Reasons for technical inefficiency of Danish Baltic Sea trawlers

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Abstract

Using the stochastic frontier method, the level of technical efficiency is estimated for Danish trawlers fishing in the Baltic Sea. Based on the estimated coefficients for the production frontier, the level of technical efficiencies and output elasticities are calculated and discussed. In order to explain differences from the production frontier, an inefficiency model is estimated. An array of variables is included, and among the results are that the level of technical efficiency increases with vessel size, crew size and skipper experience in the fishery. It is also found that the age of a trawler and not being a full-time fisherman has a negative influence on the level of technical efficiency. Regarding management, it is found that the increased flexibility given to the trawlers in 1995 had a positive influence on the level of technical efficiency.

Keywords

Baltic Sea, Danish trawlers, inefficiency model, output elasticities, stochastic production frontier, technical efficiency

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Introduction

The purpose of this paper is to find possible explanations for any technical inefficiency observed in the Danish trawl fleet fishing in the Baltic Sea. This area is the third most important fishing area for Danish fishermen, with the North Sea being the most important followed by Skagerrak.

Technical efficiency is, from an output-oriented perspective, a measure which describes the individual fisherman's (vessel's) ability to maximise the output level in form of catches, given the endowment of inputs. Thus, technical efficiency is calculated by dividing the actual catch with the potential catch. The potential catch can be calculated using either a parametric or a non-parametric approach. The most applied parametric method is the Stochastic Production Frontier method (SPF), while Data Envelopment Analysis is the most applied non-parametric method. Both methods demand a specification of the production process in form of different variables, which are considered to reflect the input endowment. Since the parametric method is chosen in this analysis, it is also necessary to assume some functional form of the production frontier. This is considered as a disadvantage of the SPF method, despite that very flexible functional forms are available.

The SPF method was independently proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1997). Since then, this method has been used to analyse technical efficiency in many sectors of the economy. These range from labour markets (Hunt-McCool and Warren 1993) and rice farms (Lee and Schmidt 1993), to weaving industries (Pitt and Lee 1981) and schools (Arnold et al. 1996). The theory of SPF will not be presented here, and readers are referred to Coelli et al. (1999) for an overview. Alternatively, a short review can be found in Andersen (2002).

In several situations, it may be interesting to investigate possible reasons for the fact that some fishermen, with their individual input endowment, deviate from the production frontier, i.e. not technically efficient. This can be done by performing estimations using the individual efficiency scores as dependent variables and possible explanatory variables as independent variables. However, Battese and Coelli (1993) recommend that these should be estimated at the same time as estimating the production frontier. In this situation, the stochastic production frontier is extended with an inefficiency model. This one-step procedure has the advantage that it does not impose any distribution assumptions on the inefficiencies.

There can be many reasons for the fact that not all fishermen behave in a way which result in the highest potential output level given their inputs. An array of explanations will be presented in this paper, but data limitations have made it impossible to include factors ranging from age, education and experience of the individual fisherman to the presence of sonar and GPS on the individual trawler. Also environmental factors such as wave height, wind force etc. have not been possible to incorporate.

Lindebo (1999) has also analysed the Danish trawlers in the Baltic Sea using SPF. The dataset only covered 23 trawlers fishing for cod in February each year from 1987 to 1999 (in total 299 observations). Despite that extensive information gathering was performed, the focus was on technological progress and not reasons for technical inefficiencies. Comparisons with Lindebo (1999) are therefore not possible.

This paper develops as follows: In Section 1, the dataset is briefly described. Afterwards, the frontier function and inefficiency model is presented in Section 2. In Section 3, the estimation results are described and finally the results are discussed in relation to management. It is considered beneficial for the reader to also have Andersen (2002) within reach, because the used method is the same and a further discussion can be found in many instances. However, Andersen (2002) analyses the Danish seiners fishing in the North Sea and Skagerrak.

1. The dataset

The dataset in this analysis is derived from the Danish Directorate of Fisheries, who collects all official statistics regarding catches and vessel characteristics. Three databases were used to construct the dataset i.e. the logbook, account and vessel databases. By combining the logbook and account databases, an extensive dataset can be derived on a trip level, which contains the area fished, the number of days at sea, the gear used, the species caught in weight and value, their quality and use (consumption or industrial)[1]. Further combining this dataset with vessel characteristics gives information about vessel type, tonnage, horsepower, length, insurance value and commercial status, for example.

Reliable information date back to 1987. The used dataset therefore covers the years from 1987 to 1999. Firstly, if it is not possible to deduce the number of days at sea the

[1] The Danish Institute of Fisheries Research combines these two databases to one, and at the same time calculates the number of days at sea per vessel per trip.

observation is excluded. Secondly, all vessels that are not registered as trawlers are excluded, and thirdly trawlers fishing primarily for common shrimp and blue mussels are excluded. Finally, the dataset contained all the trawlers that fished in the Baltic Sea in a given month, where the Baltic Sea covers three areas, namely the Sound (3B), the Belts and Western Baltic (3C) and the Eastern Baltic (3D).

In total, there are 1,028 vessels in the Baltic Sea dataset. However, in order to obtain more robust estimation results, it is chosen to exclude vessels which did not frequently fish in the Baltic Sea during the years from 1987 to 1999. Therefore, the dataset only include trawlers which were present in at least 24 months during the 13 years analysed. The final dataset consequently only contained 446 vessels, which correspond to 26,236 observations for the Baltic Sea.

Descriptive statistics with respect to catches, fishing time and fishing power measures for the dataset are presented in Table 1.1.

Table 1.1. Descriptive statistics on an average monthly level

	Average	Standard deviation	Maximum	Minimum
Catch weight (kg)	40,683	98,790	1,979,752	6
Catch value (DKK)	121,001	125,787	2,494,331	59
Deflated catch value (DKK)	149,593	154,679	2,389,612	82
Days at sea	12.00	6.42	31.00	1.00
Length (metres)	16.74	5.87	48.44	9.54
Tonnage (GT/GRT)	41.79	55.06	702.00	4.90
Engine power (HP)	234.43	145.02	1,540.14	51.49
Crew size	2.63	1	8	1
Deflated insurance value (DKK)	2,360,976	2,932,117	40,000,000	200,000

Notes: Deflated catch value is calculated using an index derived from catch value of each species caught by all Danish fishermen and landed in Danish ports.

From the descriptive statistics, it can be observed that there are observations in the dataset with values deviating significantly from the average, especially the output measures, i.e. catch weight and catch value. It is chosen to keep these observations in the analysis, because there is no reason to believe that these are due to registration errors. These are thus considered a lucky catch or unlucky catch.

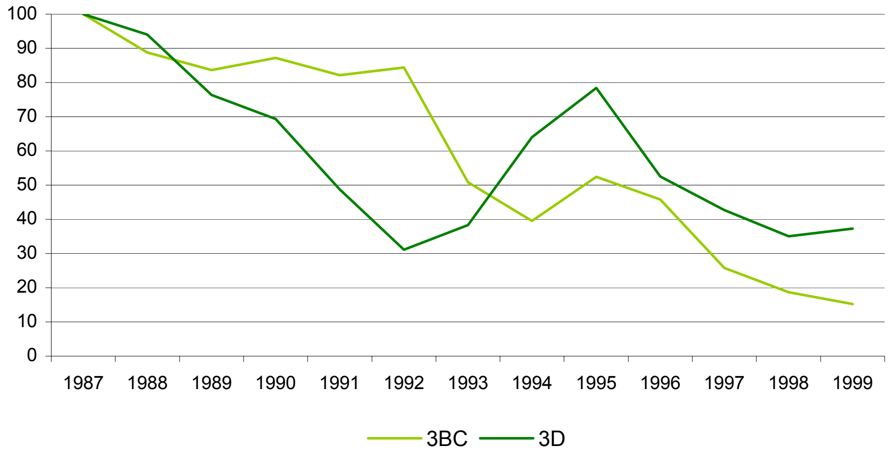
The catch composition of the included trawlers is presented in Table 1.2.

Table 1.2. Average catch composition using deflated catch value (%)

	1987	1990	1993	1996	1999	Average 1987-1999
Cod	40.87	41.25	13.15	16.49	18.16	24.02
Plaice	13.53	10.80	6.74	11.35	11.88	11.27
Turbot	10.88	13.11	8.51	11.61	11.52	11.44
Flounder	10.45	10.84	7.55	11.26	11.01	10.67
Dab	5.58	4.98	6.49	8.66	8.21	7.32
Herring	2.67	2.38	8.96	2.44	3.52	3.34
Whiting	2.16	2.66	6.56	4.45	4.68	4.09
Sprat	1.05	1.50	2.44	3.60	5.15	3.19
Brill	1.76	1.17	4.04	4.88	3.62	3.44
Other species	11.05	11.31	35.56	25.26	22.25	21.22

In 1987, the trawlers primarily targeted four species with cod being the most important. However, the collapse of the cod stock in the Baltic Sea significantly lowered the importance of cod for these trawlers on average. The other three species, plaice, turbot and flounder have not changed their relative importance, but several new species such as dab, sprat and brill have increased their importance in the fishery.

Figure 1.1. Development in cod stock indices for the Baltic Sea (1987=100)



Source: International Council for the Exploration of the Sea (ICES).

The collapse of the cod stock is apparent from Figure 1.1. Even an increase in the stock in the eastern part of the Baltic Sea (3D) in the years 1993 to 1995 did not change this development, and the size of the two stocks was therefore at a minimum in 1999.

2. Estimations to be performed

As mentioned in the introduction, a production frontier and an inefficiency model are estimated using the SPF method in one step. However, when choosing which inputs to include in the estimations, two questions need to be addressed: 1) which inputs are primarily determining the production level? and 2) which inputs are primarily influencing the level of efficiency? This deduction is not straightforward, and a prior knowledge to the fishery and how it is conducted is necessary to set up the stochastic production frontier and the inefficiency model to be estimated. Some articles (e.g. Eggert, 2001) include the same variables in the stochastic production frontier and the inefficiency model. However, whether this generally is a recommendable approach has at first glance not been considered in the literature.

Based on the above considerations, it has been chosen to estimate the following stochastic production frontier assuming the functional form of the frontier to be a translog-function:

$$
\begin{aligned}
\ln Y_{j,t} = \; & \beta_0 + \beta_L \ln L_{j,t} + \beta_H \ln H_{j,t} + \beta_D \ln D_{j,t} + \beta_S \ln S_{j,t} + \beta_T T_t + \\
& \beta_{LL}(\ln L_{j,t})^2 + \beta_{HH}(\ln H_{j,t})^2 + \beta_{DD}(\ln D_{j,t})^2 + \beta_{SS}(\ln S_{j,t})^2 + \beta_{tT}(T_t)^2 + \\
& \beta_{LH}(\ln L_{j,t} \ln H_{j,t}) + \beta_{LD}(\ln L_{j,t} \ln D_{j,t}) + \beta_{LS}(\ln L_{j,t} \ln S_{j,t}) + \beta_{LT}(\ln L_{j,t} T_t) + \\
& \beta_{HD}(\ln H_{j,t} \ln D_{j,t}) + \beta_{HS}(\ln H_{j,t} \ln S_{j,t}) + \beta_{HT}(\ln H_{j,t} T_t) + \\
& \beta_{DS}(\ln D_{j,t} \ln S_{j,t}) + \beta_{DT}(\ln D_{j,t} T_t) + \\
& \beta_{ST}(\ln S_{j,t} T_t) + \\
& \beta_{FEB}\, FEB_t + \beta_{MAR}\, MAR_t + \beta_{APR}\, APR_t + \beta_{MAY}\, MAY_t + \beta_{JUN}\, JUN_t + \\
& \beta_{JUL}\, JUL_t + \beta_{AUG}\, AUG_t + \beta_{SEP}\, SEP_t + \beta_{OCT}\, OCT_t + \beta_{NOV}\, NOV_t + \beta_{DEC}\, DEC_t + \\
& v_{j,t} - u_{j,t}
\end{aligned}
$$

where j refers to the j'th vessel (j=1,...,446) and t refers for the t'th month (t=1,…,156). For vessel j in month t, $Y_{j.t}$ refers to the total deflated catch value, $L_{j.t}$ refers to the length of vessel, $H_{j.t}$ refers to the horsepower, $D_{j.t}$ refers to the number of days at sea, $S_{j.t}$ refers to the stock index, while T_t is the yearly time measure (T=1,…,13). FEB, …, DEC are the monthly dummy variables.

Deflated catch values are chosen as the output measure, because it weights the amounts caught using market deflated market prices. Sharma and Leung (1999) discuss the applicability of catch value as an output measure. The level of technical efficiency can therefore also include allocative efficiency. The latter measures the ability a trawler has to catch the optimal combination of fish[2].

Several inputs are included in the frontier production function. Length and horsepower measure the trawler's fishing power. Both variables measure the trawler's size, but horsepower is also a good indicator of the trawler's ability to drag the trawls fast through the water. There is a correlation between these two variables, but this is not considered problematic. Number of days at sea measures the time where the trawler is at sea, and thus conducting an economic activity. Stock is included in order not to disfavour trawlers that for instance were fishing in years where the availability of fish (especially cod) was low. The stock measure is thus a composite measure, which considers the relative importance of each species for every vessel[3]. The yearly time measure is included to detect movements in the frontier primarily due to technological progress[4]. Finally, monthly dummy variables are included to measure movements in the frontier due to the seasonality of the fishery.

It is chosen to estimate the following inefficiency model:

$$
\begin{aligned}
u_{j,t} = \; & \delta_0 + \delta_1 \ln INS_{j,t} + \delta_2 \ln CREW + \delta_3 AGE_{j,t} + \\
& \delta_4 KOMB_{j,t} + \delta_5 STERN_{j,t} + \delta_6 OTHER_{j,t} + \\
& \delta_7 PART_{j,t} + \delta_8 FIRM_{j,t} + \delta_9 UNKNOWN_{j,t} + \delta_{10} T3BCD_{j,t} + \\
& \delta_{11} TPGEAR_{j,t} + \delta_{12} REG_{j,t} + \delta_{13} 3B_{j,t} + \delta_{14} 3C_{j,t} + \\
& \delta_{15} Sb12m_{j,t} + \delta_{16} S1518m_{j,t} + \delta_{17} S1824m_{j,t} + \delta_{18} S2440m_{j,t} + \delta_{19} Sa40m_{j,t} + \\
& \delta_{20} Cr_{j,t} + \delta_{21} Cn_{j,t} + \delta_{22} Cf_{j,t} + \delta_{23} Cz_{j,t} + w_{j,t}
\end{aligned}
$$

Considering the large number of variables included in the inefficiency model, a description of each variable, and what inefficiency effects they are assumed to measure,

[2] The latter is considered to be of less importance, when looking at differences in efficiencies, cf. Pascoe et al. (2001).

[3] The International Council for the Exploration of the Sea (ICES) publishes yearly stock assessments for an array of species. In the Baltic Sea, these are cod, herring, sprat and flounder. For the rest of the species, the stock is assumed unchanged over years, even though this is most likely not the case. However, independent stock measures have not been available to exclude this discrepancy.

[4] Andersen (2002) discusses the inclusion of a time measure, including other methods than the one used here.

will first be discussed in the next section. However, the acronyms used in the technical inefficiency model refer to the following:

INS	Deflated insurance value
CREW	Crew size
AGE	Vessel age, i.e. current year – building year + 1
KOMB	Dummy variable with value 1, if the trawler is a combination trawler, i.e. stern and side
STERN	Dummy variable with value 1, if the trawler is a stern trawler
OTHER	Dummy variable with value 1, if the trawler is another type than stern, side or combination trawler
PART	Dummy variable with value 1, if a part-time fisherman owns the trawler
FIRM	Dummy variable with value 1, if a firm owns the trawler
UNKNOWN	Dummy variable with value 1, if the ownership is unknown
T3BCD	The days at sea in 3BCD relative to the total number of days at sea per year
TGEAR	The days at sea using the primary gear (trawl) relative to the total number of days at sea per month
REG	Dummy variable with value 1 in the years from 1995 to 1999, because of new regulation
3B	Dummy variable with value 1, if the primary fishing area in a specific month is 3B
3C	Dummy variable with value 1, if the primary fishing area in a specific month is 3C
Sb12m	Dummy variable with value 1, if the trawler is below 12 metres
S1518m	Dummy variable with value 1, if the trawler is between 15 and 18 metres
S1824m	Dummy variable with value 1, if the trawler is between 18 and 24 metres
S2440m	Dummy variable with value 1, if the trawler is between 24 and 40 metres
Sa40m	Dummy variable with value 1, if the trawler is above 40 metres
Cr	Dummy variable with value 1, if the trawler has homeport in the county of Ribe
Cn	Dummy variable with value 1, if the trawler has homeport in the county of Northern Jutland

Cf	Dummy variable with value 1, if the trawler has homeport in the county of Funen
Cz	Dummy variable with value 1, if the trawler has homeport on Zealand

In order to avoid the dummy trap, one dummy variable is excluded in every set of dummy variables. Thus, the trawler considered in the initial situation is a side-trawler between 12 and 15 metres, owned by a commercial fisherman, fishing primarily in 3C, having homeport on the island of Bornholm and fishing in January.

3. Results

The computer programme Frontier 4.1 developed by Tim Coelli (Coelli, 1996) is used to estimate the stochastic production frontier and the inefficiency model presented in Section 2. As mentioned in the introduction, this is done in a one-step procedure[5].

3.1. Technical efficiency estimates

The parameters in the estimated stochastic production frontier have the parameter values presented in Table 3.1. Most of the parameters estimated for the included variables in the production frontier are significant[6] and the coefficients of the linear terms have the expected signs.

The table also include two parameters of variance, i.e. σ^2 and γ. If γ equals zero, then all deviations from the frontier are due to noise and if it equals one, then all deviations are due to technical inefficiency. γ is seen to be significantly different from zero. This indicates that there are deviations from the frontier, which can be referred to technical inefficiencies.

Before interpreting the estimated coefficients, several tests are performed in order to test the relevance of the chosen specification.

[5] Actually, several variables have been tested in order to find the most valid specification of the stochastic frontier function and the inefficiency model. Finally, the variables and specification chosen were the ones described in Section 2.

[6] Re-estimating the production model without the insignificant regressors has not been performed, since this would imply the creation of a new type of production frontier function that is not related to the theoretical functions generally used in the production function literature.

Table 3.1. The stochastic production frontier

	Parameter	Coefficient	Standard deviation	t-ratio	
Intercept	β_0	-5.14	0.49	-10.44	***
Ln (Length)	β_L	5.09	0.37	13.75	***
Ln (Horsepower)	β_H	1.11	0.20	5.48	***
Ln (Days at sea)	β_D	0.90	0.06	14.64	***
Ln (Stock index)	β_S	1.06	0.05	20.01	***
Time	β_T	0.12	0.01	8.25	***
Ln (Length) × Ln (Length)	β_{LL}	-0.61	0.14	-4.38	***
Ln (Horsepower) × Ln (Horsepower)	β_{HH}	-0.06	0.05	-1.32	
Ln (Days at sea) × Ln (Days at sea)	β_{DD}	-0.02	0.01	-3.42	***
Ln (Stock index) × Ln (Stock index)	β_{SS}	0.00	0.00	1.66	*
Time × Time	β_{TT}	0.00	0.00	-3.67	***
Ln (Length) × Ln (Horsepower)	β_{LH}	0.06	0.15	0.37	
Ln (Length) × Ln (Days at sea)	β_{LD}	-0.02	0.04	-0.44	
Ln (Length) × Ln (Stock index)	β_{LS}	-0.23	0.04	-6.21	***
Ln (Length) × Time	β_{LT}	0.03	0.01	4.44	***
Ln (Horsepower) × Ln (Days at sea)	β_{HD}	0.01	0.02	0.53	
Ln (Horsepower) × Ln (Stock index)	β_{HS}	-0.05	0.02	-2.44	**
Ln (Horsepower) × Time	β_{HT}	-0.02	0.00	-4.16	***
Ln (Days at sea) × Ln (Stock index)	β_{DS}	0.01	0.01	2.18	**
Ln (Days at sea) × Time	β_{DT}	-0.01	0.00	-4.35	***
Ln (Stock index) × Time	β_{ST}	-0.02	0.00	-9.83	***
February	β_{FEB}	0.06	0.02	3.95	***
March	β_{MAR}	-0.01	0.02	-0.89	
April	β_{APR}	-0.12	0.02	-7.40	***
May	β_{MAY}	-0.19	0.02	-11.08	***
June	β_{JUN}	-0.42	0.02	-21.61	***
July	β_{JUL}	-0.72	0.02	-30.74	***
August	β_{AUG}	-0.48	0.02	-24.04	***
September	β_{SEP}	-0.38	0.02	-20.10	***
October	β_{OCT}	-0.49	0.02	-26.30	***
November	β_{NOV}	-0.46	0.02	-26.48	***
December	β_{DEC}	-0.34	0.02	-19.47	***
Sigma-squared	σ^2	2.20	0.20	10.89	***
Gamma	γ	0.91	0.01	122.41	***

Notes: *** significant at the 1 percent level, ** significant at the 5 percent level, * significant at the 10 percent level.

The following tests are conducted:

1) Are there any inefficiency effects?
2) Is the frontier independent of the monthly dummy variables?
3) Could the functional form be Cobb-Douglas?
4) Is there any technological change?

These hypotheses are all tested by re-estimating the stochastic production function under the different restrictions. Decision to reject or accept a hypothesis is based on the generalised likelihood-ratio test given as LR=-2×{ln[L(H_0)] - ln[L(H_1)]}. This test size is chi-squared distributed with n degrees of freedom, where n measures the number of restrictions imposed on the frontier by the hypothesis.

Table 3.2 shows the value of the likelihood function under the null-hypothesis (H_0) and alternative hypothesis (H_1), the likelihood-ratio test size (LR), the critical chi-square value, the degrees of freedom and whether the test is accepted or rejected.

Table 3.2. Tests of the stochastic production frontier Baltic Sea

Null hypothesis (H_0)	Ln [L(H_0)]	Ln [L(H_1)]	LR	Critical χ^2	Number of restrictions	Decision
No inefficiency effects[1)]	-27,070	-25,031	4,078	37.07*	25	Reject
No monthly effects[2)]	-26,534	-25,031	3,006	19.68	11	Reject
Cobb-Douglas production frontier[3)]	-25,468	-25,031	874	25.00	15	Reject
No time effects[4)]	-25,134	-25,031	205	11.07	5	Reject

Notes: * Critical values obtained from Kodde and Palm (1986).
1) H_0:$\gamma = \delta_0 = \ldots = \delta_{23} = 0$.
2) H_0:$\beta_{FEB}=\beta_{MAR}=\beta_{APR}=\beta_{MAY}=\beta_{JUN}=\beta_{JUL}=\beta_{AUG}=\beta_{SEP}=\beta_{OCT}=\beta_{NOW}=\beta_{DEC}=0$.
3) H_0 $\beta_{LL}=\beta_{HH}=\beta_{DD}=\beta_{SS}=\beta_{TT}=\beta_{LH}=\beta_{LD}=\beta_{LS}=\beta_{LT}=\beta_{HD}=\beta_{HS}=\beta_{HT}=\beta_{DS}=\beta_{DT}=\beta_{ST}=0$.
4) H_0:$\beta_T=\beta_{TT}=\beta_{LT}=\beta_{DT}=\beta_{ST}=0$.

All of the tested hypotheses can be rejected at a 5 per cent significance level. Thus, there are technical inefficiency effects, and not all of the variables in the inefficiency model can be excluded at the same time. There are also monthly variations and time effects that influence the location of the frontier, and the translog-functional form is preferred to a frontier based on a Cobb-Douglas functional form.

Based on the above, it is thus with a certain degree of confidence that the analysis proceeds with a relevant production frontier being applied. However, the coefficients estimated in the translog-function are difficult to interpret individually (Campbell and Hand (1998), Eggert (2001)). It is instead chosen to focus on the output elasticities.

The output elasticities are shown in Table 3.3. While the output elasticity with respect to length has increased considerably during the thirteen years, it has decreased for horsepower, days at sea and stock index.

Table 3.3. Average output elasticities													
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Length	0.96	0.97	1.04	1.09	1.15	1.27	1.21	1.32	1.33	1.41	1.45	1.52	1.59
Horsepower	0.38	0.36	0.35	0.34	0.32	0.32	0.28	0.28	0.26	0.25	0.24	0.23	0.22
Days at sea	0.84	0.83	0.83	0.82	0.81	0.80	0.81	0.80	0.79	0.78	0.77	0.76	0.75
Stock index	0.22	0.19	0.18	0.16	0.14	0.14	0.11	0.11	0.10	0.09	0.06	0.04	0.02
Time	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01

The elasticity related to length is in 1999 equal to 1.59, indicating that a 10 per cent increase in vessel length will imply a 15.9 per cent increase in the deflated catch value. This can at first be considered a high elasticity, but considering that increasing a 10-metre vessel with one metre implies an even larger increase in its tonnage, this elasticity may not be that unrealistic at all[7].

The scale elasticity related to the input variables, which the fishermen can influence by their behaviour, i.e. length, horsepower and number of days at sea, are on average equal to 2.35, and thus well above one. This indicates the presence of increasing returns to scale in the trawl fishery in the Baltic Sea, when the fishing time and fishing power is measured using days at sea, length and horsepower.

The presence of increasing returns to scale indicates that the Danish trawlers fishing in the Baltic Sea are not operating at an optimal level. This may be due to the regulatory restrictions put on length, engine power and days at sea. Length is indirectly and engine power is directly regulated under the capacity regulations in Danish fisheries. These are therefore not straightforward to change, if a trawler wishes to. The number of days at sea is likewise indirectly regulated through the imposed catch restrictions.

The output elasticity calculated with respect to the time index shows that the rate of change in the frontier with respect to time is positive in all the included years[8]. However, in the years from 1987 to 1989, the frontier moved outwards with a higher rate than in the final years from 1996 to 1999. These increases can most likely be attri-

[7] The stochastic production frontier was re-estimated with tonnage instead of length. The output elasticity with respect to tonnage was then on average around 0.30, which is accordance with other work done for Danish seiners fishing in the North Sea and Skagerrak (see Andersen, 2002).

[8] The output elasticity with respect to time is for the average values calculated as follows:

$$\frac{\partial \mathrm{LnY}}{\partial \mathrm{T}} = \beta_T + 2 \cdot \beta_{TT} \cdot T + \beta_{LT} \cdot \ln L + \beta_{HT} \cdot \ln H + \beta_{DT} \cdot \ln D + \beta_{ST} \cdot \ln S$$

Thus, the time measure is not transformed by taking the logarithm, i.e. the elasticity gives the relative effect on output of an absolute change in time.

buted to technological developments, but other factors may also be included in this variable. The change in movement rate is most likely attributable to more restricting management. Management can for instance influence technological progress that is possible for fishing gears, but also, which modifications that are allowed on the vessels.

The coefficients related to the monthly dummy variables indicate that the production frontier moves inwards and outwards during the year. The frontier moves outwards in February compared to January, while March is estimated to have the same frontier as January. In the months from April to December, the frontier moves inwards with the largest shift observed in July. This corresponds to the seasonality of the fishery in the Baltic Sea, where the most important species such as cod and plaice are caught in the first three months of the year, falling to the lowest point in July, and thereafter increasing slightly until January (see also Figure 3.1).

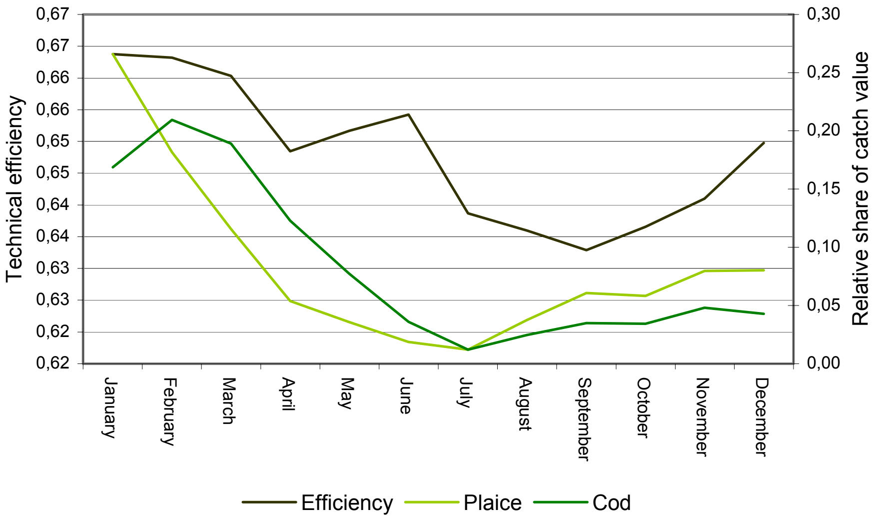
Turning attention to the level of technical efficiency, descriptive statistics are presented in Table 3.4 for each of the thirteen years. It can be concluded that the average yearly level seems to be relatively stable ranging from 0.61 in 1990 to 0.70 in 1996. A high variation is also observed. It is interesting to observe that some trawlers have very low estimates of technical efficiency in given months. Possible reasons for this will be discussed below.

Table 3.4. Characteristics of the estimates of technical efficiency

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Average value	0.65	0.66	0.64	0.61	0.62	0.61	0.62	0.65	0.70	0.70	0.68	0.64	0.67
Standard deviation	0.19	0.17	0.20	0.18	0.18	0.16	0.19	0.19	0.17	0.17	0.17	0.17	0.16
Maximum value	0.91	0.95	0.92	0.92	0.91	0.93	0.93	0.93	0.92	0.92	0.93	0.90	0.91
Minimum value	0.02	0.02	0.00	0.02	0.05	0.01	0.01	0.00	0.00	0.01	0.03	0.03	0.02

Figure 3.1 shows the average monthly efficiency scores together with the distribution of the deflated catch value over the year for the two most important species, cod and plaice.

Figure 3.1. Average monthly technical efficiency and distribution of deflated catch value for cod and plaice



It can be observed from Figure 3.1 that the development in the average technical efficiency score over the year seems to be strongly influenced by the importance of cod and plaice. In January to March, where the largest share of the yearly catch value of cod and plaice are caught, the technical efficiency score peaks, despite the fact that monthly dummy variables have been included. An increase is observed in May and June, which is related to the fact that cod and plaice actually comprise the largest share of the catches in these months.

3.2. Technical efficiency estimates

As shown above, the Danish trawlers are not on average 100% technically efficient when fishing in the Baltic Sea. Possible reasons for this fact have been analysed by estimating the inefficiency model described in Section 2. The results from this estimation can be viewed in Table 3.5.

All of the included variables except one are significant. No tests have therefore been conducted regarding the exclusion of any of the included explanations for the observed inefficiencies in the Danish trawlers fishing in the Baltic Sea. Because the estimated model is an inefficiency model, a negative coefficient indicates that the variable has a negative effect on the estimated level of technical efficiency.

Table 3.5. The technical inefficiency model

	Parameter	Coefficient	Standard deviation	t-ratio	
Intercept	δ_0	18.54	1.67	11.10	***
Deflated insurance value	δ_1	-1.43	0.14	-10.36	***
Crew size	δ_2	-0.34	0.06	-6.05	***
Trawler age	δ_3	0.50	0.09	5.57	***
Combi-trawler	δ_4	-0.15	0.05	-2.85	***
Stern-trawler	δ_5	0.18	0.04	4.12	***
Other trawler type	δ_6	0.14	0.07	1.89	**
Part-time fisherman	δ_7	2.69	0.30	8.87	***
Company/hired skipper	δ_8	0.02	0.27	0.08	
Unknown commercial status	δ_9	0.48	0.05	9.43	***
Share of time in the Baltic Sea	δ_{10}	-2.66	0.26	-10.25	***
Share of time with primary fishing gear	δ_{11}	-1.37	0.13	-10.71	***
Regulation dummy variable	δ_{12}	-0.91	0.08	-11.92	***
Primary fishing area 3B	δ_{13}	-0.32	0.11	-2.83	***
Primary fishing area 3C	δ_{14}	1.40	0.14	9.78	***
Trawler length below 12m	δ_{15}	-0.47	0.07	-6.34	***
Trawler length between 15 and 18m	δ_{16}	0.40	0.06	7.00	***
Trawler length between 18 and 24m	δ_{17}	1.30	0.15	8.75	***
Trawler length between 24 and 40m	δ_{18}	3.59	0.38	9.51	***
Trawler length above 40m	δ_{19}	4.28	0.52	8.23	***
Homeport in Northern Jutland	δ_{20}	-0.14	0.04	-3.44	***
Homeport on the west coast of Jutland	δ_{21}	1.48	0.17	8.50	***
Homeport on Zealand	δ_{22}	0.32	0.05	6.34	***
Homeport on Funen	δ_{23}	0.26	0.06	4.27	***

Notes: *** significant at the 1 percent level, ** significant at the 5 percent level, * significant at the 10 percent level.

Deflated insurance value is included in the inefficiency model to test whether size of the vessel has any influence on the level of technical efficiency. The production frontier function is solely based on physical measures, so instead of including one physical measure in the inefficiency model, a monetary measure is used. Insurance value reflects all of the physical fishing power measures, because these are usually insured. This relationship is reflected in the correlation coefficients, which for the insurance value is 0.85 with respect to tonnage, 0.80 with respect to horsepower and 0.82 with respect to length.

Other analyses have shown that larger trawlers have higher levels of technical efficiency than smaller ones, and this is what one would intuitively expect. The present analysis supports this, considering that the sign of the coefficient is negative. It can thus be concluded that a 10 per cent increase in the insurance value of a trawler will increase the level of technical efficiency by 14.3 per cent.

Even though crew size is to some extent correlated with the other physical measures of fishing power (0.75 on average), it is included in the inefficiency model in order to test whether the number of persons employed on a trawler has any influence on the level of technical efficiency. This analysis reveals that vessels with higher number of persons on board also have a higher level of technical efficiency.

The trawler age is included to test whether older trawlers have lower levels of efficiency compared to newer vessels. Even though maintenance can counteract some of the aging of the trawlers, an older vessel is generally considered less efficient compared to a newer one. The average age of the included trawlers was in 1987 approximately 26 years, but increased to almost 37 years in 1999. Based on the estimations in the inefficiency model, this increase of 40 per cent in average age thus implies a decrease in technical efficiency of 20 per cent. Thus, the aging of the trawler fleet fishing in the Baltic Sea seems to have had severe effects on the level of technical efficiency.

Turning to the dummy variables representing the trawler type, these are included in order to see whether the principal design of the trawler has any influence on the level of technical efficiency. A distinction is made between four types. The only initial expectation regarding the signs of these dummy variables is that the combi-trawlers are thought to be more efficient than the others, considering their higher level of flexibility in gear choice. The present analysis supports this a priori expectation due to the negative sign of δ_4. It can also be concluded that side-trawlers are more efficient compared to stern-trawlers and other types of trawlers.

The commercial status of the fisherman is included to test his incentives to act in a way which maximises the level of technical efficiency, i.e. seeks to obtain the highest deflated catch value given his input endowment. It is expected that being a full-time fisherman has a positive influence on the level of technical efficiency, because he directly works to make a living. Hired skippers work in a more indirect way and may therefore not have the incentives to maximise the level of technical efficiency. The analysis reveals that commercial fishermen are efficient, but also trawlers owned by a company, with a hired skipper, are equally efficient. However, part-time fishermen are the most inefficient, which is to some extent expected considering that these do not primarily fish for a living, but also for pleasure.

The share of time in the Baltic Sea and share of time with primary gear both sought to measure the experience with the area and primary gear, respectively. One would expect that the more a trawler fishes in the Baltic Sea and use their primary gear, the higher the level of technical efficiency will be. The coefficients in the inefficiency model shows that the more time that a trawler is fishing in the Baltic Sea, the more efficient it is. An explanation can be that these fishermen are more experienced with the fishing grounds compared to fishermen who only fish in the Baltic Sea for a smaller part of the year. The same conclusion can be drawn regarding the time used with the primary gear. Thus fishermen that are often using their primary gear, i.e. trawl, also have a higher level of technical efficiency.

In 1995, vessels fishing in the Baltic Sea were given the option of a yearly ration instead of rations only valid for shorter periods. This was considered to give at least the smaller vessels more flexibility in planning their fishery over the year, because these are more influenced by weather conditions than the larger vessels. Thus on a monthly ration they were “forced” to catch their ration during this month despite bad weather, while with a yearly ration they could wait until the next month. However, it is unfortunately not possible to identify which of the included trawlers used yearly instead of monthly rations. Therefore, a dummy variable is included for each observation in the period from 1995 to 1999. This analysis confirms that this period has higher levels of technical efficiency compared to the earlier years, which could indicate the improved flexibility of the trawlers.

A primary fishing area is assigned to every monthly observation, i.e. in which area have they been catching most of their catch value. This way of assigning a primary fishing area is proposed by Campbell and Hand (1998). A distinction is made between three fishing areas, i.e. the Sound, the Belts and Western Baltic Sea, and the Eastern Baltic Sea. The inefficiency analysis indicates that trawlers catching primarily in the Sound have a higher level of technical efficiency compared to trawlers primarily fishing in the other two areas. The analysis also shows that trawlers primarily fishing in the Belts and Western Baltic Sea have the lowest level of technical efficiency.

Every observation (vessel) included in the analysis is assigned to a fleet segment. A differentiation is made between six fleet segments, because these follow the ones used in the yearly forecast of expected development in the economy of the Danish fishing fleet[9]. The purpose is to be able to relate some of the technical efficiency analysis performed here to these forecasts. The estimations reveal that the small trawlers below 12 metres actually are the most efficient. The level of technical efficiency seems to be the lowest for the trawlers belonging to the fleet segment above 40 metres. These results are counterintuitive to the results related to the insurance value, i.e. the larger trawler, the higher level of efficiency.

Finally, it is analysed whether the homeport of the trawlers has any influence on the level of technical efficiency. Prior expectations are not clear, however. Long steaming time may lower the catch per day, but the vessels may have a higher catch, and still have a higher catch per day. It is also a common practise that trawlers who have ports far away from the Baltic Sea, fish in the area for longer periods and deliver their catches to the local processing plants. The analysis reveals a tendency towards trawlers from Northern Jutland being the most efficient even compared with the trawlers from Bornholm, who are situated almost in the middle of the Baltic Sea. However, trawlers from the west coast of Jutland seem to be the most inefficient, which could indicate that the longer steaming time is important. However, the reason for trawlers from Northern Jutland being the most efficient is not immediately apparent. An explanation may be related to their level of experience in the Baltic Sea as discussed earlier.

Concluding remarks

In conclusion, this short paper has investigated the level of technical efficiency in the Danish trawler fleet fishing in the Baltic Sea for period 1987 to 1999 and possible reasons for the presence of inefficiencies have been presented. An array of different explanations has been put forward. Among these are vessel size, age and type, experience, regulation changes and homeport. These are all found to have a significant influence (negative or positive) on the technical efficiency of Danish trawlers fishing in the Baltic Sea, which is in accordance with expectations. They are thus able to explain why some trawlers are more efficient than others.

Information about technical efficiency and reasons for inefficiency can be used by both vessel owners and regulatory authorities (managers). Vessel owners obtain information about how they can improve their level of technical efficiency. For example, should they improve their vessel to be more gear flexible? Should they fish more

[9] This economic forecast is conducted by the Danish Research Institute of Food Economics.

in a specific area in order to obtain more experience? Or should they relocate to a port closer to the primary fishing area? Thus, if their objective is to maximise catch value, then they obtain indications about which factors they can improve upon.

From a management perspective, the information can also be beneficial. In relation to a decommissioning programme, other management measures can be necessary to impose, in order to secure that increased catch possibilities are not counteracted by the implementation of efficiency promoting measures. However, from an economic point of view, it will always be best to give vessels the opportunity to increase their technical efficiency, and instead remove even more vessels in order to sustain catch possibilities at a high level. Despite that the fishery is a special economic sector, it is important to obtain the highest rent possible for the invested capital. If not, investors will likely seek to invest their capital in other sectors of the economy.

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