions for netters with* $CU^{eff}<1$ *in the Skagerrak in the years 1991-1998*

8.4. Second Stage Analysis

Contrary to the individual vessel analysis presented in the previous section it may also be of interest to compare how well two different groups of vessels perform relatively to each other, i.e. if the one group generally work at higher or lower capacity than the other group. Another potential problem or question might be that the vessels analysed in a common DEA model are influence differently by external factors, i.e. nondiscretionary variables, not under control of the fisherman and hence the scores are biased. This can be corrected by a second stage regression analysis.

8.4.1. Between-type comparison

Several methods for between-type comparisons are put forward in Cooper et.al. (2000). Among these is suggested to employ the Wilcoxon-Mann-Whitney rank sum test to compare the optimal frontiers of the two different types of vessels, a method that has been applied in the present context.
The comparison has covered netters and trawlers in the North Sea and the Skagerrak in two different time-periods (1991 and 1998). The comparison has comprised three different scenarios, (i) comparison by vessel type (e.g. comparison of trawlers and netters in the North Sea in 1991), (ii) comparison by area (e.g. comparison of netters in the North Sea respectively the Skagerrak in 1991) and (iii) comparison by year (e.g. comparison of netters in the North Sea in 1991 respectively 1998).

Each scenario covers four different comparisons. Assessment of netters against trawlers e.g. comprise the four comparisons (i) The North Sea in 1991, (ii) the North Sea in 1998, (iii) the Skagerrak in 1991 and (iv) the Skagerrak in 1998. Only observed capacity utilisation scores *CU* have been compared.

The comparison by vessel type have shown the following trends:

- The netters have significantly higher capacity utilisation than the trawlers in the North Sea as well as in the Skagerrak in 1991.
- The trawlers have significantly higher capacity than the netters in the North Sea as well as in the Skagerrak in 1998.

It is thus observed that netters have generally been operating more efficient than the trawlers in 1991 in the Skagerrak as well as in the North Sea, while the trawlers on the contrary have been more efficient than the netters in 1998 in both seas.

The comparison by area has shown the following trends:

- The netters have significantly higher capacity utilisation in the Skagerrak than in the North

Sea in 1991 as well as in 1998.

- The trawlers have significantly higher capacity utilization in the Skagerrak than in the North Sea in 1991 but on the contrary to this significantly higher capacity utilization in the North Sea than in the Skagerrak in 1998.

It is thus seen that the netters are generally operating more efficiently in the Skagerrak than in the North Sea in both years, and that the trawlers are likewise observed to be operating more efficiently in the Skagerrak than in the North Sea in 1991, while the opposite is true for 1998.

The comparison by year has shown the following trends:

- The netters have significantly higher capacity in 1991 than in 1998 in the Skagerrak as well as in the North Sea.
- The trawlers have significantly higher capacity in 1998 than in 1991 in the Skagerrak as well as in the North Sea.

It is thus observed that the netters have generally been operating more efficient in 1991 than in 1998 in both areas, while the trawlers on the contrary have been more efficient in 1998 than in 1991 in both areas.

The above presentation indicates that netters have generally become less efficient during the period 1991-1998, while trawlers on the contrary have become more efficient. This is shown both by the comparison by time and by vessel type, as the last comparison shows that netters have been more efficient than trawlers in both seas in 1991 while trawlers have been more efficient than netters in both seas in 1998.

Moreover trawlers shift in the period from being most efficient in the Skagerrak to being most efficient in the North Sea, while the netters are most efficient in the Skagerrak in both years.

8.4.2. Regression analysis

The CU scores will be biased if the vessels are operating under different circumstances. Here the regression approach is applied to the whole Danish trawler fleet for 1998. The CU scores are regressed on fishing area dummies and the share of the cod catch of the total catch. The last variable represents the regulation of the cod fisheries, with the expectation that vessels with higher shares of cod in their catch will have a relatively lower CU score. The estimation shows that the share of the cod catch has a negative impact on the CU score, indicating the tight regulation of the cod fisheries. The CU scores obtained in areas, Kattegat (3as) and North Sea (4abc), are significantly higher than the scores for Skagerak (3an). This is in accordance with the results from the between-type analysis presented above.

8.5. Industry comparison

The industry model developed in chapter 4 is applied to the Danish fleet for the year 1998. However, because of the multi-area issue, the model has been modified, see the Danish country report. The analysis includes 923 vessels. The outcome of the model is a fleet structure that minimized the use of fixed inputs, i.e. provide the necessary number of and optimal kind of vessels to fill the quota of each species.

It was decided to run 3 different scenarios of the industry model. In all the scenarios the production has to meet the TAC given for each species in each area. In the first scenario, the use of fixed inputs is minimized for each gear type. In the second scenario, the use of fixed inputs is reduced for each area. In the third scenario, the overall use of fixed inputs is minimized.

In Table 8.3, the results of the industry model are presented. In terms of fixed inputs, the conclusions are that the industry capacity can be reduced in the short run between 37% and 47% depended on the chosen objective. The relative largest overcapacities are located in the fleets combination and gill-netters, while the purse seiner fleet has the lowest overcapacity.

In terms of number and size of vessels the impact on the fleet structure is given in Table 8.4. The total number of active vessels varies in the three scenarios between 450 and 505 vessel out of a total number of vessels at 963. The fleet structure is not the same in the three scenarios. Focusing on reduction of the total use of fixed inputs leaves space for more small size vessels (scenario 3) while the number of larger vessels is not reduced as much when the focus is on gear and area (scenario 1 and 2) as in scenario 3. The conclusion is that it depends on the objective of the fleet reduction which vessels-groups that are targeted.

Table 8.3. Current and optimal use of fixed inputs at industry level

	Current	Vessel Capacity	%	1. scenario Gear	%	2. scenario Area	%	3. scenario Overall	%
Trawlers									
Grt.	62921	59988	5	44527	29	35619	43	33626	47
HP	205388	192317	6	124639	39	109694	47	103768	49
Danish Seiners									
Grt.	3658	3382	8	2814	23	2219	39	2119	42
HP	15908	15092	5	12592	21	10584	33	10380	35
Purse seiners									
Grt.	8237	8016	3	6833	17	7092	14	7092	14
HP	15833	15412	3	13133	17	13469	15	13469	15
Combination									
Grt.	1460	1444	1	487	67	279	81	222	85
HP	7745	7550	3	1961	75	2036	74	1748	77
Gill netters									
Grt.	4862	4349	11	2204	55	2233	54	2041	58
HP	30480	28895	5	14255	53	16223	47	15365	50
Total	356492	336445	6	223445	37	199448	44	189831	47

Table 8.4. Numbers of vessels in the optimal industry fleet compared to the current fleet

		<20 Grt.	**20-40 Grt.**	**40-60 Grt.**	**60-100 Grt.**	**100-250 Grt.**	**>250 Grt.**	**Total**
Trawlers	Current number	254	43	72	30	91	93	583
	Industry (gear)	57	19	47	20	72	78	293
	Industry (area)	96	24	39	20	69	60	308
	Industry (overall)	111	17	34	17	61	60	300
Gill-netters	Current	128	22	23	11	0	0	184
	Industry (gear)	37	14	16	9	0	0	76
	Industry (area)	77	13	11	4	0	0	105
	Industry (overall)	82	11	7	3	0	0	103
Purse Seiners	Current	0	0	0	0	0	11	11
	Industry (gear)	0	0	0	0	0	10	10
	Industry (area)	0	0	0	0	0	10	10
	Industry (overall)	0	0	0	0	0	10	10
Combinations	Current	40	3	4	1	2	0	50
	Industry (gear)	7	1	2	0	1	0	11
	Industry (area)	13	1	1	0	0	0	15
	Industry (overall)	13	0	1	0	0	0	14
Danish Seiners	Current	25	34	32	2	2	0	95
	Industry (gear)	17	27	28	2	2	0	76
	Industry (area)	18	26	20	2	1	0	67
	Industry (overall)	18	25	20	2	1	0	66
Total	Current	447	102	131	44	95	104	923
	Industry (gear)	118	61	93	31	75	88	466
	Industry (area)	204	64	71	26	70	70	505
	Industry (overall)	224	53	62	22	62	70	493

9. Dissemination activities

The project has produced a number of scientific outputs based on the research. Several conference presentations have already been made and will be made in the future, e.g. at the forthcoming EAFE Conference 2002 the project team will make 4 presentations. Several papers have been submitted to journals for publication, one of which has already been published. These are listed below.

Three members of the project team participated in the FAO Technical Consultation on the Measurement of Fishing Capacity in Mexico 1999.

At the EAFE conference 2000 in Esbjerg, Denmark, a special session on fishing capacity was arranged by the project team, where Dr. Dale Squires, NMFS, was key-note speaker.

Journal articles published, submitted or in preparation

Hoff, A. and N. Vestergaard, A Comparison, employing DEA Analysis, of Capacity Frontiers for Different Fishing Fleets.

Pascoe, S., L. Coglan and S. Mardle, 2001 'Physical versus harvest based measures of capacity: the case of the UK vessel capacity unit system', I*CES Journal of Marine Science*, 58(6) 1243-1252.

Pascoe, S., Hatcher, A. and James, C. Estimating fleet adjustment under individual transferable quotas using Data Envelopment Analysis. Submitted to the *European Review of Operational Research*.

Tingley, D., and Pascoe, S. Factors affecting capacity utilisation in fisheries. In preparation to be submitted to *Journal of Agricultural Economics*.

Tingley, D., Pascoe, S. and Mardle, S., Estimating capacity utilisation in multi-purpose, multi-métier fisheries. Submitted to *Fisheries Research*.

Vestergaard, N., D. Squires and J. Kirkley, Measuring Capacity and Capacity Utilisation in Fisheries: The Case of the Danish Gill-net Fleet. Invited to resubmission to *Fisheries Research.*

Vestergaard, N., D. Squires and K. Kerstens, Industry Capacity for a Common Pool resource: The Danish Fishery.

Conference presentations so far

Pascoe, S. Coglan, L and Mardle, S. 2000. Physical versus harvest based measures of capacity: the case of the UK vessel capacity unit system, paper presented at the 10th Biennial Conference of the International Institute of Fisheries Economics and Trade, Oregan State University, Corvallis, 10-14 July 2000

Tingley, D., Pascoe, S. and Mardle, S. 2001. Trends in capacity utilisation in the English Channel, Paper presented at the XIIIth Annual conference of the European Association of Fisheries Economists, Salerno, Italy, 18-20 April 2001

Vestergaard, N., D. Squires and J. Kirkley, Measuring Capacity and Capacity Utilisation in Fisheries: The Case of the Danish Gill-net Fleet. Presented at the FAO Technical Concultation on the Measurement of Fishing Capacity, Mexico City, 29. November – 3. December 1999 and at the 10th Biennial Conference of the International Institute of Fisheries Economics and Trade, Oregan State University, Corvallis, 10-14 July 2000.

EAFE Conference 2002 presentations

Hoff, A. and N. Vestergaard, A Comparison, employing DEA Analysis, of Capacity Frontiers for Different Fishing Fleets.

Hoof, L.V., Data Envelopment Analysis

Tingley, D., and Pascoe, S. Factors affecting capacity utilisation in fisheries. In preparation to be submitted to *Journal of Agricultural Economics*.

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