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Measuring capacity and capacity utilization in fisheries: the case of the Danish Gill-net fleet

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Abstract

Different measures of capacity and capacity utilization (CU) are estimated and examined for the multi-species Danish Gill-net fleet using a mathematical programming approach—data envelopment analysis (DEA). The potential capacity output is calculated using an output-orientated measure. CU is assessed using both a partial CU measure, which permits CU to be assessed relative to each output, and a ray measure. Based on the ray measure, the average CU for the Danish Gill-net fleet was estimated to be between 0.85 and 0.95. The partial CU measure for cod was determined to be approximately the same as the overall or ray CU measure, but the partial CU measure for plaice was less than the level of the ray measure, which indicated that the production of plaice could be increased by a higher proportion than could the production of cod. The optimal variable input utilization was also estimated. It was determined that, on average, the variable input—number of trips—could be increased by 27% compared to the optimal level. Results also indicated higher excess capacity for cod and sole than for other species, which is in accordance with how the fishery developed.

Keywords: Fleet capacity; Capacity utilization; Danish Gill-net fishery; Data envelopment analysis

1. Introduction

Capacity and capacity utilization (CU) have been important concerns for fisheries management. It has long been recognized that in an open-access fishery, capital levels, harvest capacity, and levels of harvests will be sub-optimal. Alternatively, there will be over capitalization and excess harvesting capacity. Since fisheries in many countries and on the high seas are managed using open-access regulations, the control of capacity has consequently been on the political agenda. Recently, to address these concerns, the Food and Agriculture Organization (FAO) initiated an international plan of action on management of fishing capacity (FAO, 1999).

In the European Union (EU), a Multi-Annual Guidance Programme (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

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(see EEC, 1992) have pointed out that the reduction in the size of the EU 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.

This paper presents an analysis and examination of capacity and CU in the multi-species Danish gill-net fishery. The analysis is based on data envelopment analysis (DEA), which is a mathematical programming approach. Multi-species fisheries characterize many, if not most, of the world's most important fisheries. The paper is organized as follows. Section 2 discusses the major issues of defining and measuring capacity in fisheries; Section 3 discusses the empirical methodology used to estimate capacity and CU in the Danish gill-net fishery; Section 4 discusses the gill-net fishery and the data used for the analysis; Section 5 summarizes the results and provides additional commentary on the estimates, and Section 6 provides a summary and conclusions.

2. Capacity and CU in fishing industries

In simple terms, capacity may be defined as the ability of a firm or industry to produce a potential output. There are two distinct measures of capacity, a technical-economic measure and a strictly economic measure (Morrison, 1985a). What distinguishes the two notions of capacity is how the underlying economic aspects are included to measure capacity. With the technical-economic measure, also referred to as a technological-economic measure, no economic behavioral objective is explicitly assumed. Under the pure economic measure, the capacity output is defined as the output that is consistent with the output level that optimizes the behavioral objective of the firm. CU, regardless of the concept of capacity, is then the ratio of output to capacity output (Morrison, 1985a). Färe et al. (1989), however, argue that a more appropriate measure of CU is the ratio of the technically efficient output level to the capacity output level.[1] This latter concept has become increasingly used as the measure of CU.

The most common economic measure of capacity output assumes cost minimization of exogenous or predetermined output and is the output level corresponding to the tangency between the short-run and long-run average cost curves (Cassels, 1937; Klein, 1960; Berndt and Morrison, 1981; Morrison, 1985a). Berndt and Fuss (1989) and Segerson and Squires (1990) extended the notion of capacity from a single output to multiple outputs. Morrison (1985b), and Fousekis and Stefanous (1996) extended the static (single period) concept of capacity to a dynamic (multi-period adjustment of the capital stock) concept of capacity. Squires (1987), Segerson and Squires (1993) and Fousekis and Stefanous (1996) extended the concept of capacity for when the firm or vessel's behavioral objective is profit-maximization. Segerson and Squires (1993, 1995) and Färe et al. (2000) provide a revenue-based economic concept of capacity for a multi-product firm, which requires information on revenue and output prices. This revenue-based concept has not yet been sufficiently empirically estimated and examined, and therefore, its usefulness remains uncertain as a measure of capacity. For most fisheries, the economic concept of capacity cannot be assessed because the necessary economic data are rarely available.

In contrast, the technological-economic measure can be calculated even when economic data are unavailable. In fact, the technological-economic measure is the most widely used concept of capacity. The United States Federal Reserve and the United States Department of Commerce routinely assess the technological-economic measure of capacity. The Department of Commerce conducts an annual survey of manufacturing plants in which plant managers are asked about the likely potential maximum production. It is a technological-economic measure because it represents the potential maximum output for a plant conditional on prevailing output and input prices and demand conditions. No explicit economic optimizing behavior is assumed for the plant or firm.

The technological-economic measure is a concept of capacity offered by Johansen (1968, p. 68), who defined capacity as, "... the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable fac-

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[1] Technical efficiency occurs when firms or vessels produce the maximum output attainable for a given set of inputs, given the state of technology, environmental conditions, and in fisheries, the resource stock.

tors of production is not restricted".[2] This concept of capacity conforms to that of full-input utilization (i.e., maximum utilization of the variable inputs given the fixed factors of production) on a production function, with the qualification that capacity represents a *sustainable* maximum level of output (Klein and Long, 1973). The Johansen concept of capacity, however, was unbounded. The technological-economic measure was initially offered by Färe (1984) and is a weaker version of the Johansen measure because output or production is bounded by the fixed factors of production.

In the context of fisheries, this weaker concept of the Johansen measure of capacity corresponds to the maximum catch a vessel can produce if inputs are fully utilized given the biomass, the fixed inputs, the age structure of the fish stock, and the present state of technology. This concept of capacity output cannot equal the output level that can be realized only at prohibitively high cost of input usage, and hence, is economically unrealistic. The capacity output is measured relative to the observed best-practice frontier (i.e., based on observed points) and based on observed input and output levels. It is, therefore, not an absolute technically derived number based on an engineering[3] notion of maximum possible catch; instead, the observed input and output levels reflect changes induced by economic behavior of firms. That is, the observed best-practice frontier is established by the existing fleet and implicitly reflects economic decisions made by vessel operators.

The decision to maintain a given level of capacity or vessel size is a long-run decision based on expectations about future production possibilities (e.g. resource stock, environmental conditions, and regulation), and input and output prices. Capacity output is determined relative to a given point in time fixed, and hence, is a short-run concept. This is consistent with the definition offered by Johansen (Prochaska, 1978). CU is also a short-run concept, since current output or production can be adjusted given changes in input and output prices, but only subject to fixed inputs and the available technology. Over the long run, there is not a capacity problem in most industries, because the firm adjusts its capital stock and production level to the appropriate levels and all available inputs are utilized in terms of their most effective long-run equilibrium levels. However, in open-access fisheries, because of the "Tragedy of the Commons," excess capacity is generally expected in which the firms or vessels collectively, as the fleet, tend to harvest a level of catch that exceeds the sustainable long-term target level and the fish stocks tend to become overfished.

In the case of fisheries, the concept of capacity needs to address several specific issues.[4] An additional issue for fisheries, as compared to many other industries, is that the fishermen harvest from a fixed pool of resources where nature limits production and the individual fisher's ability to control catches (Prochaska, 1978). Measuring capacity in a renewable resource industry is, therefore, more complicated than measuring capacity output in a more "conventional" industry because the measure must be conditional upon the resource stock. The production technology for a fishery is stock-flow, in which inputs are applied to the resource stock to yield a flow of catch (output). Hence, if the capacity output is measured over a time period, the measure must reflect changes in the resource stock as well as changes in the capital stock.

Resource abundance and availability, however, may vary because of unexpected or seasonal changes in environmental conditions. If output or production levels vary seasonally or change because of extremely unusual environmental changes, capacity measures need to incorporate and recognize these changes.

Many fisheries throughout the world involve production of more than one output. Hence, multi-product or multi-species production is likely to be the norm rather than the exception (Clark, 1985), and any empirical method for estimating and assessing capacity must be able to account explicitly for multiple outputs. Another issue important for determining a method for assessing capacity in fisheries is the mobile nature of the vessel. Vessel operators may often switch from

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[2] Klein and Long (1973, p. 744) state that, "Full capacity should be defined as an attainable level of output that can be reached under normal input conditions—without lengthening accepted working weeks, and allowing for usual vacations and for normal maintenance." In addition, Färe (1984) developed a formal proof of the existence for Johansen's definition of capacity.

[3] Which means what is possible to produce if the vessel is working at maximum physical load.

[4] For an overview of capacity in fisheries see Kirkley and Squires (1999).

one fishery to another during a given period of time, or from one period to another.

The ability to change fisheries raises complex issues about aggregating measures of capacity for different fisheries. That is, what level of aggregation should be considered when assessing capacity output? The level of aggregation determines the outcome of the analysis. A high level of aggregation including all fisheries within the year of the whole fleet shows the overall level of capacity and CU. However, the problem is that there may be fisheries with very high CU and fisheries with low CU that can counterbalance so the combined CU result is not alarming. The fisheries with high-low CU are typically high value fisheries, and hence, the most important economically. If the fisheries are technologically distinct, they may be treated separately.

In open-access fisheries, in which the access to each single fishery is not excluded, a problem called latent capacity might arise. This problem has its origin in the fact that the fishing effort can change allocation between the fisheries during the season. A fishery with a high CU might in the next period have a low CU because of incoming vessels resulting in other fisheries having a high CU, all things equal. An assessment of the excess capacity in this kind of fishery has to take the regulation into account. A decommissioning scheme oriented towards reducing capacity in a fishery with both high- and low-valued species, therefore, may subsequently only reduce the capacity of the low-valued components, while not effectively reducing capacity relative to the high-valued species.

3. Empirical methodology

The methodology used in this paper to empirically estimate and assess capacity is DEA. The DEA approach is a mathematical programming technique for which an optimal solution is determined given a set of constraints. The approach has been widely used to find the technical efficiency of firms (Charnes et al., 1994). This approach can also be used to measure capacity and CU following Färe et al. (1989, 1994). The approach readily incorporates multiple output and input technologies.

Färe et al. (1989) demonstrated that an output-oriented measure of technical efficiency could be used to estimate the capacity output and optimum variable factor usage. An output-oriented measure of technical efficiency determines the maximum possible expansion of outputs (i.e., the frontier production) with no change in the fixed factors of production. The frontier or best-practice technology is a reference technology or production frontier that depicts the most technically efficient combination of inputs and outputs. The production frontier is formed as a non-parametric, piece-wise, linear combination of observed best-practice activities.

Under the Färe et al. (1989) framework, only the fixed inputs are bounded at their observed level, allowing the variable inputs to vary and be fully utilized. This is slightly different from the concept offered by Johansen, because it explicitly allows the fixed factors to restrict output. 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 (i.e., the score measures the distance between the observed output and the frontier). If the solution is 1.25, the capacity output is 1.25 times the observed output. The CU is then simply $1/1.25 = 0.8$. The DEA approach also provides the optimal utilization rate of variable inputs, λ_{jn}^*, or the utilization of the variable inputs required to produce at full capacity output.

Estimation of capacity output may be obtained by solving a mathematical or linear programming problem. Initially, designate the vector of outputs as u and the vector of inputs by x. There are m outputs, n inputs, and j firms or observations. Capacity output and the optimum or full input utilization values require solving the following equations:

$$\operatorname*{Max}_{\theta,z,\lambda} \theta_1$$

subject to

$$\theta_1 u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, \quad m = 1, 2, \ldots, M,$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, \quad n \in \alpha,$$

$$\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, \quad n \in \hat{\alpha},$$

$$z_j \geq 0, \quad j = 1, 2, \ldots J,$$

$$\lambda_{jn} \geq 0, \quad n \in \hat{\alpha},$$

where z_j is the intensity variable for the jth observation; θ_1 the technical efficiency score or the proportion by which output may be expanded when production is at full capacity; and λ^*_{jn} the ratio of optimum use of input x_{jn} to observed input use of x_{jn}.

Capacity output is then determined by multiplying θ^*_1 by actual production. CU, based on observed output, may be calculated as follows:

$$\mathrm{CU(observed)} = \frac{u}{\theta^*_1 u} = \frac{1}{\theta^*_1}$$

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). The ray measure converts the multiple-output problem to a single-product problem by keeping all outputs in fixed proportions. This ray measure corresponds to a Farrell (1957) measure of output-oriented technical efficiency due to the radial expansion of outputs.[5]

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

$$\underset{\theta, z}{\mathrm{Max}}\, \theta_2$$

subject to

$$\theta_2 u_{jm} \leq \sum_{j=1}^{J} z_j u_{jm}, \quad m = 1, 2, \ldots, M,$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, \quad n = 1, 2, \ldots, N,$$

$$z_j \geq 0, \quad j = 1, 2, \ldots, J.$$

The technically efficient output vector is calculated by multiplying θ^*_2 by observed production for each output. The technically efficient or “unbiased” ray measure of CU is then the following:

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

The output-oriented measure can be used in several ways. For each vessel, the capacity output is determined. Summing over vessels by given criteria (e.g. regional or gear-type) the necessary number of vessels can be found where the total reach some specified target (e.g. total allowable catch, TAC). In the multi-species case, this can be done for each species. We stress, however, that summing over each vessel presents a lower bound for the industry or fleet level of capacity (i.e., the industry or fleet level of capacity is greater than or equal to the sum of the vessel levels of capacity).

The variable input utilization outcome, λ^*_{jn}, measures the ratio of optimal use of variable input to observed use; the optimal variable input usage is the variable input level which gives full technical efficiency at the full capacity output level. If the ratio of the optimal variable input level to the observed variable input level exceeds (falls short of) 1.0 in value, there is a shortage (surplus) of the ith variable input currently employed and the firm should expand (contract) use of that input.

3.1. Second-stage analysis

Several external factors not included in the analysis might influence the CU scores. Coelli et al. (1998) suggest a second-stage analysis, where the scores obtained by the DEA analysis in the first stage are regressed on variables that are expected to influence the scores. Using the results from the second-stage regression, the efficiency scores can be adjusted. In the case of a fishery, the variables could be season, size of vessel, home port, etc. In our case of the Danish Gill-net fleet, where only 1 year is included and also

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[5] A non-radial expansion of outputs would correspond to Koopmans (1951) notion of technical efficiency.

the vessels are relatively equal in size, only the port is included in the second-stage analysis. Capacity and CU might, however, vary widely by port, which in turn reflects differences in institutional practices, resource availability and abundance, and market conditions (Squires and Kirkley, 1996). This variation in capacity and CU can be evaluated using a Tobit analysis. Tobit analysis accounts for censoring of the capacity measure at zero and of CU measure at both zero and 1. The capacity and CU measures regressed upon port dummy variables, without an intercept, gives a one-way analysis of variance with $5-1=4$ degrees of freedom when the null hypothesis of equal coefficients between all port dummy variables is applied. The model we consider for the Tobit regression for CU is as follows:

$$\mathrm{CU} = \sum_{i=1}^{5} \alpha_i D_i$$

where i indexes individual ports and 5 denotes the total number of ports. The null hypothesis of equal CU for all ports is $H_0: \alpha_\mathrm{I} = \cdots = \alpha_i = \cdots = \alpha_5$. With a Tobit regression, the appropriate test of the null hypothesis is the Wald test with a χ^2 distribution with 4 degrees of freedom. If the null hypothesis is rejected, then a sequence of other tests is needed where the ports are compared in pairs. With five different ports the number of pairs will be 10.

3.2. *Partial capacity measures*

Several measures permitting non-radial or non-proportional changes in outputs have been developed, e.g. Russell (1985) and Zieschang (1984), but they have not, so far, been used to estimate capacity. Partial CU measures developed by Segerson and Squires (1990) in the parametric case are here applied in the non-parametric framework. A partial CU approach varies only a single output. All other outputs are held fixed at their actual levels. The partial measure can be seen as the first stage in the asymmetric Färe efficiency measure (Färe et al., 1983) adjusted to the case of capacity. A partial CU measure is defined as the observed output level divided by the capacity level of the output of concern given the actual output levels of all other products and fixed factor. The numerical value of this CU measure will vary across products so it is not unique for a given firm. The partial CU measures might indicate that the degree of over capitalization in the fishery can vary considerably across products (Segerson and Squires, 1990). There may be more excess capacity or higher rates of CU in the fishery of one species than another. The stocks in the North Sea are managed on a species-by-species basis. For species that are closer to full partial CU (i.e., close to 1) or have lower levels of excess capacity, the future demand for that species is likely to be of more importance in determining the future expansionary or contractionary forces in the fishery than is the demand for the species with lower CU or higher excess capacity. The partial CU measure is estimated for cod and plaice, since these are the most important species in the fishery. The partial CU for a given firm and species is as follows:

$$\mathrm{CU(partial)} = \frac{1}{\theta_3^*}$$

where θ_3^* is the score obtained by solving the following DEA-problem:

$$\underset{\theta,z}{\mathrm{Max}}\, \theta_3$$

subject to

$$\theta_3 u_{j1} \le \sum_{j=1}^{J} z_j u_{j1},$$

$$u_{jm} = \sum_{j=1}^{J} z_j u_{jm}, \quad m = 2, \ldots, M,$$

$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn}, \quad n \in \alpha,$$

$$z_j \ge 0, \quad j = 1, 2, \ldots, J,$$

where species 1 is the species for which the partial measure is found.

4. The Gill-net fleet and fishery—background and data

The Danish fisheries are normally divided into human consumption and industrial fisheries. The human consumption fisheries, which comprise many fisheries, are defined as those where no species are landed for industrial purpose. The industrial fisheries are fisheries where some of the species are landed for industrial purpose (processing of meal and oil), meaning that species caught in these fisheries can also be landed for human consumption. The human consumption fisheries are, in general, multi-species fisheries (i.e., more than one species is caught in one setting of the gear or in one trip). In several of the fisheries, different gear types (e.g. trawl, gill-netters, Danish Seiners) are used.

A large part of the Danish human consumption fleet is multipurpose, which can participate in several fisheries during the year, including industrial fisheries. Relative prices between species and inputs, regulatory constraints, production costs, biological conditions, and change in seasons are factors that determine the choice of fishery. The gill-netters participate in the mixed human consumption fishery harvesting roundfish and flatfish in the North Sea and Skagerrak. The catch composition varies over the year and between fishing grounds. The gears involved are trawl, gill-net, and Danish Seine. The target species also varies over the year and according to the gear type used; however, cod, haddock, saithe, plaice, and sole are the main species, with cod being the most important. Nearly all the gill-netters participate in the fishery in the North Sea and about half of them also participate in the Skagerrak fishery. Only a few gill-netters take part in the fishery in Kattegat and the Baltic Sea.

4.1. The regulation and the regulatory process

The EU council annually determines the TAC for quota species in the exclusive economic zones (EEZs) of the EU member states. A fixed scale (called the principle of relative stability) divides the TACs among the member states into national quotas. The member states then decide the distribution of their respective national quota among fishermen. Since there is no banking of national quotas, the member states design the regulation to ensure full utilization of their quotas.

The Danish regulation of the fishery for cod, haddock, saithe, and sole is based on the Danish share of the TAC's divided into quarterly total quotas for the whole fishery, which in turn are divided into rations for a given period,[6] in some cases depending on the size of vessels. The number of participating vessels, however, is not regulated for these fisheries. During a given time period, therefore, rations can decline or the ration period can be shortened. If the Danish quota for a species is caught before the end of the year, the fishery is simply closed.[7]

In the beginning of the year, the Danish Ministry of Fisheries sets both the size of the quarterly quotas and rations based on the experience from former years and based on the size of the total Danish quota. Over the year, the Ministry closely monitors the fishery by recording all catches, and if necessary the regulation is changed, so that the quota is not exceeded. The purpose of the regulation is, in general, to achieve a better distribution of the fisheries over the year and a better utilization of the Danish quotas compared to a free fishery of the quotas. The regulatory instruments, quarterly quotas and rations, are used to stretch out the fishery over the whole year. In summary, it can be concluded that the cod and saithe fishery in all four areas has been constrained by the limited TAC. Sole has been constrained in the North Sea. The TAC for plaice in the Skagerrak was exploited over 90%, but there was no regulation.

Access to the Danish fisheries is restricted. To achieve an entry right, two authorizations are needed, one, recognition as a commercial fisherman and two, a vessel license, where recognition is a necessary condition for the vessel license. A vessel license can be obtained only if corresponding capacity leaves the fishery.

Only with permission from the Ministry is an extension of the existing number of vessels allowed. For the purpose of management, capacity output has been assumed to be related to a number of physical inputs used by the vessel. The inputs are GRT, length, width, depth, hold capacity, and engine power. However, the relationship between these physical measures of capacity and capacity output of vessels is not straightforward, and capacity can be increased through changing the combination of these inputs, or through changes

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[6] It is possible in a number of cases for the fishermen to transfer ration from one period to the next.

[7] Sometimes a fishery is closed if the quarterly quota is caught. The fishery opens again at the start of the next quarter.

in other inputs not included in the management definition of physical capacity.[8]

The primary purpose of the regulations is to harmonize the total capacity of the fleet to the resource stock conditions. Regulation of the total existing capacity is based on control of the physical inputs relating to the capacity of the individual vessels. This system can regulate the individual vessels, but cannot control the total fishing effort, because the access to each fishery, in general, is non-regulated. The most economically attractive fisheries will attract effort and each fisherman will try to use his ration first, because once the quarterly quota is exhausted, the fishery is closed. The conclusion is that the overall limited access to the Danish fishery and limited possibilities to extend the existing capacity will not reduce the over capacity in the most profitable fisheries, although the effort in the least attractive fisheries may be reduced. From the point of efficiency, the result is that too much effort is attracted into certain fisheries. Therefore, the situation emerges where the overall capacity problem is solved on the sector level but not in all fisheries.

4.2. Data

Data necessary for analyzing capacity output and CU were available only for gill-net vessels larger than 20 GRT. As a consequence, the analysis was limited to 69 vessels (i.e., only those vessels larger than 20 GRT). Available data pertained to trip-level data and vessel operations during 1993, and consisted of the following information: (1) the volume and value of the landed catch of each of the following species: cod, haddock, saithe, plaice, sole and other species (added together); (2) the month of landing; and (3) the fishing area.

The trip information allows for a division of the annual fishery activity based on month and area. The gill-netters participate only in the mixed human consumption fishery in the North Sea and Skagerrak, which can probably be divided into several different fisheries; given the available data, however, it is not possible to precisely further divide the fishery into other fisheries.

There is no information available about the length of the trips,[9] and hence, no information on the variable inputs per trip was available. It was decided to aggregate the trip-level information to annual activity per vessel. For each vessel, therefore, the total landings (output) and the number of trips (representing variable input), together with information on the KW and GRT (representing fixed factors or the capital stock), were used in the analysis.[10]

5. Results and discussions

Of the 69 Danish gill-net vessels, 36 (38) vessels had a (ray) CU based on technically efficient production (CU based on observed production) less than 1 (Fig. 1). Nearly 2/3 (43 vessels out of 69) of the fleet had a CU higher than 0.9, while 10 vessels had a CU less than 0.8. Using the CU measure based on observed output shows that 40 vessels had a CU higher than 0.9 and 20 vessels had a CU less than 0.8. The average CU was 0.92 (0.88) with a standard deviation of 0.11 (0.16) (Table 1). These CU values illustrate that a minor, but significant part, of the gill-net fleet had relatively low levels of CU. These results are in accordance with those obtained in Vestergaard (1998), where the gill-net was shown to be more efficient than other types of gear in the Danish human consumption fishery.

The second-stage analysis sought to determine whether or not the homeport might explain some of the variance in CU-scores. Of the 69 vessels, 48 were from the port of Hvide Sande. Of these 48 vessels, 30 had a CU less than 1. The observation that 30 out of 48 vessels from the port of Hvide Sande had a CU score less than 1 suggests that this fleet may have more excess capacity than the rest of the fleet. The

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[8] Equating the capital stock (physical inputs such as vessel size and engine power) to capacity implicitly assumes a linear relationship between the capital stock and capacity. In general, these coincide only if there is but one fixed input or stock of capital, all variable inputs are in fixed proportions to the fixed input, production is characterized by constant returns to scale (a 1% increase in all inputs, both variable and fixed, increases catch by one percent) (Berndt and Fuss, 1989). In fisheries, there is an added condition, that of a constant fish stock(s).

[9] Since the fisheries in question are human consumption fisheries, where the trip length varies between 1 and 5 days, it is not assumed that the use of trips instead of number of days will give biased results when looking at similar vessels.

[10] Because of the lack of better data on the variable inputs, the relatively homogenous vessel group of gill-netters was selected.

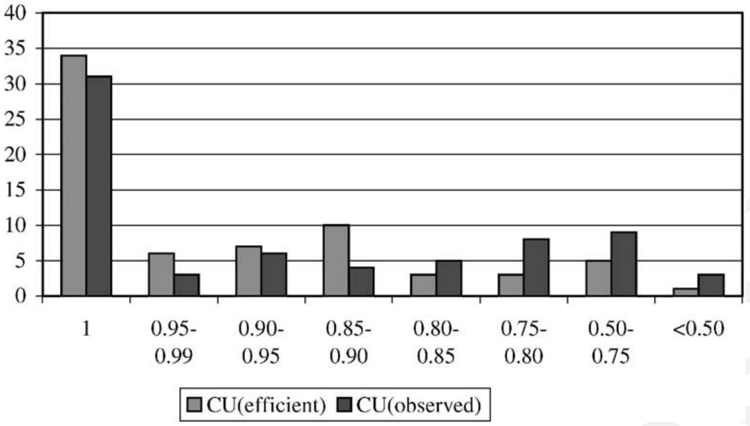

Fig. 1. Distribution of capacity utilization scores.

Table 1
Average CU, variable input utilization, number of vessels with CU equal or different to 1[a]

	CU(observed)	CU(efficient)	VIU	CU_{cod}	CU_{Plaice}
Average (standard deviation)	0.88 (0.16)	0.92 (0.11)	1.27 (0.39)	0.93 (0.15)	0.85 (0.28)
NR with CU = 1	31	33		57	50
NR with CU < 1	38	36		12	19
NR with VIU = 1			31		
NR with VIU < 1			2		
NR with VIU > 1			36		

[a] CU: ray CU; VIU: variable input utilization; Cu_{cod} and Cu_{plaice}: partial CU of cod and plaice, respectively.

result of the test of the null hypothesis that CU was equal for all ports could not be rejected (a χ^2 value of 8.19 with a probability of 0.085), at the significance level of 5%.

The distribution of the variable input utilization rates had the same pattern as the CU rates (Fig. 2). About half of the vessels could increase the use of variable inputs, although doing so would increase output by only one-half the difference between observed output and capacity output (Table 2). On average, the variable input utilization rate is 1.27 (standard deviation is 0.16), indicating that vessels should increase the number of trips compared to the optimal number of trips by 27% (Table 1) if vessel operators desire to operate at full capacity output.

Capacity output and technically efficient output were calculated using the estimated scores obtained from the DEA problems. The capacity and technically efficient output levels were calculated for each species and aggregated to obtain an estimate of excess capacity for each species (Table 2). For example, the total fleet production of cod could at full capacity have been 651,730 kg higher, which corresponds to an

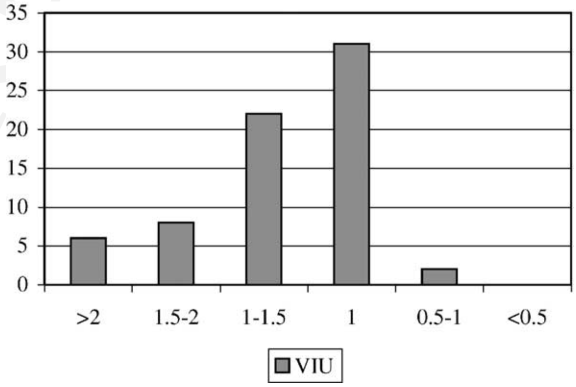

Fig. 2. Distribution of variable input utilization scores (VIU).

Table 2
Fleet capacity and CU (gill-netters, Kilo)

	Cod	Haddock	Saithe	Plaice	Sole	Other
Catch	4,369,095	123,121	412,577	1,566,142	268,426	1,227,071
Technical efficient output	4,617,355	125,389	426,275	1,644,746	285,472	1,279,219
Capacity output	5,020,825	132,631	451,611	1,764,363	314,116	1,375,729
Excess capacity	651,730	9,510	39,033	198,221	45,690	148,658
Excess capacity (%)	14.9	7.7	9.5	12.7	17.0	12.1
Ray CU(observed)	0.87	0.93	0.91	0.89	0.85	0.89
Ray CU(efficient)	0.92	0.95	0.94	0.93	0.91	0.93
Partial capacity output	4,777,448			1,883,159		
CU(cod), CU(plaice)	0.91			0.83		

excess capacity for cod of 15.9%. In total, the excess capacity for each species shows fundamentally the same results and varies within the same range as those on the vessel basis with CUs around 0.85–0.95. Cod and sole have the highest excess capacity, which is in accordance with how the regulation proceeded this year. Surprisingly, saithe has a lower excess capacity than plaice, which could indicate that plaice is a more important species for the gill-net fleet than saithe. Haddock and saithe have the lowest excess capacity.

The distribution of the partial CU measures for cod and plaice shows that a very high share of the vessels did not have the ability to increase output (Fig. 3). However, the average partial CU for cod and plaice was significantly lower than 1. The partial CU and the CU (observed) (or CU(efficient)) measure for cod were not very different on an aggregate basis (Table 2), which indicated that cod was one of the species that determined the capacity. For plaice, the situation was slightly different. The partial CU for plaice was less than both the CU (observed) and CU(efficient), which showed that the potential output of plaice was higher than both the actual and capacity output. This result suggests that the vessels had excess capacity in its production of plaice.[11]

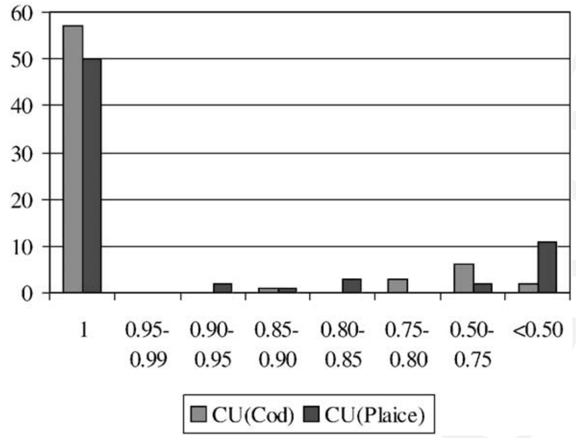

Fig. 3. Distribution of partial capacity utilization scores for cod and plaice.

Analysis and results were applied to only a single year—1993. The measures of capacity, therefore, were conditional on the regulatory and resource conditions that prevailed in 1993. Changes in these conditions might alter the results, which our analysis would not depict. As a consequence, the results presented in this paper might not be very indicative of capacity output levels and CU under different regulatory and resource conditions. An additional shortcoming of the approach used in this paper to estimate capacity output is the deterministic nature of DEA.[12] That is, DEA assumes all deviations from the frontier are caused by inefficient operations, which in fact, some deviations may be induced by events beyond the control of the vessel operator. The use of annual data, however, likely

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[11] One reviewer notes that cod and plaice might be harvested using different fishing techniques. Therefore, if plaice is bycatch in cod nets this can explain the lower partial CU. However, the data do not allow for a division into cod and plaice netters.

[12] A stochastic approach, the stochastic production frontier, can be used. However, there are also shortcomings with this approach. It cannot handle the case of multiple output, unless very complex stochastic multiple output distance functions are used, and so far it has not been used to estimate capacity. The stochastic production frontier, with out without a multiple output distance function specification, also cannot handle the case of zero-valued outputs.

reduces the possibility of attributing deviations from the frontier to inefficiency.

6. Conclusions

The Danish gill-net fleet exhibits moderate symptoms of over capacity. For the most important species, cod, excess capacity is 14.9% and varies between 7.7 and 17.0% for the other species. There is some potential for reducing fleet capacity. On average, the overall CU is 0.88, and when measured with technically efficient production, overall CU is 0.92, with nearly half of the vessels displaying a CU less than 1. CU does not systematically vary by port.

The non-radial measure, the partial CU measure, indicates how much the production of one output can be increased keeping the other outputs (along with the fixed factors and resource stock) fixed. For cod, the partial CU measure is relatively high, showing comparatively little excess production of cod. The partial CU measure for plaice is smaller, indicating comparatively more excess capacity and the possibility to expand the production of plaice.

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