# Technical Efficiency of the Danish Trawl fleet: Are the Industrial Vessels Better Than Others?[1]

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# Abstract

Technical efficiency in the Danish trawl fishery in the North Sea is estimated for 1997 and 1998 by a stochastic production frontier model. This model allows noise when the frontier and the technical efficiency is found, which for fisheries is a reasonable assumption. The results show that the production frontier can be modelled by a translog function without time effects and a technical inefficiency function. The type of fishery (industrial or consumption), size of vessel (greater or lesser than 60 GRT) and year give a good explanation for the inefficiency in the fleet. The average technical efficiency is estimated to be 0.82. On average, industrial vessels have a higher technical efficiency than human consumption vessels, and smaller vessels have higher technical efficiency than larger vessels. In sum, the analysis reveals that vessel larger than 60 GRT and fishing industrial species are the most efficient.

**Keywords:** Technical efficiency, stochastic production frontier, Danish trawl fishery.

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# 1. Introduction

The purpose of the analysis is to contribute to the discussion on renewal of capacity of the Danish fishing fleet. Renewal of capacity of the fishing fleet is today subject to several constraints, including The Multi-Annual Guidance Programme implemented in the European Union (EU). The purpose of these programmes is to control the development in capacity of the fishing fleet in each Member State. The decommissioning scheme, which has been one approach, has been applied in Denmark since 1986. In recent years, the number of decommissioned vessels per year has fallen from a level ranging between 50-100 to under 20. In total, 1.200 vessels in Denmark have received the decommissioning grant in the period 1987-2000.

This adjustment has - in reality - taken place without knowledge of the technical efficiency of the vessels. Measurement of the technical efficiency of the vessels gives information about whether the vessels produce on the production frontier. Deviation from the frontier shows that the vessels are technically inefficient, i.e. that the existing technology is not applied with its total potential. Substantial remaining technical inefficiency suggests the potential for remaining vessels to increase their fishing capacity through improvements in technical efficiency, which in turn counteracts the intent of the decommissioning programme. In a more general sense, this information is interesting for the regulator, when determining the most appropriate regulations for the fishery.

It is important to know the technical inefficiency when trying to control the fishing capacity. The Multi-Annual Guidance Program may decommission less efficient vessels, which then undermines the purpose of the program. This paper examines the technical inefficiency in the Danish trawl fishery in the North Sea for 1997 and 1998 through econometric estimation of a stochastic production frontier. The estimated mean technical efficiency is very high. Furthermore, the results indicate that industrial vessels are more efficient than vessels fishing for human consumption and those vessels smaller than 60 GRT are more efficient than vessels above 60 GRT. Therefore, the Multi-Annual Guidance Programme could more effectively remove fishing capacity by targeting human consumption vessels larger than 60 GRT.

In section 2, a description of the Danish trawl fishery in the North Sea is given, while section 3 presents the empirical model. Section 4 presents the results and a discussion of the results in relation to the Multi-Annual Guidance Programme is placed in section 5. Section 6 concludes the paper.

## 2. The Danish Trawl fisheries in the North Sea

The North Sea is the most important fishing water for the Danish fishery. In 1998, it comprised approximately 65 per cent and 54 per cent of the total Danish catch weight and value, respectively. Trawlers are the most important vessel type in Denmark, comprising around 71 per cent of total tonnage and 59 per cent of total horsepower.[2] These facts highlight the importance of analysing the Danish trawl fishery in the North Sea. The trawl fishery targets both species for human consumption and species for industrial purposes. A vessel is called an industrial vessel, when it catches these species throughout the year.

This article focuses only on those trawlers that fished in the North Sea in 1997 and 1998. Data was derived from the official catch statistics collected by the Danish Directorate of Fisheries. In the following, a basic description of the used dataset will be made in order to present the basic characteristics of the trawlers analysed.

Only trawlers that fished in both years were included in the dataset. There were 267 trawlers in total, giving 534 observations in the balanced panel data set. The production, i.e. catches caught by these trawlers, is described in Table 1.

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[2] These two physical characteristics are important in relation to the Multi-Annual Guidance Program (MAGP) implemented as a part of the fisheries policy in the European Union, in order to obtain a reduction in fleet size.

***Table 1: Descriptive statistics for measures of catches (1997-1998)***

| | **Value (1,000 DKK)** | | **Weight (tonnes)** | | **Weighted weight (tonnes)** | |
|---|---|---|---|---|---|---|
| | **1997** | **1998** | **1997** | **1998** | **1997** | **1998** |
| Total | 1,035,648 | 1.091,664 | 955,263 | 872,958 | 942,732 | 858,909 |
| Average | 3,879 | 4,089 | 3,578 | 3,270 | 3,531 | 3,217 |
| Minimum | 19 | 13 | 3 | 1 | 2 | 1 |
| Maximum | 15,117 | 12,789 | 15,985 | 14,420 | 15,915 | 14,400 |

Three different measures of output for the included trawlers were considered; value, weight and weighted average of weight. The latter is calculated using revenue shares as weights, when aggregating the catch weight. The catch value was relatively high in the two years considered, because the industrial fishery obtained good prices for their catches.

***Table 2: Catch composition (weighted weight, per cent)***

| | **Cod** | **Other codfish** | **Plaice** | **Sole** | **Norway lobster** | **Deep-water shrimps** | **Herring and mackerel** | **Other consumption species** | **Industrial species** |
|---|---|---|---|---|---|---|---|---|---|
| All trawlers | 4,83 | 5,65 | 4,01 | 0,18 | 5,33 | 2,80 | 6,37 | 4,66 | 66,17 |
| Consumption trawlers | 15,71 | 21,11 | 14,39 | 0,73 | 25,26 | 12,61 | 0,04 | 10,15 | 0,01 |
| Industrial trawlers | 2,10 | 1,76 | 1,41 | 0,04 | 0,33 | 0,33 | 7,97 | 3,28 | 82,79 |

A comparison between consumption and industrial trawlers is later made in the analysis. Table 2 depicts the catch composition for all the trawlers, the consumption trawlers and the industrial trawlers, where the latter is defined as trawlers with a catch of industrial species above 1000 kilos per day at sea. Almost 40 per cent of the weighted average weight caught by the consumption trawlers was comprised of codfish, but Norway lobster, plaice and deepwater shrimps were also important species for these trawlers. The industrial trawlers on the other hand had a more straightforward catch composition, with industrial species, i.e. sand eel, Norway pout and sprat, comprising above 80 per cent of total catches measured in weighted average weight. The rest of catches taken by the industrial trawlers primarily were in the form of pelagic species, i.e. herring and mackerel.

Using the term fishing effort facilitates the description of the physical characteristics of the trawlers. Based on the theory of production, fishing effort can be divided into two separate measures, i.e. fishing power and fishing time, where fishing power is a function of the capital and labour employed (see Andersen (1999)) and fishing time provides a flow of services. Tonnage, horsepower, length and insurance value are measures of the capital employed, while crew size is a measure of the labour employed, and the number of days at sea is a measure of fishing time used.

Descriptive statistics for measures of fishing effort of the included trawlers are found in Table 3. Table 3 only presents the average values over the two years, because only minor differences were observed between the years.

***Table 3: Descriptive statistics for measures of fishing effort***

| | **Tonnage (GT/GRT)** | **Horsepower (kW)** | **Length (m)** | **Insurance value (1,000 DKK)** | **Crew size** | **Number of days at sea** |
|---|---|---|---|---|---|---|
| Total | 51,726 | 134,595 | 7,595 | 2,328,765 | 1,046 | 32,520 |
| Average | 194 | 504 | 28 | 8,722 | 4 | 122 |
| Minimum | 7 | 81 | 12 | 600 | 1 | 1 |
| Maximum | 711 | 1,603 | 52 | 35,000 | 8 | 300 |

High correlations were observed between the four capital measures of fishing power, as would be expected, see Table 4. However, there were not very strong correlations between any of the capital measures, the labour measure and fishing time.

*Table 4: Correlation between measures of fishing effort*

| | Tonnage | Horse-power | Length | Insurance value | Crew size | Fishing time |
|---|---|---|---|---|---|---|
| Tonnage | 1.00 | | | | | |
| Horsepower | 0.87 | 1.00 | | | | |
| Length | 0.94 | 0.85 | 1.00 | | | |
| Insurance value | 0.93 | 0.85 | 0.84 | 1.00 | | |
| Crew size | 0.75 | 0.74 | 0.77 | 0.72 | 1.00 | |
| Fishing time | 0.42 | 0.34 | 0.45 | 0.38 | 0.38 | 1.00 |

All output and input variables used in the analysis were measured on a yearly basis. Since the method of stochastic frontier function only can handle a single output, total revenue served as the aggregate measure of output.

# 3. Empirical model

A fishing firm's technical efficiency is a measure of its ability to produce relative to the fleet’s best-practice frontier, the maximum output possible from a given set of inputs and production technology (Aigner, Lovell, and Schmidt 1977; Meeusen and van den Broeck 1977).[3] Technical inefficiency is the deviation of an individual firm’s production from the best-practice frontier. The estimated frontier is specified stochastic, because fishing is sensitive to random factors such as weather, resource availability and environmental influences (Kirkley, Squires, and Strand 1995). The estimation takes the current state of technology, resource abundance and availability, regulatory structure and open access property rights regime as given. The stochastic frontier and technical efficiency results could alter under a different set of conditions. Hannesson *et al.* (1981) and Hannesson (1983) estimated the first production frontier in fisheries, albeit a deterministic frontier.

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[3] Technical efficiency can be either output-oriented or input-oriented. They are equal under constant returns to scale. Output-oriented technical efficiency is consistent with the notion of a production function, in which output is endogenous and inputs are fixed. Moreover, output-oriented technical efficiency corresponds to fishing capacity as the maximum possible output given fixed factors and full utilization of variable inputs.

The translog[4] stochastic production frontier, where symmetry conditions have been imposed, is specified by:

$$\begin{aligned} \text{Ln } Y_{it} = {} & \text{"}_0 + \text{"}_1 \ln K_{it} + \text{"}_2 \ln L_{it} + \text{"}_3 \ln T_{it} + \alpha_4 D_Y + \alpha_{11} \ln K_{it}^2 \\ & + \alpha_{22} \ln L_{it}^2 + \alpha_{33} T_{it}^2 + \alpha_{12} \ln K_{it} \ln L_{it} + \alpha_{13} \ln K_{it} \ln T_{it} \\ & + \alpha_{23} \ln L_{it} \ln T_{it} + \alpha_{14} \ln K_{it} D_Y + \alpha_{24} \ln L_{it} D_Y \\ & + \alpha_{34} \ln K_{it} D_Y + \varepsilon_{it} \qquad (1) \end{aligned}$$

$Y_{it}$ denotes total revenue of catches of all species landed by firm (vessel) i in year t. The vessel capital stock ($K_{it}$) is a volumetric measure given by vessel gross registered tonnes (GRT); labour ($L_{it}$) is the number of crew employed on vessel i in year t, including the captain. The variable days fished per year ($T_{it}$) for vessel i in year t represent variable input usage (e.g., diesel and/or gasoline, lubricant and/or oil, ice, and miscellaneous variable inputs).[5] Since no separate biomass measures were available, a distinction between biomass effects and other time-related effects such as changes in the state of technology or the environment cannot be made. These time-related effects are captured by the dummy variable $D_{Y,}$ which represents the year 1997, where the base year is 1998. The interaction terms between $D_Y$ and the variable inputs ($K_{it}$, $L_{it}$, $T_{it}$) allow for Hick's-biased time effects. The time effect $D_Y$ captures changes in biomass of the different species, any technological innovations, changes in regulations, weather effects, changes in fishing practices and patterns, and so forth. Hence, $D_Y$ is not a standard representation of changes in the state of technology.

The error term $\varepsilon_{it}$ in Equation (1) is defined as $\varepsilon_{it} = V_{it} - U_{it}$. The two-sided error term $V_{it}$ captures exogenous stochastic shocks and is assumed to be symmetrical and independently and identically distributed as $N(0, F_V^2)^{\cdot}$. The non-negative error term $U_{it}$ captures differences in technical inefficiency and is assumed to be an independently distributed non-negative random variable, i.e. $U_{it}$ is the truncation of a normal distribution at zero, with mean $\mu_{it} = Z_{it}$* and vari-

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[4] The translog functional form is known as a flexible functional form. A second-order local approximation to any functional form is provided.

[5] Variable inputs are frequently represented by the proxy variable fishing time in fisheries models due to unavailable data on variable input usage. The use of fishing time is also consistent with the notion of fishing effort.

ance $F_U^2$, $N(Z_{it}*,F_U^2)$.[6] The one-sided non-negative random variable, $U_{it}$, representing technical inefficiency, must be non-negative so that no firm can perform better than the best-practice frontier. The independent distribution of $V_{it}$ and $U_{it}$ allows the separation of noise and technical inefficiency. $Z_{it}$ defines a (1xM) vector of explanatory variables associated with the technical inefficiency function, and * is a (Mx1) vector of unknown parameters to be estimated (Battese and Coelli 1995).

The technical inefficiency may be a function of explanatory variables and regressed against these variables. However, Kumbhakar, Ghosh, and McGuckin (1991) and Reifschneider and Stevenson (1991) first noted the inconsistency between inefficiency effects in the first stage estimation of technical inefficiency from a stochastic production frontier, and a second-stage regression of technical inefficiency upon explanatory variables. In the first stage, the errors are independently and identically distributed and the predicted inefficiency effects in the second stage are specified as a function of a number of firm-specific factors (which implies that they are not identically distributed unless all the coefficients of the factors are simultaneously equal to zero). The two-stage procedure is unlikely to provide estimates which are as efficient as those that are obtained from a one-step estimation procedure in which the stochastic production frontier is simultaneously estimated with a second function relating technical inefficiency (estimated from the production frontier) to the vector of explanatory variables (Coelli 1996). Huang and Liu (1994) and Battese and Broca (1997) expanded the one-stage approach to model technical inefficiency effects as a function of some firm-specific factors along with their interactions with the input variables of the frontier function. Battese and Coelli (1995) further developed and refined this approach to accommodate panel data. The Battese and Coelli model permits the estimation of the parameters of the factors believed to influence the levels of the technical inefficiency effects along with the separate components of technical inefficiency change and technical change over time, or in this case, to the entire set of time-related factors.

The technical inefficiency function, comprised of the vector of variables Z, is specified as a function of the annual dummy variable $D_Y$ and whether the vessel

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[6] The truncated normal distribution was originally proposed by Stevenson (1980).

harvested predominately consumption or industrial species, $D_I$, and vessel size, $D_s$. The technical inefficiency function is therefore specified as:

$$U_{it} = \delta_0 + \delta_1 D_Y + \delta_2 D_I + \delta_3 D_S + W_{it} \tag{2}$$

The variable $D_Y$ denotes a dummy variable for the year 1998, $D_I$ denotes a dummy variable for industrial fishing, $D_S$ is a dummy variable for small vessels, and $W_{it}$ is a normally distributed error term.

Technical inefficiency for each firm i in year t, $U_{it}$, is defined as the ratio of actual output to the potential frontier output. $U_{it}$ is not directly observable, but Jondrow *et al* (1982) found its expected value of $U_{it}$ conditional on the value of $\varepsilon_{it} = V_{it} - U_{it}$, i.e. $E(U_{it}| \varepsilon_{it})$. Technical efficiency for each firm is defined as $TE_{it} = \exp(-U_{it}) = \exp(-Z_{it}^* - W_{it})$, where exp is the exponential operator (Battese and Coelli 1988). The range of technical efficiency for firm i in year t ($TE_{it}$) is 0 $TE_{it}$ £1, where $TE_{it} = 1$ represents the achievement of maximum output (adjusted for random fluctuations) for the given inputs, or 100 percent efficiency.

The stochastic production frontier, Equation (1), and the technical inefficiency function, Equation (2), were jointly estimated by maximum likelihood using Frontier 4.1 (Coelli 1996), under the behavioural hypothesis that fishers maximize expected profits (Zellner, Kmenta, and Dreze 1966).[7] Campbell (1991) makes this case for fisheries due to the stochastic nature of output and acts of nature.

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[7] The specification of technical inefficiency as unexpected and unknown, or as expected and foreseen, when the firm chooses its inputs affects the specification and estimation of the production function (Kumbhakar 1987). Given the overwhelming importance of “captain’s skill” in locating and catching fish and the inherent stochastic effects from weather, temperature, and biological variations in fishing, it is likely that technical inefficiency that is unforeseen is more important than the foreseen. The point is that technical inefficiency is likely to be never entirely foreseen or unforeseen, but in fishing, technical inefficiency is more likely to be unexpected and unknown. Thus we specify the technical inefficiency as unexpected or unforeseen. Given unknown and unexpected technical inefficiency, the argument of expected profit maximization (Zellner, Kmenta, and Dreze 1966) can be used to treat inputs as exogenous (Kumbhakar 1987). If technical inefficiency is known to the firm, estimates of the production function parameters obtained directly from the profit function will be inconsistent.

Several hypotheses about the model can be tested using generalized likelihood ratio tests. The first null hypothesis is whether or not technical inefficiency effects are absent ($F_U{}^2 = 0$). This test is performed with the full translog stochastic frontier given in Equation (1). (Hence, all inputs interact and there are Hick's-biased time effects.) This null hypothesis is specified as ( = 0, where ( = $F_U{}^2/(F_V{}^2 + F_U{}^2)$ and lies between 0 and 1. Non-rejection of the null hypothesis, $H_0$: ( = 0, indicates that the $U_{it}$ term should be removed from the model (Battese and Coelli 1995). This result further indicates that the stochastic production frontier is rejected in favour of ordinary least squares estimation of the average production function in which the explanatory variables in technical inefficiency function ($Z_{it}$) are included in the production function.[8]

The second null hypothesis is whether or not there are Hick's-biased time effects with the translog functional form. The null hypothesis can be specified as $H_0$: $\alpha_{14} = \alpha_{24} = \alpha_{34} = 0$ in Equation (1). There are 3 degrees of freedom, since there are three independent restrictions.

The third null hypothesis is whether or not the functional form of the stochastic production frontier, Equation (1), is Cobb Douglas, while retaining the Hick's-biased time effects. This null hypothesis is not strictly nested within the second null hypothesis, but is instead tested only if the second null hypothesis is rejected, so that it is tested against the full translog form. The null hypothesis is, $H_0$: $\alpha_{11} = \alpha_{12} =$ C C C $= \alpha_{23} = 0$ in Equation (1), i.e. all of the input interaction terms equal 0, where Hick's-biased time effects remain. There are 6 degrees of freedom, since there are six independent restrictions. The fourth null hypothesis is whether or not the functional form is Cobb-Douglas and there are no Hick's-

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[8] Any generalized likelihood ratio statistic associated with a null hypothesis involving the ( parameter has a mixed $P^2$ distribution because the restriction defines a point on the boundary of the parameter space (Coelli 1996). The critical values are given in Table 1 of Kodde and Palm (1986). The number of restrictions, and hence the degrees of freedom for the null hypothesis ( = 0, is the difference in the number of parameters in the test of the OLS model versus the stochastic production frontier, equal to one for (, one for μ with the truncated normal (associated with $*_0$, the intercept of the technical inefficiency function) plus the number of terms in the technical inefficiency function, excepting $*_0$, which would not enter the traditional mean response function (Battese and Coelli 1995,footnote 6). In this case, all variables in Z, except $*_0$, would enter the translog production function as control variables, so that the degrees of freedom for $H_0$: ( = 0 is two.

biased time effects. This null hypothesis is written, $H_0$: $\alpha_{11} = \alpha_{12} =$ C C C $= \alpha_{23} = \alpha_{14} = \alpha_{24} = \alpha_{34} = 0$. There are 9 degrees of freedom, since there are nine independent restrictions. The fifth null hypothesis is whether or not the technical inefficiency function, Equation (2), is influenced by the level of explanatory variables, and is tested with the final form of the stochastic production frontier. Under the assumption that the inefficiency effects are distributed as a truncated normal, the null hypothesis is that the matrix of parameters, excluding the intercept term $\delta_0$, is null such that, $H_0$: $\delta_1 = \delta_2 = \delta_3 = 0$.[9]

## 4. Empirical Results

The generalized likelihood ratio tests of the null hypotheses, summarized in Table 5, indicate that at the one percent level of significance: (1) the stochastic production frontier is appropriate for the sample of data ($H_0$: ( = 0 is rejected); (2) Hick's-biased time effects are not included with the translog functional form ($H_0$: $\alpha_{14} = \alpha_{24} = \alpha_{34} = 0$ is not rejected given the results of the second hypothesis test); (3) there is no need to test the third null hypothesis; (4) the functional form is translog without Hick's-biased time effects ($H_0$: $\alpha_{11} = \alpha_{12} =$ C C C $= \alpha_{23} = 0$ is rejected); and (5), the technical inefficiency function is comprised of the vector of explanatory variables ($H_0$: $*_1 = *_2 = \delta_3 = 0$ is rejected). In sum, a translog stochastic production frontier without Hick's time effects, but with a technical inefficiency function comprised of explanatory variables emerges from the hypothesis testing. On the basis of these results, the following specification of the stochastic production frontier is used:

$$\begin{aligned} \text{Ln } Y_{it} = {}& "_0 + "_1 \ln K_{it} + "_2 \ln L_{it} + "_3 \ln T_{it} + \alpha_4 D_Y + \alpha_{11} \ln K_{it}^2 \\ & + \alpha_{22} \ln L_{it}^2 + \alpha_{33} T_{it}^2 + \alpha_{12} \ln K_{it} \ln L_{it} + \alpha_{13} \ln K_{it} \ln T_{it} \\ & + \alpha_{23} \ln L_{it} \ln T_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

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[9] Not including an intercept parameter ($*_0$) in the mean ($Z_i$ *) may result in the estimators of the *-parameters, associated with the Z-variables, being biased and the shape of the distributions of the inefficiency effects, $U_{iti}$, being unnecessarily restricted (Battese and Coelli 1995). Battese and Coelli (1995) note that when the Z vector has the value 1 and the coefficients of all other elements of Z are 0, Stevenson's (1980) model with a truncated normal inefficiency error term is represented. The intercept $*_0$ in the technical inefficiency function will have the same interpretation as the μ parameter of Stevenson's (1980) model (Coelli 1996).

The technical inefficiency function specified in Equation (2) remains unchanged.

***Table 5: Generalized likelihood ratio tests of hypotheses for parameters of the stochastic frontier production function and technical inefficiency function***

| **Null Hypothesis** | **Likelihood Ratio** | **df** | **Critical Value (5%)** | **Critical Value (1%)** | **Reject?** |
|---|---|---|---|---|---|
| 1. $\square = 0$<br>(No stochastic frontier with full translog) | 144.84 | 5 | 10.371 | 14.325 | Y |
| 2. $\alpha_{14} = \alpha_{24} = \alpha_{34} = 0$<br>(Translog without Hick's-biased time effects) | 6.92 | 3 | 7.815 | 11.345 | N |
| 4. $\alpha_{11} = \alpha_{12} = \bullet \bullet \bullet = \alpha_{34} = 0$<br>(Cobb-Douglas frontier without Hicks-biased time effects) | 78.08 | 9 | 16.919 | 21.666 | Y |
| 5. $\square_1 = \square_2 = \square_{\square} = \alpha_{14} = \alpha_{24} = \alpha_{34} = 0$<br>(No technical inefficiency fn. with full translog and without Hicks-biased time effects) | 73.72 | 6 | 12.592 | 16.812 | Y |

Notes:
1. Test for $\square = 0$ follows mixed chi-square distribution with critical values found in Table 1 of Kodde and Palm [1986].
2. Df = degrees of freedom.
3. A truncated-normal distribution is specified for the technical inefficiency error term.

The parameter estimates of the final form of the stochastic production frontier, Equation (3), and the technical inefficiency function, Equation (2), are reported in Table 6.

*Table 6: Parameter Estimates*

| Variable | Coefficient | Standard Error | t-Ratio |
|---|---|---|---|
| **Stochastic Production Frontier** | | | |
| Intercept $a_0$ | 9.234 | 0.390 | 23.670 |
| Capital (K) $a_1$ | -0.550 | 0.156 | -3.530 |
| Labor (L) $a_2$ | 0.478 | 0.349 | 1.370 |
| Days Fished (T) $a_3$ | 1.413 | 0.089 | 15.835 |
| 1988 Dummy Variable ($D_Y$) $a_4$ | 0.126 | 0.021 | 5.911 |
| Capital*Capital ($K^2$) $a_{11}$ | -0.065 | 0.131 | -0.500 |
| Labor*Labor ($L^2$) $a_{22}$ | -0.031 | 0.010 | -3.089 |
| Days Fished*Days Fished ($T^2$) $a_{33}$ | -0.015 | 0.086 | 0.174 |
| Capital*Labor (K*L) $a_{12}$ | -0.030 | 0.025 | -1.225 |
| Capital*Days Fished (K*T) $a_{13}$ | -0.046 | 0.077 | -0.596 |
| Labor*Days Fished (L*T) $a_{23}$ | 0.055 | 0.034 | 1.630 |
| **Technical Inefficiency Function** | | | |
| Intercept $d_0$ | -1.629 | 0.932 | -1.748 |
| 1997 Dummy Variable ($D_Y$) $d_1$ | 0.893 | 0.283 | 3.158 |
| Industrial Fishing Dummy Variable ($D_I$) $d_2$ | -4.901 | 1.885 | -2.600 |
| Small Vessel Dummy Variable ($D_S$) $d_3$ | -1.340 | 0.495 | -2.705 |
| $s^2$ | 0.972 | 0.362 | 2.685 |
| g | 0.943 | 0.025 | 37.769 |

Notes: Translog stochastic production frontier.
Truncated normal distribution for technical inefficiency.

Of the estimated parameters $\alpha_0$, $\alpha_1$, $\alpha_3$, $\alpha_4$, and $\alpha_{22}$ are significant at a 5% level. However, surprisingly, the algebraic sign of the parameter for $\ln K_{it}$ is negative and the parameter for $\ln L_{it}$ is statistically insignificant. The coefficient for $\ln K_{it}^2$ and $\ln T_{it}^2$ is statistically insignificant, while the coefficient in front of $\ln L_{it}^2$ is statistically significant. However, Kim (1992) points out that the interpretation of the individual parameters of a translog function may not be particularly meaningful.

The annual dummy variable for 1997 is statistically significant in both functions, indicating meaningful time effects in both production and technical inefficiency. The factors affecting technical inefficiency can be analysed by the magnitude, algebraic signs, and significance of the estimated coefficients in the technical inefficiency function, equation (2). In the technical inefficiency model, all the estimated parameters are significant. The dependent variable is technical inefficiency as opposed to technical efficiency. Hence, a negative (positive) sign for a coefficient in the technical inefficiency model indicates a decline (rise) in technical inefficiency or a rise (fall) in technical efficiency. Note also, that the estimate for $\gamma$ is 0.94 and that the t-ratio value is very high. This result suggests that fishing type, year and the size of the vessel makes a good contribution in explaining the inefficiency in the trawler industry. From the sign of $\delta_2$ it is seen that industrial vessels are more efficient than the vessels primarily targeting consumption species. This result may also be seen from the frequency distribution of the technical efficiency scores in Table 7.

***Table 7: Frequency distribution of the technical efficiency scores***

| **Score Range** | **Total** | **Industrial Fishery** | **Consumption Fishery** | **Large vessel** | **Small vessel** |
|---|---|---|---|---|---|
| 0.90-0.99 | 26.6 | 39.4 | 4.1 | 24.5 | 31.6 |
| 0.80-0.89 | 41.2 | 52.4 | 21.6 | 45.2 | 31.6 |
| 0.70-0.79 | 15.4 | 5.9 | 32.0 | 13.3 | 20.3 |
| 0.60-0.69 | 6.4 | 1.2 | 15.5 | 5.9 | 7.6 |
| 0.50-0.59 | 3.7 | 0 | 10.3 | 3.2 | 5.1 |
| 0.40-0.49 | 3.4 | 0 | 9.3 | 4.3 | 1.3 |
| 0.30-0.39 | 1.9 | 0.6 | 4.2 | 2.1 | 1.3 |
| 0.20-0.29 | 1.5 | 0.6 | 3.1 | 1.6 | 1.3 |

**1998**

| **Score Range** | **Total** | **Industrial Fishery** | **Consumption Fishery** | **Large vessel** | **Small vessel** |
|---|---|---|---|---|---|
| 0.90-0.99 | 37.1 | 52.9 | 9.3 | 37.2 | 36.7 |
| 0.80-0.89 | 39.3 | 41.2 | 36.0 | 41.5 | 34.2 |
| 0.70-0.79 | 14.2 | 4.7 | 30.9 | 12.8 | 17.7 |
| 0.60-0.69 | 4.1 | 1.2 | 9.3 | 3.7 | 5.1 |
| 0.50-0.59 | 2.2 | 0 | 6.2 | 2.1 | 2.5 |
| 0.40-0.49 | 1.5 | 0 | 4.2 | 1.6 | 1.3 |
| 0.30-0.39 | 0.7 | 0 | 2.1 | 0 | 2.5 |
| 0.20-0.29 | 0 | 0 | 0 | 0 | 0 |
| 0.10-0.19 | 0.7 | 0 | 2.1 | 1.1 | 0 |

From Table 7 and the statistically significant, positive sign of the annual dummy variable in the technical inefficiency function ($D_Y$ ), it is clearly seen that vessels in 1998 are more efficient than in 1997. The result that industrial vessels are more efficient than consumption vessels is indicated by the frequency distribution of technical efficiency scores in Table 7 and the statistically significant, negative sign of the industry fishing dummy variable in the technical inefficiency function ($D_I$).

For 1998, the inefficiency scores vary between 0.7 and 0.99 for industrial vessels. The mean technical efficiency over both years is 0.82. Thus, on average, the sample vessels could have increased their catch by about 18% by operating at full technical efficiency, conditional upon a constant resource stock and state of technology, simply by using their existing inputs more technically efficiently. The frequency distribution of technical efficiency scores in Table 7 and the statistically significant, negative sign of the small vessel dummy variable in the technical inefficiency equation ($D_s$) indicate that technical efficiency is lower for larger vessels than for smaller vessels.[10]

One stochastic production frontier cannot be compared directly against another in another fishery, since each frontier represents a best-practice frontier only for the corresponding fishery. However, the mean value of 0.82 indicates that compared to other fisheries for which technical efficiency from a stochastic production frontier has been analysed, the Danish fishery's technical efficiency is comparatively high. For example, mean technical efficiency in: the mid-Atlantic (USA) sea scallop fishery was 0.75 (Kirkley, Strand, and Squires); in the Hawaii longline fishery was 0.84 (for an output of total revenue) (Sharma and Leung 1999); in the British Columbia longline halibut fishery was 0.56 (Grafton, Squires, and Fox 2000); in the mini purse seine fishery of the North Java Sea was 0.63 (Susilowati *et al.* 2000); in the Java sea purse seine fishery was 0.61 (Jeon *et al.* 2000); in the Northern Australian Prawn Fishery was 0.71 (Kompas and Che 2001); in the Kedah, Malaysia trawl fishery was 0.49 (Kuperan *et al.* in press); in the Swedish demersal trawl fishery was 0.66 (Eggert and Tveterås 2001).

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[10] The use of revenue as single output might lead to price effects in the measure of technical efficiency, meaning that the result of the high technical efficiency score in the industrial fishery can be due to higher prices in the considered years. However, since fishermen decide to a certain degree the catch composition, revenue is the logical measure.

Technical efficiency in fisheries has been identified with fishing skill of the captain (Kirkley, Squires and Strand 1998, Squires and Kirkley 1999). The comparatively high level of technical efficiency displayed by the Danish trawl fishery in the North Sea indicates that Danish fishermen display the highest level of fishing skill of any of the fleets surveyed, which might be a result of the decommission scheme being in force from 1986.

# 5. Discussion

Technical efficiency and variable input usage comprise the two components that determine the level of fishing capacity for given stocks of capital and fish and states of technology and the environment (Färe *et al* 1989).[11] Reducing the capital stock or capacity base, such as decommissioning vessels through the Multi-Annual Guidance Programme, in turn reduces the level of fishing capacity that the stock of capital – the capacity base – and the resource stock supports, conditional on the states of technology and the environment. Improvements in technical efficiency or fishing skill, as skippers learn more about where to find and catch fish, or if skippers shift from fishing for human consumption to industrial purposes, or if skippers shift toward larger vessels, all serve to increase fishing capacity. Moreover, improvements in technical efficiency increase fishing capacity in a manner that is unobservable to the regulators of the Multi-Annual Guidance Programme. In addition, because technical efficiency or fishing skill varies by vessel (Table 7), the Multi-Annual Guidance Programme, which is a voluntary vessel buyback programme, may attract the least efficient vessels first, considering that the most committed and skilled skippers and vessels can reasonably be expected to want to remain in the fishery.

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[11] The technological-economic capacity of a firm can be defined following Johansen's (1968, p. 52) definition of plant capacity as, "...the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted." Capacity output thus represents the maximum production the fixed inputs are capable of supporting. For renewable resources, capacity measures are contingent on the level of the resource stock. Capacity is, therefore, the maximum yield in a given period of time that can be produced given the capital stock, regulations, current technology and state of the resource (FAO 1998, Kirkley and Squires 1999).

Thus, because of the effects of technical efficiency or fishing skill, the Multi-Annual Guidance Programmes ostensible reduction in fishing capacity – as measured by reductions in one or two components of the heterogeneous capital stock rather than fishing capacity itself – will differ from that ostensibly indicated by this reduction in the capital stock. For example, the decline in technical inefficiency (i.e. increase in technical efficiency) from 1997 to 1998 indicates that this contribution to fishing capacity increased capacity output over this time period.

This explanation may certainly be an important contributing factor in the current dissatisfaction with the current performance of the Multi-Annual Guidance Programme. A programme aimed at reducing fishing capacity rather than the more narrow programme of reducing the capital stock would implicitly account for the variation in technical efficiency among vessels and any advances in fishing skill that may occur. The presence of annual variability in technical efficiency also suggests that fishing capacity will also annually vary, giving a corresponding variability in the degree to which capacity reduction targets are reached. Unless this variability in satisfying capacity reduction targets is explicitly recognized and accounted for, there may be considerable unnecessary consternation over the pace, annual variation, and mixed results of the Programme.

Isolating the effects of technical efficiency from the other component of fishing capacity, the quantity of variable inputs employed highlights the importance of controlling fishing effort and variable input usage in general, along with reducing the capacity base – the capital stock, in reducing fishing. Since technical efficiency or fishing skill is difficult to routinely measure and regulate, and may be inherent in customary and usual operating procedures, capacity reduction in the EU in general, and in Denmark in particular, might also consider limiting fishing effort – variable input usage – in addition to reductions in the capital stock.[12]

The variation in technical efficiency between industrial and human consumption fishing also suggests that any decommissioning programme explicitly rec-

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[12] The other basic approach is to introduce some form of transferable property rights, such as Individual Transferable Quotas, which are catch rights.

ognize the uncertainty in fishing capacity measures generated by the corresponding differences in fishing capacity between these two fishing targets. Simply by switching between industrial and human consumption fishing changes the fishing capacity.

# 6. Conclusion

This paper examines the technical inefficiency of the Danish trawl fishing fleet in the period 1997 and 1998. A stochastic production frontier model is estimated and total revenue serves as the output measure. The empirical results show that the stochastic production frontier can be modelled by a translog functional form without time effects but with a technical inefficiency function. The type of fishery, the size of the vessel and the year provide a good explanation for the inefficiency in the fleet. Industrial vessels are more efficient than human consumption vessels and smaller vessels have a higher efficiency than larger vessels.

The discussion of technical efficiency is extremely relevant for the discussion of control of fishing capacity in the Danish fishing fleet. The European Union’s Multi-Annual Guidance Programme’s decommissioning scheme has been one approach to reduce the severe excess fishing capacity that plagues the North Sea and fuels overfishing. The approach has been applied in Denmark since the end of the 1980´s. However, the adjustment of capacity has taken place without knowledge of the technical efficiency or fishing skill of the vessel captains. Multi-Annual Guidance Programmes may decommission less efficient vessels, which undermines the purpose of these programmes. Thus, large, human consumption vessels are likely to make more use of the decommissioning scheme.

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