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Time-inconsistency in DEA: a study of Norwegian factory trawlers

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Abstract

DEA is widely used to assess efficiency and returns to scale of production units. Such analysis will be useful only to the extent the data used are representative of efficiency over time, but often the data used are likely to be cross section observations for only one year. This paper reports DEA for Norwegian factory trawlers for a 12-year period and concludes that there are shifts in efficiency scores that fail to identify a time-consistent hierarchy of production units in terms of efficiency. Likewise, the analysis largely fails to identify vessels of an optimal scale.

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1. **INTRODUCTION**

Data envelopment analysis (DEA) has become widely used to analyze economic efficiency and returns to scale in industries. Such information is relevant for, among other things, mergers and acquisitions. If two production units are both operating below the optimal scale, it would make sense to merge them and increase the scale of operations. More generally, DEA provides benchmarks against which production units can be compared, spurring measures to improve the performance of laggards.

For this analysis to be useful, the ranking of production units in terms of efficiency and returns to scale must be consistent over time. If this is not the case, we run the risk of incorrectly identifying production units that are inefficient or on a suboptimal scale. This is potentially a serious problem, because one does not necessarily have time series of data to perform DEA but only cross section data pertaining to one particular year. If there is an underlying but unidentified time-inconsistency, one would risk coming up with recommendations that lack the necessary factual basis. There are a number of reasons why the ranking of production units in terms of efficiency could change over time. One is simply random factors beyond human control. Another is change in product mix. A third is adjustments in the production process.

In this paper we discuss the results of a DEA for a sample of Norwegian factory trawlers covering twelve years (1990-2001). The focus is on time consistency in the ranking of vessels in terms of efficiency and scale efficiency. As it turns out, the results show serious time-inconsistency, casting doubts on their usefulness for identifying efficient benchmark vessels and vessels of an optimal scale.

2. THE DATA

The Norwegian factory trawlers are relatively large vessels, 50-75 meters long, with a replacement value of 100-180 million kroner and 25-35 people employed.[1] They catch cod, saithe and other bottom-dwelling fish and process the catch on board, mainly into frozen fillets. The data have been obtained from the Norwegian Directorate of Fisheries and cover a sample of vessels each year. The sample covers a relatively large part of the fleet, and so there are vessels which are represented in the sample all twelve years. All in all there are 25 vessels in the sample, but in the presentation below we will focus in particular on nine vessels represented in the sample in at least nine of the twelve years.

The data cover quantity and value of catches, in total and split into four different types of fish, with a fifth covering all others. Operating costs are split into various categories, the most important being quasi-fixed, such as insurance, and variable, such as fuel, ice, and packaging. Below we will in some cases identify variable costs as a third factor of production alongside capital and labor. For capital we shall use the replacement value of the vessel, estimated or updated every year. Labor is the average number of people employed over the year.

The data also provide the number of operating days per year. This is potentially important information, as all vessels are not necessarily operated throughout the entire year because of insufficient fish quotas. What otherwise would appear as a difference in efficiency could be

[1] The replacement value refers to 2001.

due to differences in the number of days of operations. Below we will adjust for this. Unfortunately, however, there is some reason to believe that the recording of operating days may not be consistent, and that in particular the definition of a year-round operation has changed over the period considered. This will obviously cause problems in measuring efficiency correctly. Apart from that there is reason to believe that the data are of good quality. They are obtained from the accounts of the boatowners and controlled for quality by the staff of the Directorate of Fisheries. The catch data are obtained from the catch data base of the Directorate. The data have been made available in anonymous form but so that it is possible to follow each vessel over time.

3. THE FISHERY

The factory trawlers catch different kinds of fish. The most important species are cod, saithe, Greenland halibut, and haddock. There are large inter-annual variations in the catches of these species, depending on the conditions of the fish stocks. Figure 1 shows catch value and volume per vessel in the sample. In good years, about half of the catch value consists of cod. The variations in catch value are largely accounted for by the variations in the catches of cod and saithe, and there is a tendency for the value of "other" species to go down when the catches of cod and saithe are large. Even if prices vary over time, the variations in catch value are largely accounted for by the variations in catch volumes.

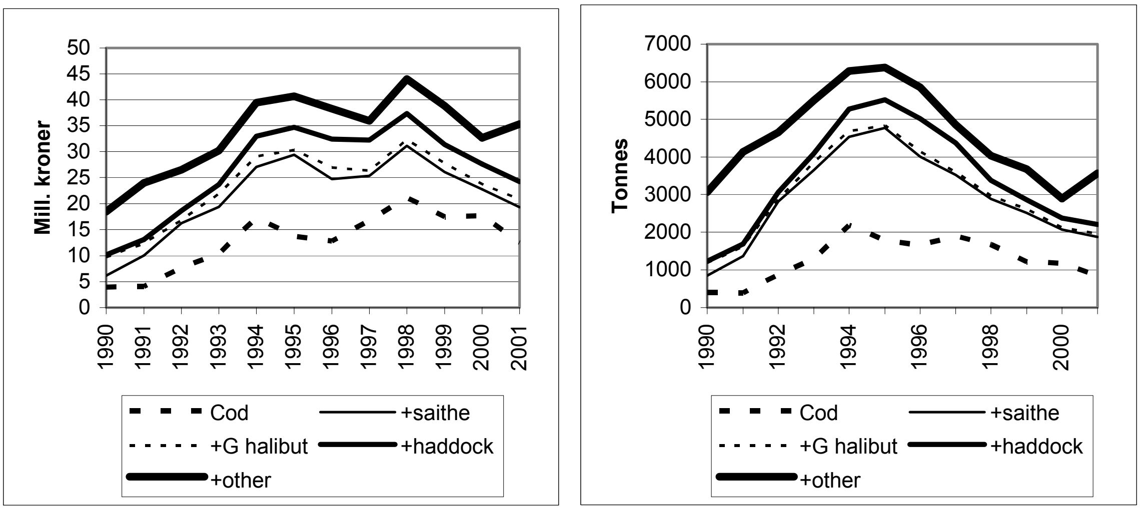

Figure 1

Catches per vessel of the factory trawlers represented in the sample.

The catches of the four said species are now subject to output controls. There is a limit on how much can be caught from each particular stock, usually referred to by the acronym TAC (total allowable catch). The TACs are split between the countries sharing the stock in question; for example, Norway and Russia split the TAC of Northeast Arctic cod evenly between themselves, after allowing for a certain quantity for third countries.[2] The Norwegian share of the TAC is divided between different segments of the fishing fleet. For most types of boats these allocations are further subdivided into individual vessel quotas. For several years these vessel quotas have been transferable, albeit with certain restrictions; it has been possible to buy quotas for a certain period,[3] or to transfer the quotas of one vessel to another within the same firm, and in some cases even between firms, for a period of up to three years. The vessel quotas are expressed as shares of the total quota allocated to each fleet segment, and so the tonnage goes up and down with the TAC.

These output controls have been imposed gradually over time. The catches of cod have been subject to output controls since before 1990. Quotas on saithe in the North Sea were introduced in 1995 and take the form of a total quota for the entire vessel group. Under this type of regulation the fishery is stopped when the quota has been fished, irrespective of what the individual vessels have caught. A similar regime was in force for haddock in the early 1990s, with individual vessel quotas introduced in 1999. Individual vessel quotas were put in place for saithe north of the 62nd parallel in 1998. For Greenland halibut there has been a bycatch quota, but targeted catch of this fish is prohibited.

Given these output controls, it appears to make most sense to use an input-oriented approach, especially for observations for the latter half of the 1990s. An output-oriented approach was also tried but gave very similar results. Hence we employ the input-oriented approach for the entire period, noting that the same vessels will be identified as the most efficient ones under both approaches.

4. ANALYSIS: CONSTANT RETURNS TO SCALE

The input-oriented DEA approach involves minimizing the use of inputs for a given output, or set of outputs. The linear programming problem for the input-oriented approach is (Coelli et al., 1994)

$$\underset{\theta,\lambda}{\text{minimize}}\ \theta$$

subject to

$$y_i \leq \sum_{j=1}^{N} \lambda_j y_j$$

$$\theta x_i \geq \sum_{j=1}^{N} \lambda_j x_j$$

$$\lambda_j \geq 0,$$

[2] It happens that these countries exchange catch allowances; in some past years a part of the Russian share of the TAC for Northeast Arctic cod has been transferred to Norway. It also happens that Norwegian boatowners rent catch quotas from Russia.

[3] The length of this period is 13 or 18 years, depending on whether the vessel from which quotas are transferred is destroyed. In early 2005 the Ministry of Fisheries put forward a proposal to make the quota transfer permanent.

where y_i is either a single output or a vector of outputs for vessel i, x_i is a vector of inputs for vessel i, and N is the number of vessels. Hence there are N separate LP-problems to be solved.

As already mentioned, all vessels are not represented every year. If there is a consistent hierarchy among vessels in terms of efficiency, we would expect that exclusion or inclusion of a certain vessel in a certain year would displace the efficiency scores up or down in a parallel fashion. If the most efficient vessel drops out, the next efficient one would take its place and get an efficiency score of 1, pulling the rest of the vessels up in a similar fashion. Hence, if we look at the efficiency scores over time, we would see a pattern of parallel, wavelike lines that never cross. In the following we shall display our results in this fashion, but as it turns out, this perfect hierarchy does not materialize. This raises the question of what could be a useful measure of consistency in efficiency among the vessels. Such a measure would be useful to evaluate how close different approaches might come to identifying differences in efficiency among vessels. We propose the following index (I) for time-inconsistency in efficiency:

$$I_{t,t+1} = \sum_{i=1}^{N_{t,t+1}} abs\left(\frac{\theta_{i,t+1}}{\theta_{i,t}} - 1\right)$$

where $N_{t,t+1}$ is the number of vessels represented in both of two adjacent years, t and t+1. The vessels are ranked in order of efficiency in both years. Hence, if the order of efficiency scores is the same in both years, the index is zero. If not, the index is positive, and the greater the larger the deviation between the efficiency scores in year t+1 of the ith most efficient vessel in year t and year t+1.

Table 1

Example of the time-inconsistency index (I).

Vessel	θ_t	θ_{t+1}	θ^*_{t+1}
1	0.5	0.7	0.8
2	0.6	0.75	0.85
3	0.7	0.8	0.7
4	0.8	0.85	0.75
5	0.9	0.9	1.0
6	1.0	0.95	0.9
7		1.0	0.95

A numerical example will help to explain this. Table 1 shows the efficiency scores of vessels in years t and t+1. In year t+1 a new vessel has been added to the sample, but the order of the vessels in terms of efficiency is the same, even if the efficiency scores have changed, so the index would be zero. If the efficiency scores would be like in the last column (θ^*_{t+1}), the order of the vessels in terms of efficiency would be different in year t+1, and the efficiency index would be 0.729.

The first case considered is the single output case, with output being defined as gross revenue, and two inputs, labor and capital, with no correction for operating days. Table 2 shows the number of operating days per vessel, as well as the maximum and minimum number of days.

In some years there is a difference of a hundred days or more between the highest and the lowest number of days a vessel has been in operation, as the catch quotas of some vessels are too small to allow a year round operation. It may also be noted that the average number of operating days varies between years. The reason is similar; in the early 1990s, and again around 2000, there was a dearth of fish, and so most vessels did not need the whole year to fish their quotas.

Table 2

Average, maximum and minimum number of operating days of factory trawlers.

	Average	Maximum	Minimum
1990	307.6	330	250
1991	307.9	330	210
1992	320.8	330	264
1993	327.7	330	318
1994	332.6	365	256
1995	334.9	351	311
1996	322.5	356	297
1997	329.9	364	284
1998	311.8	363	211
1999	309.7	350	248
2000	221.2	355	163
2001	251.2	335	123

Differences in the number of operating days, if not adjusted for, would presumably show up as differences in efficiency. Therefore, we have adjusted for this by multiplying the input of capital and labor by the number of operating days divided by 365. Figure 2 shows, among other results, the efficiency scores with and without this adjustment, for the vessels which are represented in at least nine of the twelve years for which we have data. As discussed earlier, we would expect to see roughly parallel lines, as we would not expect to see major shifts back and forth in the relative efficiency of vessels. The results obtained without adjusting for operating time appear to produce more tangled lines, which indicates that adjusting for operating time provides a more relevant comparison of vessels. This is supported by the time-inconsistency index *I* discussed above. Table 3 shows the index values obtained with and without the adjustment for operating time. The index is lower in all years except three when we adjust for the number of operating days, which indicates fewer and smaller shifts in the relative efficiency of vessels.

The reason why the time-inconsistency index is higher for some years when we adjust for operating days could be an inconsistent assessment of the number of operating days. One thing we may note is the jump in the maximum number of days from 330 to 365 or something appreciably higher between 1993 and later years. From those who compile the data we have been told that prior to 1994 it was customary to set the number of operating days to 330 per year, as roughly one month would be necessary for vessel maintenance. Hence there appears to have been some adjustment of the definition of operating days from 1994 onwards. This could explain why the efficiency index for the years 1993-94 is higher when adjustment is made for operating days. The results for 1997-98 and 1998-99 are less easily explained, however. This notwithstanding, it seems that making the said correction for the number of operating days is more appropriate than the opposite, and we will do so in the two cases to follow.

In addition to capital and labor, fishing depends on the use of various inputs such as fuel, ice, salt, etc. Greater revenues could be obtained by a more intensive use of such factors, and so including these would be expected to explain some of the variability in efficiency and produce a more consistent ranking of vessels over time. Hence we have included the cost of the said variable factors as a third input, alongside capital and labor input per day. For the factory trawlers, fuel is by far the most important of these variable factors, and so, if the inclusion of this third factor would explain some of the differences in revenue, it could be due to vessels going further afield to obtain greater catches. Quasi-fixed costs such as insurance and maintenance are not included in this third factor of production.

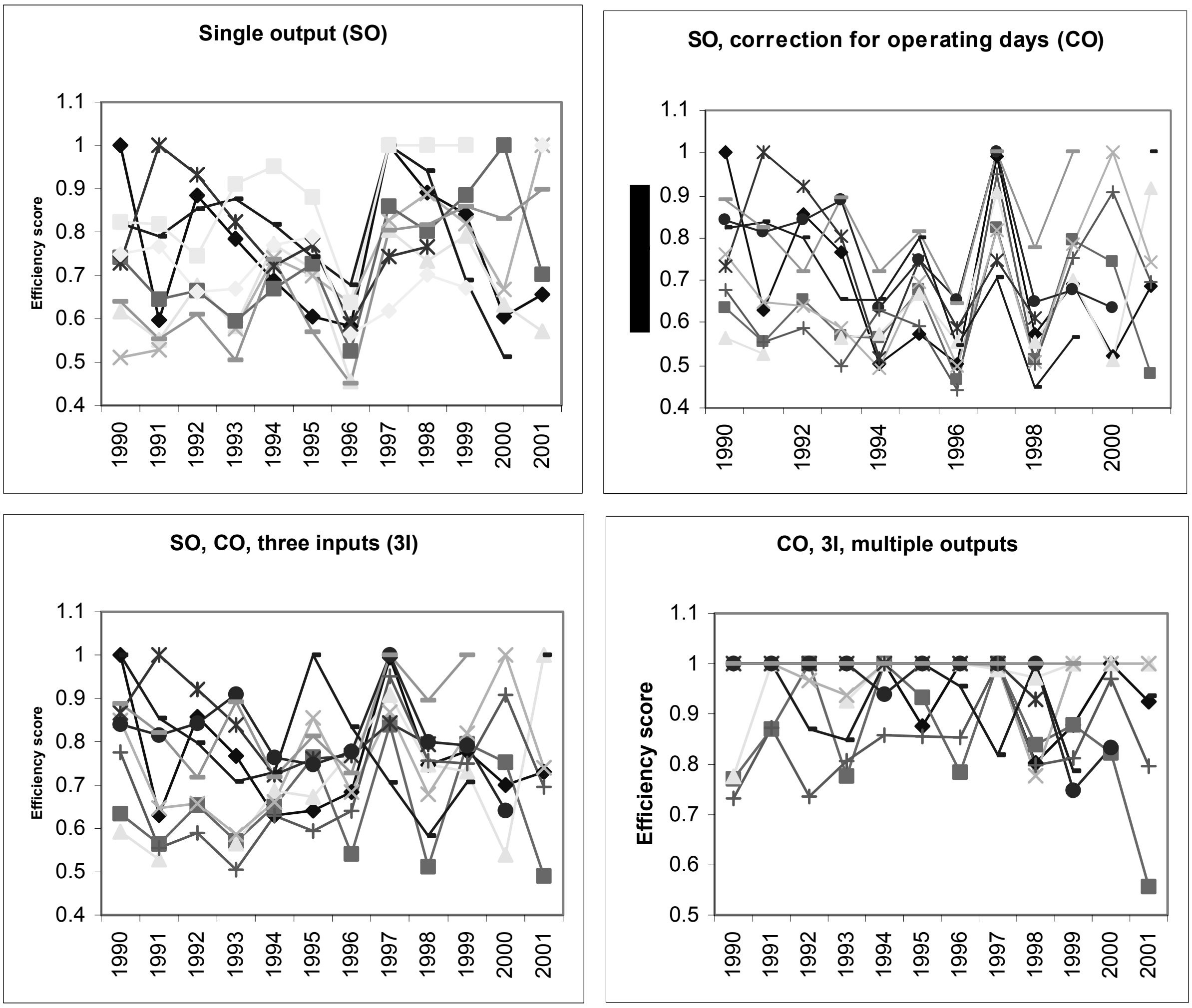

Figure 2

Efficiency scores of the vessels represented in at least nine out of twelve years. Constant returns to scale.

The results of including the variable factors are also shown in Figure 2 under the heading of three inputs. The consistency in efficiency ranking of the vessels is not much improved. A lower time-inconsistency index would indicate a greater time consistency in ranking of the vessels, but the index (Table 3) is lowered for only six of the twelve years. Hence it seems that differences in the use of fuel do not explain much of the differences in efficiency among the vessels.

Table 3

The time-inconsistency index of the efficiency scores. Constant returns to scale.

	No correction for operating days	Correction for operating days	Inclusion of variable inputs	Multi-output case
1990-91	1.079	1.004	1.025	0.280
1991-92	0.882	0.860	0.848	0.663
1992-93	1.709	1.648	1.400	0.528
1993-94	1.559	2.679	1.547	0.428
1994-95	1.883	1.514	3.176	1.835
1995-96	1.076	0.920	1.698	0.582
1996-97	2.098	1.637	2.043	0.434
1997-98	1.335	1.945	1.821	1.713
1998-99	2.131	3.632	1.607	1.655
1999-00	7.520	6.700	8.004	3.838
2000-01	3.095	2.167	2.126	1.655

Finally, let us consider the multiple output case. The various kinds of fish caught by the factory trawlers fetch different prices. The catch quotas for these fish differ among the vessels, and so the differences in efficiency that occur in the aggregate output case could be due to different portfolios of quotas. Table 4 shows the average, maximum and minimum revenue shares of the five different outputs of fish which we have identified; cod, saithe, haddock and Greenland halibut, all north of the 62nd parallel, and other species, the most important of which is saithe south of the 62nd parallel.[4] Clearly there are considerable variations in these shares, both between vessels and between years. The former is due to different portfolio holdings of quotas, the latter to variations in total quotas between years.

The efficiency scores are shown in Figure 2 under the heading of multi-output. The lines tracing the efficiency scores over time do cross a few times, but not as often as in the previous cases. The time-inconsistency index also shows greater consistency of efficiency scores over time (Table 3); for all years except one we get a lower score than in the single output case, and for some years much lower. One vessel is identified as consistently the most efficient one, although others do occasionally score maximum efficiency ($\theta = 1$), and a second is usually better than the rest. No vessel seems, however, to be consistently the least efficient one. We thus conclude that the variation in efficiency among the vessels does not appear to be due primarily to different utilization of factors of production but to different composition of the catch, which goes back to different portfolios of quotas of different species.

[4] There are separate quotas set for fish north and south of the 62nd parallel, which identifies the boundary between the North Sea and the Norwegian Sea.

Table 4

Average, maximum and minimum share of five species in the catch of the factory trawlers in the sample.

		Cod	Haddock	Saithe (north)	Greenland halibut	Others
1990	Average	0.22	0.02	0.10	0.19	0.46
	maximum	0.44	0.06	0.39	0.50	0.81
	minimum	0.13	0.00	0.00	0.01	0.14
1991	Average	0.17	0.03	0.09	0.10	0.60
	maximum	0.24	0.05	0.24	0.34	0.84
	minimum	0.12	0.00	0.01	0.00	0.47
1992	Average	0.28	0.07	0.19	0.02	0.44
	maximum	0.51	0.10	0.31	0.13	0.72
	minimum	0.15	0.01	0.03	0.00	0.15
1993	Average	0.33	0.06	0.18	0.08	0.35
	maximum	0.59	0.12	0.27	0.26	0.54
	minimum	0.22	0.03	0.09	0.00	0.10
1994	Average	0.43	0.10	0.13	0.05	0.29
	maximum	0.62	0.17	0.33	0.15	0.49
	minimum	0.28	0.05	0.04	0.01	0.08
1995	Average	0.33	0.11	0.23	0.02	0.31
	maximum	0.59	0.14	0.38	0.06	0.46
	minimum	0.23	0.06	0.13	0.00	0.04
1996	Average	0.32	0.14	0.16	0.06	0.33
	maximum	0.59	0.19	0.29	0.14	0.54
	minimum	0.21	0.09	0.08	0.01	0.02
1997	Average	0.46	0.16	0.12	0.03	0.22
	maximum	0.67	0.21	0.21	0.10	0.34
	minimum	0.29	0.11	0.10	0.00	0.09
1998	Average	0.48	0.11	0.07	0.03	0.32
	maximum	0.66	0.16	0.10	0.18	0.53
	minimum	0.31	0.05	0.05	0.00	0.09
1999	Average	0.45	0.09	0.07	0.04	0.35
	maximum	0.64	0.13	0.13	0.17	0.53
	minimum	0.32	0.06	0.05	0.01	0.14
2000	Average	0.52	0.13	0.09	0.03	0.22
	maximum	0.69	0.31	0.21	0.24	0.51
	minimum	0.34	0.07	0.06	0.00	0.02
2001	Average	0.36	0.10	0.10	0.05	0.40
	maximum	0.63	0.14	0.16	0.12	0.59
	minimum	0.22	0.07	0.07	0.01	0.20

5. ANALYSIS: VARIABLE RETURNS TO SCALE AND SCALE EFFICIENCY

The above formulation of the LP-problem implies constant returns to scale. Variable returns to scale are allowed for by imposing the additional constraint $\sum_{j=1}^{N} \lambda_j = 1$. This amounts to comparing each production unit to units of a similar size (Coelli et al., p. 150). There is some presumption that this would make the units more similar in terms of efficiency and lead to a better time consistency in the ranking of the units. This is indeed the case here.

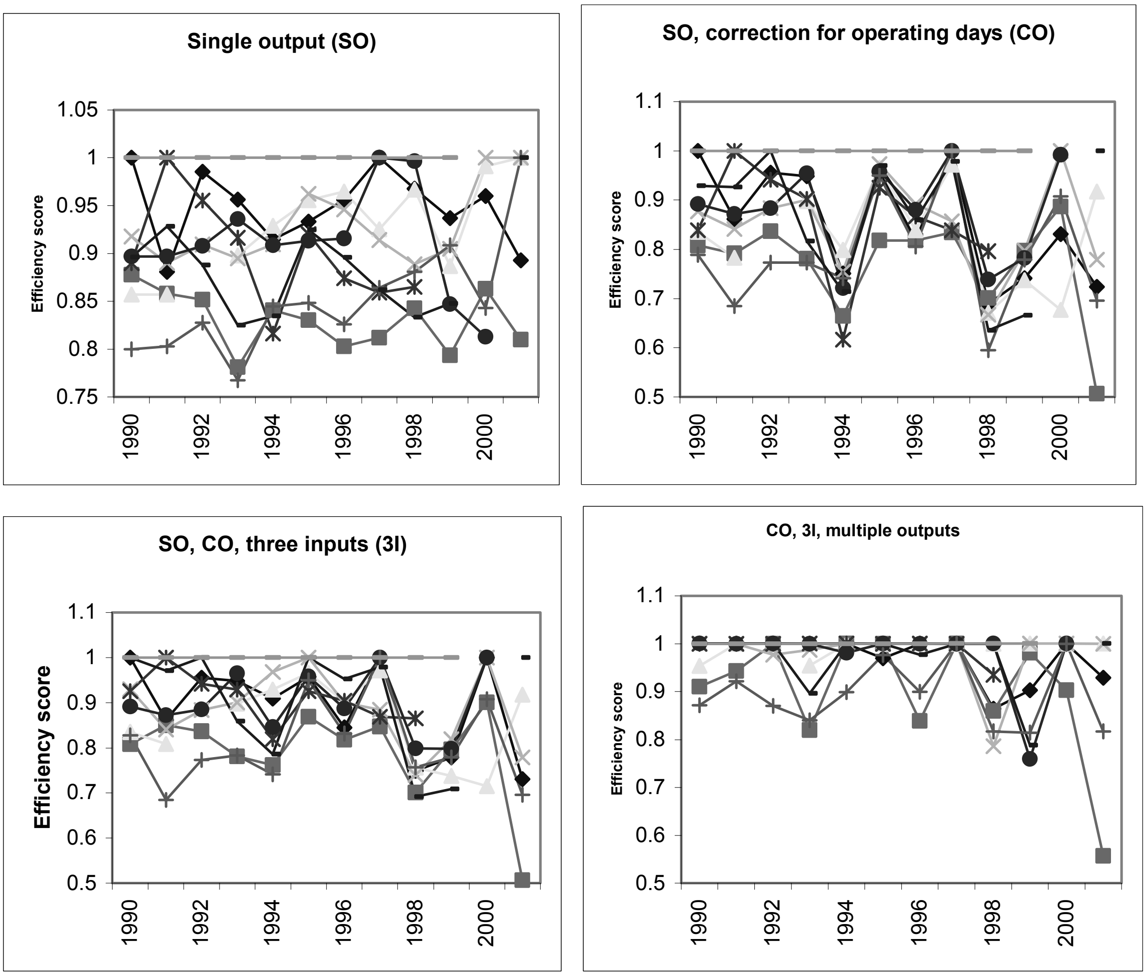

Figure 3

Efficiency scores of the vessels represented in at least nine out of twelve years. Variable returns to scale.

Figure 3 shows the efficiency scores and Table 5 the time-inconsistency index. The index is in all cases except one much lower for the VRTS case than for the CRTS case, indicating a greater consistency in the ranking of the vessels over time. But there is one surprising result. Correcting for the number of operating days produces a higher time-inconsistency index for nine of the twelve years. The main reason is that making this correction increases the difference between the least and the most efficient vessels, while the ranking of the vessels appears to be more consistent over time. This is not what one would expect; on the contrary it would seem likely that differences in efficiency between vessels could be accounted for by differences in the number of operating days. There is thus a suspicion that the number of operating days may not be correctly recorded, or not consistently defined over time, as discussed above.

Including fuel and other variable factors of production reduces the time-inconsistency index in only five years out of twelve and thus does not much improve the time consistency of efficiency comparisons. Allowing for several outputs lowers the time-inconsistency index for nine years out of twelve and reduces it in some cases to zero. Hence, as in the CRTS case, much of the differences in efficiency is accounted for by different portfolios of quotas. In the VRTS case, as in the CRTS case, one vessel is consistently more efficient than the rest and receives top score for all years.

Table 5

The time-inconsistency index of the efficiency scores. Variable returns to scale.

	No correction for operating days	Correction for operating days	Inclusion of variable inputs	Multi-output case
1990-91	0.474	0.390	0.777	0.000
1991-92	0.238	0.405	0.388	0.047
1992-93	0.434	0.454	0.658	0.441
1993-94	0.816	1.567	1.074	0.226
1994-95	0.597	0.524	0.759	0.721
1995-96	0.190	0.506	0.524	0.565
1996-97	0.514	0.719	0.837	0.000
1997-98	0.440	1.692	1.251	0.676
1998-99	0.995	2.557	0.781	1.611
1999-00	0.851	1.373	1.121	1.034
2000-01	0.545	1.939	2.016	1.656

The ratio $\theta_{CRTS}/\theta_{VRTS}$ has come to be identified as scale efficiency (Coelli et al., 1994). It is doubtful, however, whether this measure can be used to identify production units of an optimal size in terms of returns to scale in cases like this one where there is not much variation in the *K/L* ratio and there is substantial variation in the efficiency of the individual production units (see Hannesson, 2005).

Figure 4 shows the scale efficiency of the nine vessels which are represented in the sample in at least nine of the twelve years. The maximum scale efficiency is unity, and so the scale-efficient vessels would be found among those for which this value is obtained. There are several years in which this value is not obtained by any of the vessels, but this is due to the fact that vessels with a scale efficiency of one are not shown in the figure, as they are not represented in the sample in nine years or more. Still, one would expect that the ranking of vessels in terms of scale efficiency would not change form one year to another. This, however, is precisely what happens. Some vessels rank at the bottom in terms of scale efficiency in some years and bounce to the top in other years. In the case of several outputs there is one vessel that consistently ranks at the top, with a scale efficiency of unity. It turns out that this vessel is the smallest one in terms of invested capital and the number of people employed. Figure 5 shows the number of people employed and the replacement value of the vessels in the 1999 sample. The vessel with the consistently highest scale efficiency is the one with a replacement value of 64.5 million kroner and 25 people employed. This would indicate that there are decreasing returns to scale in this industry. In the single output cases this particular vessel does not consistently show the highest scale efficiency, like the others it bounces from the bottom to the top over the period considered.

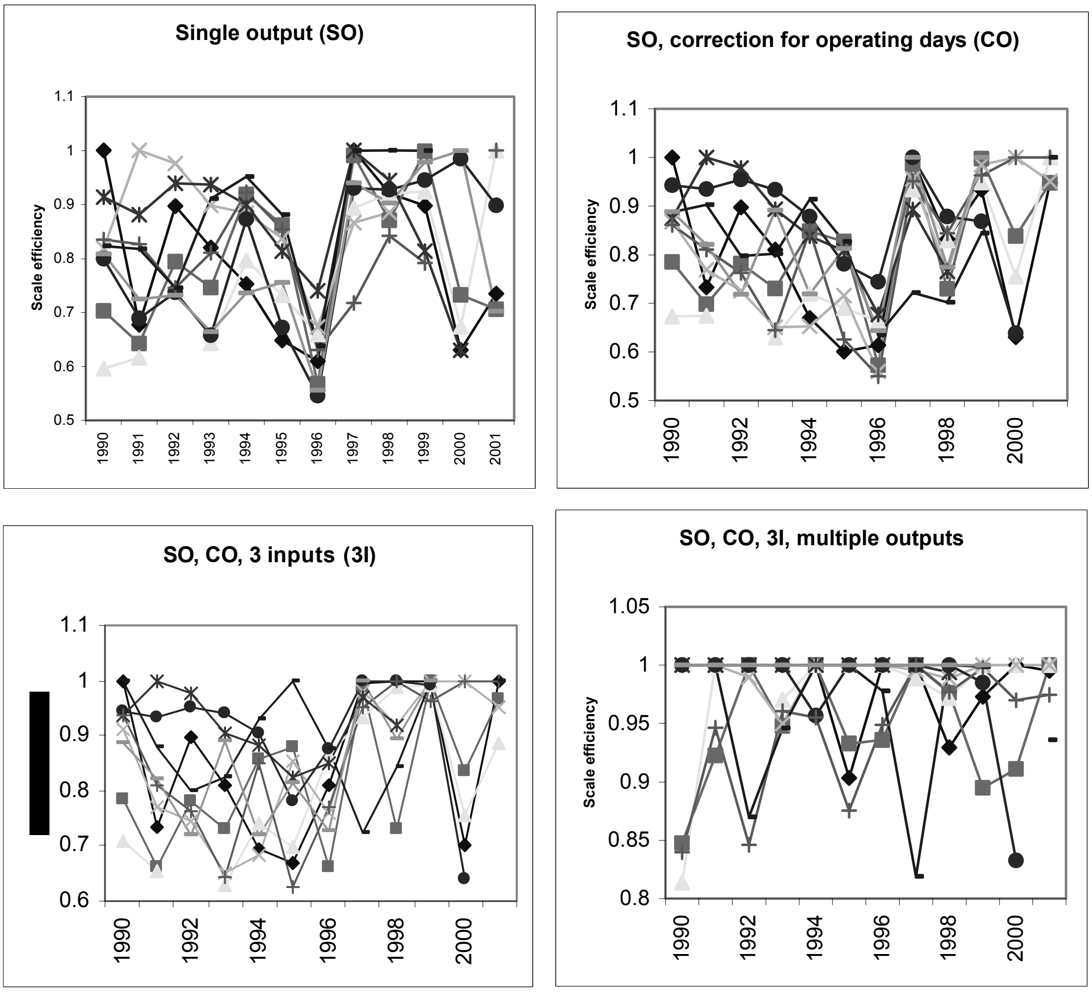

Figure 4

Scale efficiency of the nine factory trawlers represented in the sample in at least nine years out of twelve.

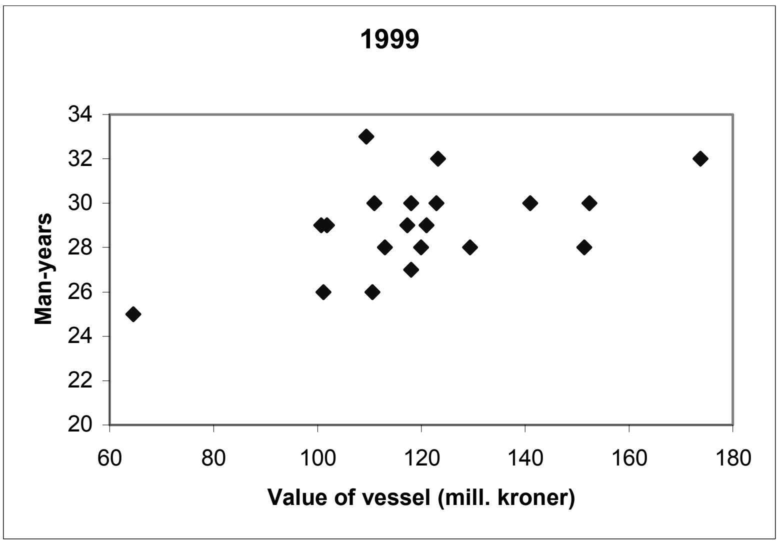

Figure 5

Replacement value and number of people employed in the 1999 sample of factory trawlers.

6. CONCLUSION

The efficiency analysis above has shown major shifts over time in the ranking of production units in terms of efficiency. Units that in one year are ranked at the top drop to the bottom in another. Such changes in relative efficiency must be due either to random changes affecting the production environment of the firms, or to deliberate adjustments which are not reflected in the data at our disposal. These shifts are a problem both under the assumption of constant returns to scale and variable returns to scale, but perhaps less so in the latter case. The most promising results are obtained for the case where five different product groups are identified. Each of these is subject to its own output constraints, and the portfolio of quotas for these different outputs differs among the units involved. These differences in output quotas appear to be the most promising explanation of the differences in efficiency.

There are similar problems in identifying the optimal scale of the production units. Units of different size occupy the pride of place in different years, making it difficult to unambiguously identify the optimally sized unit. The smallest unit does, however, rank consistently on top in the multi-output case.

Such variations in efficiency rankings and scale efficiency are troublesome, from the point of view of coming up with recommendations about industrial structure or identifying units where efficiency can be enhanced. Basing such recommendations on data for only one year may turn out be off the mark, if there are substantial and not easily explained shifts over time in the efficiency rankings of production units.

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