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Abstract
In this paper we estimate technical and scale efficiency of Icelandic fish processing firms and calculate structural measures of efficiency for the industry as a whole. For this purpose, data envelopment analysis (DEA) is applied, and Tobit regressions then used to analyse the determinants of efficiency at firm level. The sample consists of an unbalanced panel of 43 firms observed during the period 1985-1995. Technical efficiency is positively related to firm size and capital intensity, and firms producing fish meal and fish oil appear to be more efficient than others. Diversity of operation hampers efficiency. Firms in the South and West of Iceland are less efficient than their counterparts in the North and East. We also find that technical efficiency has been decreasing over the period. Scale efficiency is a negative function of both the capital-labour ratio and output diversity, as well as a negative function of time. Structural technical and scale efficiency fell in 1994 and 1995 after remaining fairly stable for the other periods, and this fall can probably be attributed mainly to falling cod catches. Estimated total revenue losses due to inefficiency during the period 1985-1995 amount to almost 18 billion Icelandic kronur, just over one-third of total industry sales in 1990.

JEL classification: C14, C34, D29.
Keywords: Fish processing, DEA, efficiency, Tobit.

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1. Introduction

Applied production theory has traditionally been based on analysing the economic performance of the average production unit or firm. This preoccupation with averages masks the fact that firms do differ and are not all equally apt in getting the most out of available inputs. In recent years, several methods have been developed to account for the fact that some firms are more efficient than others, and numerous studies on the subject have been published. In this paper, one of these methods, data envelopment analysis (DEA), is applied to 43 firms in the Icelandic fish processing industry, and measures of technical and scale efficiency are derived, both for each firm and for the industry as a whole.

Fishing and fish processing have been Iceland's most important economic activity for centuries, although the fish processing industry really did not take off until the late 19th and early 20th centuries. Fish products make up around 75% of total exported goods and are the largest, single source of foreign currency earnings. In addition, fishing and fish processing is of vital importance for the many small coastal communities. The country's rural policies have to a large degree centred on lending these firms a helping hand, either directly through loans with low interest rates or through other forms of financial support, or indirectly through the exchange rate policy. In recent years, these firms have, however, not met the same understanding as previously, and other aims, such as low inflation and price stability, have taken precedence over the viability of the fishing and fish processing sectors in the formation of the exchange rate policy.

Other fundamental changes in these sectors have also occurred in the last decade or so. In 1986, a fairly complex system of funds and transfers within the sectors was abolished with the result that price formation was made more transparent, although the fish prices paid by the processing firms did not change much. In the years following the abolition of this system, domestic fish auction markets were established in Iceland, and the emergence of these markets put an end to the operation of a government agency that previously had determined prices of all fish landed in Iceland. In 1995, almost one-third of all cod catches were sold at these markets, with the rest either sold to processing firms in the ownership of the fisheries companies or closely aligned with them, or sold abroad.

Finally, between 1985 and 1995 great strides were made in reducing inflation in Iceland. High inflation was prevalent in the economy in the 1970s and 1980s, with inflation peaking in 1983 at 84%. In 1992, inflation was down to 2.4%, and the price level remained stable in the next few years.

By analysing the change in efficiency of the fish processing firms, we hope to determine if the different economic reality the firms were facing in the 1990s has in some ways affected the development of efficiency, and if possible, to determine the sources of these efficiency changes. The method chosen for this purpose is DEA, which consists of solving a number of linear programming problems. In a separate stage, the determinants of the efficiency estimates obtained from DEA are analysed using parametric methods.

This paper is organised in the following fashion. A brief description of the Icelandic fish processing industry during 1985-1995 is provided in Section 2. DEA measures of efficiency are discussed in Section 3, while the data used is described in Section 4. The DEA and regression results are presented in Section 5, and Section 6 concludes the study.

2. The Icelandic fish processing industry

The Icelandic economy has an almost schizophrenic appearance. On the one hand, it is a highly developed service-based economy, while it resembles, on the other, a developing country relying heavily on just one export product for its currency earnings. Thus, although fishing and fish processing only accounted for 15-17% of GDP in 1985-1995, the share of fish products in total exported goods was 70-80% during the same period. The export share of fish has however been declining in recent years.

The role of fishing in the economy is nevertheless far greater than would appear from GDP and export statistics. Iceland is characterised by a severe regional imbalance, with 2/3 of the population living in the capital, Reykjavik, or nearby.[1] Fishing is the main economic activity in most of the towns and villages outside the capital area; fishing and fish processing is almost the sole livelihood in many of the villages. As a consequence, the financial viability of the fishing and fish processing industries is of crucial importance not only because of the export earnings they

[1] The Icelandic population was 275,000 in 1999.

generate but also because of their regional importance. The government has therefore frequently been willing to aid these firms in troubled times, either directly by helping the firms find loans or by granting them other financial support, or indirectly through the exchange rate policy.

Most of the fish processing firms operated in Iceland are small. As revealed in Table 1, about a third of the companies only had the equivalent of one or two full-time employees on their books in 1989. Many of these were family firms. Two-thirds of the firms had fewer than 10 employees, and close to 80% of the firms were operated with less than 20 full-time employees. In 1989 only 30 firms had more than 60 full-time employees. However, these large firms produced the bulk of the fish products in Iceland. It should, however, be noted that vertical integration is quite frequent, and that one owner often holds shares in more than one fish processing firm.

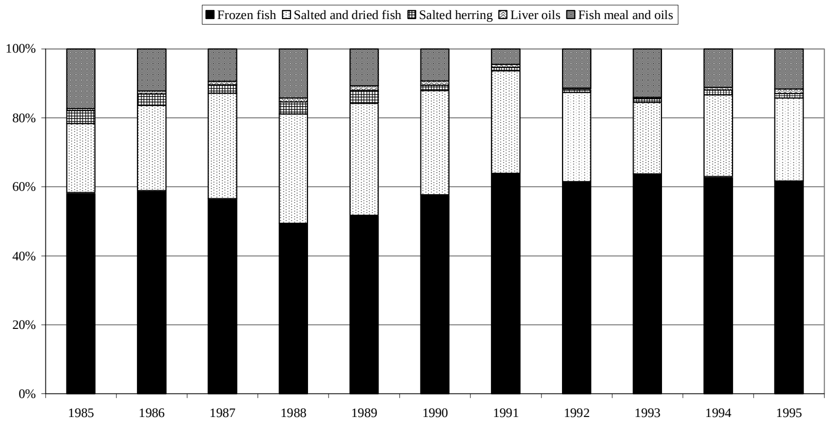
Table 1
Size distribution of Icelandic fish processing firms 1989

Products	Total number of firms	Number of full-time employees								
		0-1	1-2	2-5	5-10	10-20	20-30	30-40	40-60	>60
Frozen salted and dried	469	126	49	74	65	57	31	13	25	29
Salted herring	21	4	3	5	4	4	1	-	-	-
Liver oils	5	1	1	2	-	-	-	-	1	-
Fish meal and oils	19	2	1	3	5	2	3	1	1	1
All firms	514	133	54	84	74	63	35	14	27	30

The fish processing industry can be divided into the production of frozen products, salted and dried products, salted herring, fish meal and fish oils and liver oils. Frozen products are by far the most important of these, accounting for around 60% of the total value of fish products. The 1980s saw the introduction of freezing trawlers, i.e., large trawlers that have freezing facilities aboard. Many of the traditional fresh-fish trawlers have now been converted to freezing trawlers, and most of the new trawlers bought in recent years have these facilities. The products of the freezing trawlers are in many ways superior to those produced on land, as the quality of the raw material used is higher. The freezing trawlers have provided stiff competition for the land-based processing industry, which in some cases has even led to the closure of fishing plants

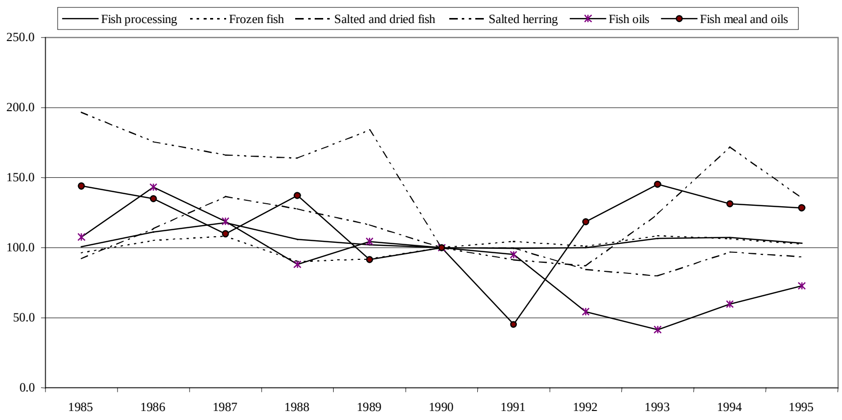
Salted and dried fish represented 20-25% of the total value of fish products during the period under observation. Dried fish has become less and less important in the last 15 years, accounting in the 1990s for just over one percentage point of the total value of fish products. Dried fish products were mainly exported to Africa, but the markets there closed in the 1980s. Salted fish has, on the other hand, retained its status in Icelandic exports. The main markets are found in southern Europe; Spain, Portugal, Italy and Greece, and these have remained stable.

Figure 1
Value shares of output of each fish processing industy 1985-1995



The Icelandic herring stocks were fished to the brink of extinction in the 1960s, and herring catches remained very low throughout the 1970s. However, catches increased from 50,000 tons in 1985 to 125,000 tons in 1995. In 1994, Icelandic boats also began to harvest the Norwegian spring-spawning herring, with catches reaching 220,000 tons during the 1997/98 season. Scandinavia and Russia are the largest markets for salted herring.

Figure 2
Volume indices of the fish processing industries 1985-1995. 1990=100



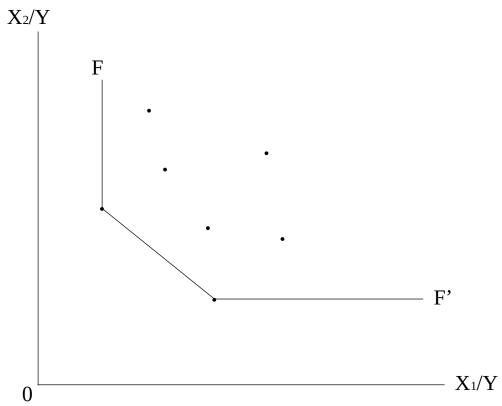
Fish meal and fish oils are mainly produced from pelagic species, such as herring and capelin. The capelin fisheries collapsed in 1991, falling from 800,000 tons the previous year to 260,000 tons. This dramatic decline is well documented in Figure 2.

3. Efficiency and the DEA methodology

3.1 Technical efficiency

In a seminal paper, Farrell (1957) defined a simple measure of efficiency that could be used to compare the efficiency of one firm with that of another. To estimate this efficiency, Farrell suggested the use of either a non-parametric piece-wise linear convex isoquant or a parametric function. The former is illustrated in Figure 3, where the unit-isoquant FF´ is constructed so that no observation lies below or to the left of it.

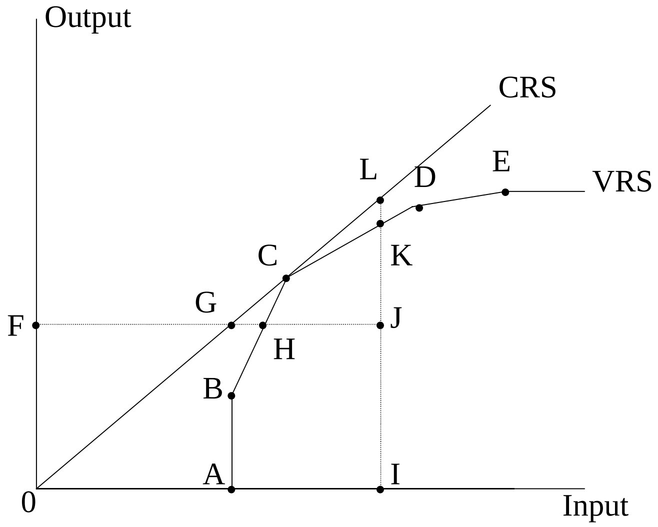
Figure 3
Piece-wise linear unit isoquant



Farrell decomposed this firm efficiency into two components, technical and allocative efficiency. The former reflects the ability of a firm to obtain maximal output from a given set of inputs. The latter reflects the ability of the firm to use the optimal combination of inputs, given their respective prices and the production technology. Combining these two measures then yields a measure of total economic efficiency. Calculation of allocative efficiency requires information on relative prices, and since this information is unavailable for the data at hand, in what follows, we will concentrate on technical efficiency.

Technical efficiency can be calculated from either the input side (input saving efficiency) or the output side (output increasing efficiency), as shown in Figure 4. Here, CRS and VRS represent two efficiency frontiers drawn under the assumptions of constant and variable returns to scale, respectively, in input-output space. Point J represents how much of a certain input firm J uses to produce output.[2] Firm J is clearly inefficient, as it is below, rather than on, the efficiency frontiers.

Figure 4
Technical efficiency measures



The input- and output-oriented technical efficiency measures can now be calculated along rays from the axis of the graph to the observed data. These radial measures are unit invariant. For the constant returns to scale technology, the ratios FG/FJ and IJ/IL will measure the input-saving and output-increasing efficiency, respectively. In the case of variable returns to scale, represented by the convex hull ABCDE, these two measures of efficiency are calculated as FH/FJ and IJ/IK, respectively. Under CRS, both input- and output-oriented measures will yield the same estimate of inefficiency, but this equality does not hold when VRS are present.

3.2 Efficiency and DEA

In economics, efficiency estimates have usually been obtained using either of two methods, DEA or stochastic frontiers. DEA is a non-parametric method while stochastic frontiers is a parametric method and consists of estimating a cost, profit or

[2] It is assumed here that just one input is used to produce one output, but a vector of inputs could just as easily be used to produce a vector of outputs.

production function where the error term is split into an efficiency component and a pure random error component.

In this paper we will use DEA to estimate efficiency and productivity of Icelandic fish processing firms. DEA is especially well suited to the data at hand, as it neither requires information on prices nor assumes any behavioural objective, such as cost minimisation or profit maximisation. Furthermore, it requires no specific functional form of the function to be estimated.

DEA does however also have its shortcomings. In particular, the method does not account for measurement errors or other noise upon the frontier. Instead, it is assumed that all deviations from the frontier are caused by technical inefficiency. The lack of a statistical basis also means that it is not possible to carry out traditional hypothesis testing when DEA is used.

Charnes, Cooper and Rhodes (1978) coined the term Data envelopment analysis (DEA) and developed an input-oriented model with CRS. The analysis consists of applying linear programming to construct a non-parametric, piece-wise frontier over the data. The efficiency measures of each firm are then calculated relative to this frontier. In this study, output-oriented rather than input-oriented measures of efficiency are computed, as it is my belief that the aim of the fish processing firms is to maximise output that can be produced from the inputs available. The firms are in no way output-constrained, and thus it does seem logical to follow this path. It may be noted that the same firms will appear inefficient regardless of which efficiency orientation is chosen. The output-oriented measure obviously corresponds to the conventional production function, where it is assumed that producers maximise output, given inputs.

This study takes the VRS model, put forward by Banker, Charnes and Cooper (1984), as a benchmark, implying that all efficiency measures will be calculated relative to a VRS frontier. The ratio of the CRS and VRS efficiency measures will then yield an estimate of the pure scale efficiency (SE), i.e.,

$$(1) \qquad SE = \frac{TE_{crs}}{TE_{vrs}} \, .$$

where TE_{crs} and TE_{vrs} denote efficiency measures relative to a constant and variable returns to scale frontier, respectively. In the input-saving case, the pure scale efficiency can be represented by FG/FH in Figure 4, while in the output-increasing case it is defined as the ratio IK/IL.

Scale inefficiency can arise from two sources. Either firms enjoying increasing returns to scale are not taking advantage of their scale economies, or the production of firms facing decreasing returns is too large. In the former case, the firms should increase their level of operation, while in the latter firms should decrease their level of operation.

To establish the nature of the scale efficiencies, it is necessary to run the third linear programming model and calculate technical efficiency relative to a non-increasing return to scale (NRS) frontier. In Figure 4, the NRS-frontier is represented by the line 0CDE. If the NRS and VRS scores are unequal, the firm in question is enjoying increasing returns to scale, while decreasing returns are experienced if the NRS and VRS scores are equal. Consequently, it is now possible to determine whether the scale inefficiency arises from failure to take advantage of increasing returns to scale, or from over-utilisation of the production process.

The measures discussed so far have dealt with the efficiency of individual firms, but measures relating to a whole industry have also been used. Farrell (1957) suggested measuring structural efficiency as the weighted sum of all individual measures, using observed output levels as weights. However, as pointed out in Forsund and Hjalmarsson (1987), this structural efficiency measure does "not have a straight-forward interpretation in terms of the objectives of the structural measures, i.e., in terms of resource saving or output increasing"[3]. Instead, Forsund and Hjalmarsson advocate that an average firm for the industry be constructed by taking a simple arithmetic mean of the amount of each input and output, and the relevant efficiency measures for that firm then computed. Here, this approach is used to construct structural measures of pure technical efficiency and pure scale efficiency.

4. Data

The data used in this study comes from the Icelandic National Economic Institute (NEI) and consists of observations on 43 firms engaged in fish processing during the period 1985-1995. However, the panel is incomplete since some firms are not observed each year. The number of observations is consequently only 404. Most of

[3] Forsund and Hjalmarsson (1987), p. 94.

these firms, especially the larger ones, also operate their own boats or own shares in other fishing companies.

The data is taken from the tax records of the firms and all variables, both inputs and outputs, are therefore measured in millions of Icelandic kronur. Four inputs are used in the analyses; material costs, wages, fuels costs and capital costs, but the revenue from the sales of the different products is lumped together into one output variable. It may, however, be useful to distinguish between three types of output; frozen products, salted and dried products and fish meal and fish oil. Of the 404 observations in the sample, 298 are on firms producing frozen products, 246 on firms producing salted and dried products and 78 on firms producing fish meal and fish oil. In all, 239 observations are on firms producing just a single product group; in 112 cases firms produced two product groups, while only 53 observations are on firms that produced all possible outputs. Specialisation was therefore more common than producing the whole range of possible outputs.

Materials include expenditures on fish and ammonia, salt and sugar, and other materials used directly in the production process, as well as packaging expenditures.

Labour costs are the sum of all payments to production workers and administrative employees, employers' contributions and payroll taxes.

Fuel and heating costs include all expenditures on oil and other fuels, electricity and heating.

The tax records also contain information on the value of the capital stock each year. However, as noted in Agnarsson (2000), these capital stock series are very volatile and yielded very unsatisfactory results when parametric methods were used to estimate productivity. Using the perpetual inventory method, new capital stock series were therefore constructed for each firm. Specifically, the capital stock is measured as

$$K_t = K_{t-1}(1+b_t)(1-\partial) + I_t \qquad (2)$$

where K_t and I_t represent the capital stock and investment, respectively, in year t, b_t is the rate of inflation per year, as measured by change in the building construction index, and δ is the depreciation rate, here 12% for machines and equipment and 4% for buildings. The depreciation rate chosen corresponds to the rate allowed for by the tax authorities.

All variables used are deflated to 1990 prices using the consumer price index (materials and fuels), building construction index (capital), wage index and an index for the price of exports (output).

Table 2
Descriptive statistics. Revenue and inputs in millions of Icelandic kronur. Number of observations is 404

	Mean	Std. dev.	Minimum	Maximum
Revenue	478.2	408.8	4.1	1954.0
Inputs:				
Materials	239.1	225.6	1.8	1097.8
Capital	126.0	168.2	1.4	1380.1
Wages	87.4	83.2	0.9	463.1
Fuel and heating costs	11.2	16.7	0.1	101.4

The firms vary a great deal in size, as is clearly revealed in Table 2. Thus, although average revenue amounted to 478 million kronur, the revenue of the smallest firm was only 4 million kronur, but sales of the largest firm were 1,954 million kronur. Materials are by far the largest inputs, averaging almost 240 million kronur, while average imputed capital costs and wages are 126 and 87 million kronur, respectively. Expenditures on fuels and electricity are quite small by comparison, only amounting to 11 million kronur on average.

As shown in Table 1 above, the Icelandic fish processing industry was composed of 514 firms in 1989, most of which were small. The sample used here therefore only includes a small proportion of the total number of firms. However, the sample includes a disproportionate number of large firms. Thus, combined sales of the firms in the sample amounted to 30-37% of sales of the industry as a whole each year.

5. Development of efficiency

As discussed above, the efficiency measures obtained using DEA make it possible to distinguish between pure technical efficiency (TE) and pure scale efficiency (SE) of each firm by calculating efficiency under the assumptions of constant and variable returns to scale and determine if the firms in question are enjoying increasing, constant or decreasing returns. In this section, we will also analyse the determinants of efficiency. Lastly, the structural efficiency of the whole industry will be calculated.

Figure 5
Technical efficiency of firms with average of less than 150 million kronor

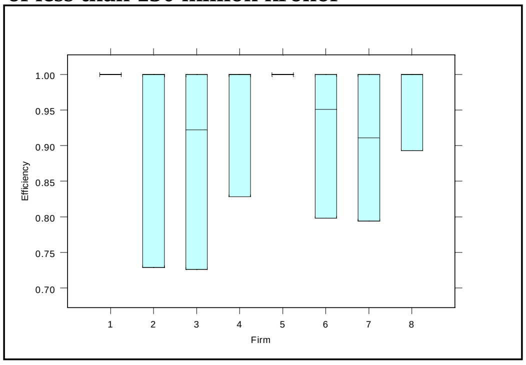


Figure 6
Technical efficiency of firms with average sales sales of 150–300 million kronor

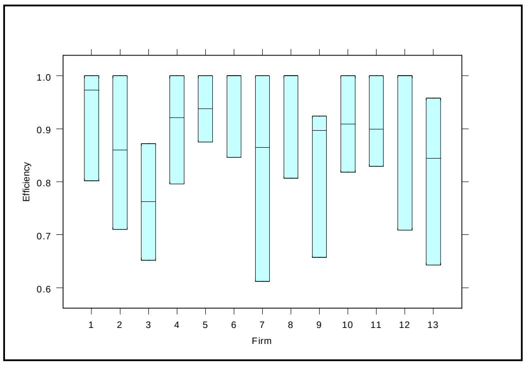


Figure 7
Technical efficiency of firms with average of 300–600 million kronor

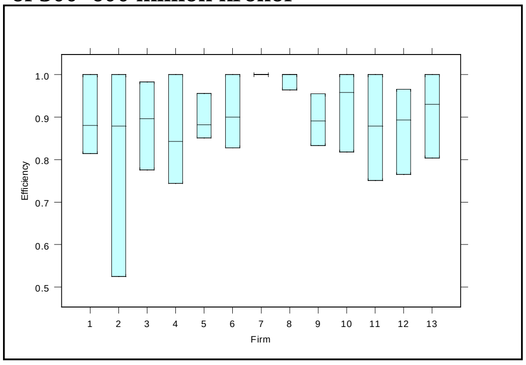
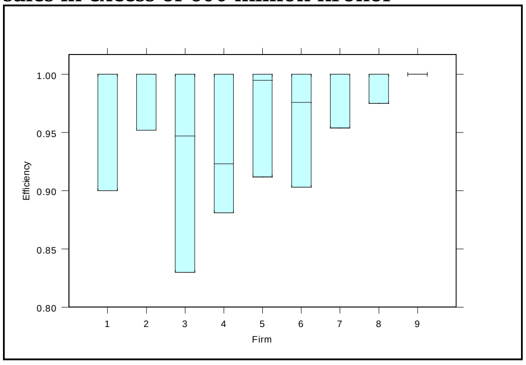


Figure 8
Technical efficiency of firms with average sales sales in excess of 600 million kronor



In Figures 5-8 the technical efficiency distribution of each firm is analysed (see also Table A1 in Appendix). Firms are classified into four categories according to average annual sales; less than 150 million kronur, between 150 and 300 million kronur, between 300 and 600 million kronur and greater than 600 million kronur. The width of each box shows the efficiency distribution with the horizontal line inside the box representing the median. A value of 1.0 indicates the firm is on the frontier, while a value of less than unity indicates the presence of inefficiency. A single horizontal line implies that the measured efficiency of the firm was always the same. In Figure 5, firms 1 and 5 were always found to be on the frontier, and their efficiency distribution is therefore a single horizontal line. Firm 7 in the 300-600 million kronur category and firm 9 in the greater than 600 million kronur categories were also always fully efficient. The efficiency of the other firms varies considerably, but most of the firms are estimated to be on the frontier at least once.

Figure 9
Scale efficiency of firms with average sales less than 150 million kronor

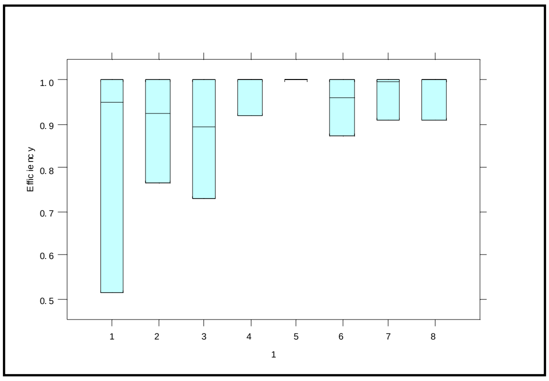


Figure 10
Scale efficiency of firms with average sales of 150–300 million kronor

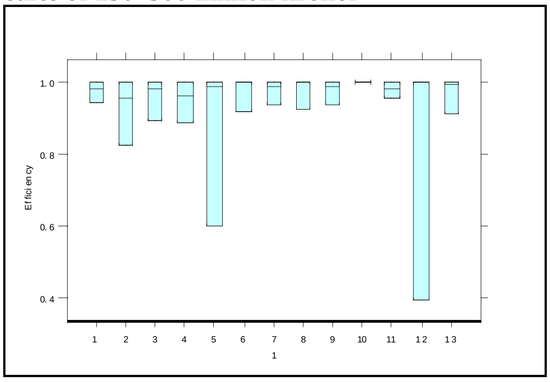


Figure 11
Scale efficiency of firms with average sales of 300–600 million kronor

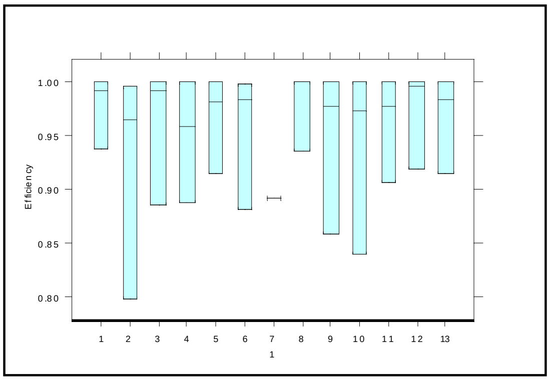
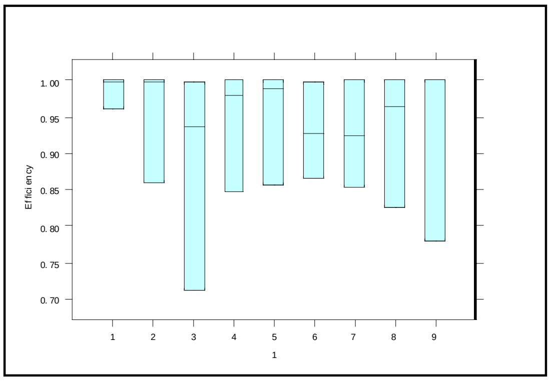


Figure 12
Scale efficiency of firms with average sales in excess of 600 million kronor



The distribution of scale efficiency is shown in Figures 9-12 (see also Table A2 in Appendix). As before, the firms are classified into four groups. Here, only two firms are always on the frontier; firm 5 in group 1 and firm 10 in group 2. Two observations emerge from comparing Figures 5-8 and 9-12. First, on average, the measured scale efficiency of each firm appears to vary less than the corresponding technical efficiency. Second, whereas technical efficiency appears to increase with firm size, the converse seems to hold true for scale efficiency. The relationship between efficiency and firm size is analysed further in Figures A1-A22 in Appendix.

The minimum estimated technical and scale efficiency each year is shown in Table 3. The former is lowest in 1995, 0.525, which indicates that the firm in question could have almost doubled its production that year without using more inputs. The lowest individual scale efficiency is observed in 1989, 0.397. That firm could therefore increase production by 150% by taking better advantage of its scale characteristic.

Table 3
Minimum technical (TE) and scale (SE) efficiency each year

	TE	SE
1985	0.726	0.906
1986	0.678	0.744
1987	0.776	0.839
1988	0.720	0.891
1989	0.794	0.397
1990	0.730	0.877
1991	0.709	0.824
1992	0.829	0.884
1993	0.737	0.892
1994	0.745	0.703
1995	0.525	0.517

The number of firms on and below the frontier each year is shown in Table 4. The number of firms found to be fully technically efficient varies between 7 and 21. It is worth noting that more firms were found to be fully efficient in 1991 than below the frontier, but the number of technically inefficient firms exceeds the number of fully efficient firms during all other years. Relatively fewer firms are estimated to be fully scale efficient, and the number of firms on the frontier never exceeds the number of firms below it. Table A5 in the Appendix records the number of times each firm is on and below the frontier.

Table 4
Number of firms on and below the frontier each year

	Technical efficiency		Scale efficiency	
Year	On frontier	Below frontier	On frontier	Below frontier
1985	13	27	10	30
1986	14	22	8	28
1987	15	23	9	29
1988	7	25	5	27
1989	15	21	8	28
1990	12	26	11	27
1991	21	17	11	27
1992	16	21	13	24
1993	17	18	12	23
1994	14	21	8	27
1995	15	24	5	34

As shown in Table 5, most of the fish processing firms in the sample appear to have been experiencing decreasing returns to scale during the period under observation. On average, 18 firms had decreasing returns, while 9 had constant returns and 9 increasing returns to scale. No obvious trend is apparent from Table 5, but the number of firms in each scale category appears to vary substantially between years. This is though to be expected, as the DEA applied measures the relative performance of the firms each year, but not across periods.

Table 5
Scale characteristics of Icelandic fish processing firms 1985-1995; decreasing (DRS), constant (CRS) and increasing (IRS) returns to scale

	DRS	CRS	IRS
1985	25	10	5
1986	20	8	8
1987	14	9	15
1988	12	5	15
1989	20	8	8
1990	14	12	12
1991	23	11	4
1992	12	13	12
1993	20	12	3
1994	11	8	16
1995	30	5	4
Mean	18	9	9

To further understand the determinants of technical and scale efficiencies, parametric methods were employed. In particular, Tobit regressions were estimated where the dependent variable is defined as one minus the efficiency score of each firm. This truncated variable equals zero if the firm is fully efficient, but takes on a positive value if the firm is inefficient.

The following variables were used to explain the different efficiency of individual firms; volume of sales, capital-labour ratio, diversity of operation, fish meal and fish oil production variable, location variables and trend variables.

The sales variable is simply the annual revenue of each firm normalised by the mean of sales.

The capital-labour ratio is the ratio of the imputed capital costs and observed wages. Both variables were normalised by their respective means.

The diversity variable indicates the number of different outputs each firm produced. Total sales were divided into revenue from sales of frozen products, salted and dried products and fish meal and fish oil. The variable equals one if the firm in question only produced one type of output, two if two output types were produced and three if the firm produced the whole range of possible outputs.

The fish meal and fish oil dummy takes a value of unity if the firm in question was engaged in the production of these outputs and zero otherwise. The motivation behind the use of this variable is the fact that the technology used in the production of fish meal and fish oil is radically different from that used for producing frozen and salted and dried products.

Three dummy variables were used to take account of the geographical location of each firm; land1 denotes that the firm was located in Southwest Iceland; land2 that the firm was located in the Northwest, and land3 denotes the firm was located in the North or East of the country.

Finally, linear and quadratic trend variables were added to allow for inter-temporal changes in efficiency.

Results from estimating Tobit regressions for both technical and scale efficiency are reported in Table A4 in the Appendix, while the marginal effects are given in Table 6. Turning first to the technical efficiency equation, we find that all the parameters but one are significant at the 5% level or better. The parameter associated with the capital-labour ratio is the only one not significant. Technical inefficiency decreases with size, indicating that large firms are more likely to be efficient than smaller ones. Rather surprisingly we find that diversity has a negative effect on efficiency, but firms that are engaged in the production of fish meal and fish oil appear to be more efficient than others. The parameter estimates of these three variables, size, diversity dummy and fish meal and fish oil dummy, would seem to yield conflicting results, as the larger firms are more likely to produce various outputs. The results are, however, consistent with the idea that large, specialised firms are more technically efficient than more diversified firms.

Firms in the South and West of Iceland are found to be less efficient than firms in other parts of the country. One possible explanation could be that many of the firms producing fish meal and fish oil products are located in eastern Iceland and, as discussed above, these firms were generally found to be more efficient than other firms.

Table 6
Tobit regressions, marginal effects

	Technical inefficiency		Scale inefficiency	
Variable	Parameter estimate	t-statistic	Parameter estimate	t-statistic
Constant	0.0458	2.183	0.0234	1.643
Sales	-0.0414	-8.516	-0.0036	-1.197
Capital/labour	-0.0006	-1.270	0.0003	2.086
Diversity	0.0276	3.479	0.0118	1.808
Fish meal and fish oil	-0.0352	-2.984	-0.0142	-1.457
South Iceland	0.0229	2.555	-0.0282	-0.438
West Iceland	0.0264	2.572	-0.0133	-1.531
Time	-0.0130	-2.529	-0.0120	-3.313
Time squared	0.0010	2.639	0.0012	4.217

The results also indicate that technical efficiency has been changing over time. The linear trend is negative, while the quadratic one is positive, indicating that efficiency has been deteriorating during the sample period. As observed earlier, the economic environment of the fishing and fish processing industry changed dramatically during this period. Inflation was much lower in the 1990s than in the previous decade, and the exchange rate policy took much less notice of the needs of the fish export sector than before. At the same time, direct support to the fishing and fish processing industry, inexpensive loans or grants, was less than in the 1970s and 1980s. Bank loans carried small or even negative real interest rates until the late 1980s when financial institutions were finally allowed to determine their own interest rates. Capital costs were therefore considerably higher in the 1990s than in earlier decades. These effects are all captured in the time trend variables, but the effect of each of these changes can unfortunately not be separated. A priori there is however little reason to believe that all firms were affected equally by these changes. Further analysis is unfortunately beyond the scope of this study.

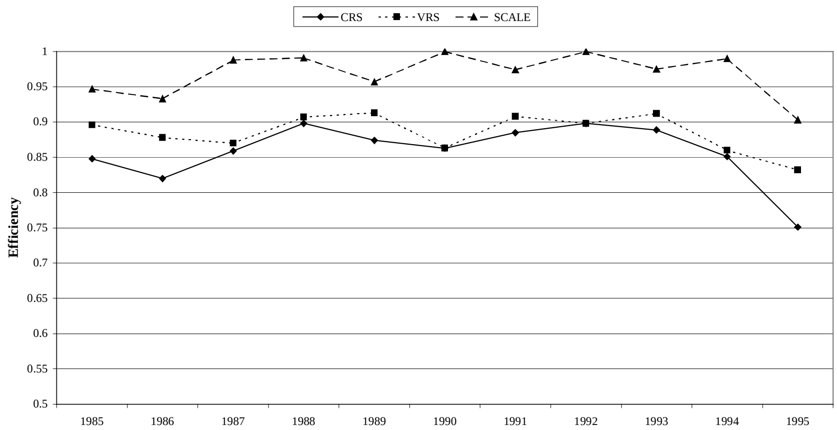
Finally, we note in passing that although the capital/labour parameter is only significant at a low level, it is negative, indicating that firms with a high K/L ratio are more likely to be efficient. This is well congruent with our earlier statement that large firms are more efficient than small ones.

The scale efficiency regression parameters are not as precisely estimated as in the previous regression with only four of them significant at reasonable levels. As before, both time variables are significant and tell a similar story of increasing inefficiency over time. The capital/labour variable has a small but significant positive effect on scale inefficiency, but the effect of the diversity variable is much stronger. None of the other variables is significant, but there are signs that firms in western Iceland are more scale-efficient than others. Firms producing fish meal and fish oil are also likely to be less scale-inefficient than others.

These results indicate that capital-intensive firms producing a variety of outputs do not take full advantage of the their existing scale economies. These findings also support the view that Icelandic fish processing firms are over-capitalised, and that production capacity is far higher than needed.

As mentioned in section 3, it is possible to estimate structural efficiencies for the fish processing industry as a whole by constructing an average firm and calculating the various efficiency measures for that firm each year. Here, three such measures are calculated: technical efficiency, relative to both CRS and VRS technologies, and scale efficiency. The development of the structural efficiencies is traced in Figure 13.

Figure 13
Structural efficiency in the Icelandic fish processing industry 1985-1995



All three measures reveal that structural efficiency remained almost constant for most of the observation period before falling considerably in the last two years, 1994 and 1995. In view of the drastic changes that have taken place in the economic surroundings of these firms, these results are quite remarkable. Among other things, they imply that efficiency in the Icelandic fish processing industry has not improved since inflation was brought down to acceptable levels. The results also indicate that the initial effect on efficiency of liberalising fish prices in 1987 was small.

A possible explanation for the decline in efficiency the end of the period could be the fall in cod catches in 1994 and 1995. Cod is by far the most important species harvested in Icelandic waters, and in the 1993/94 season the total catch was only 196 thousand tons, as opposed to 240 thousand the previous season. The cod catch declined even further the next season, falling to 164 thousand tons, and remained nearly the same during the 1995/96 season, or 169 thousand tons. This shortage of raw materials for the fish processing firms results in a lower production volume, which could show up as decreased overall efficiency as the fixed capital costs are quite high and do not fall correspondingly when the availability of raw material diminishes.

One way of visualising these losses is to translate the inefficiencies into value terms. This can either be done for the industry as a whole, using the above-calculated structural efficiency measures, or by using the efficiency measures derived for each firm. In the latter case, total losses, TL_t, due to efficiency in year *t* are calculated as

$$(3) \qquad TL_t = \sum_{i=1}^{I}(1-TE_{ti})R_{ti} + \sum_{i=1}^{I}(1-SE_{ti})R_{ti}$$

where TE_{ti} and SE_{ti} denote technical and structural efficiency of firm *i* at time *t* and R_{ti} revenue of firm *i* at time *t*.

In Table 7, estimated total losses due to efficiency are reported in millions of Icelandic kronur, as well as a percentage of total revenue. On average, technical inefficiency amounted to 5% of total revenue, while average scale efficiency amounted to 4%. Together, these two inefficiency sources thus reduced revenue by 9%. The total efficiency loss for the whole period 1985-1997 equalled 17.7 billion Icelandic kronur in constant 1990 prices, with 9.7 billion stemming from technical inefficiency and 8.0 billion from scale inefficiency. By comparison, the total sales for the whole fish processing industry amounted to almost 50 billion kronur in 1990. The inefficiency losses thus represent just over one-third of that year’s revenue.

Table 7
Revenue losses due to pure technical inefficiency and scale inefficiency in the Icelandic fish processing industry 1985-1995

	Technical inefficiency		Scale inefficiency		Sum	
	Revenue losses in millions of ISK	Revenue losses as % of total revenue	Revenue losses in millions of ISK	Revenue losses as % of total revenue	Revenue losses in millions of ISK	Revenue losses as % of total revenue
1985	900	5.67	393	2.47	1293	8.14
1986	892	5.16	1 177	6.80	2069	11.95
1987	1403	7.57	562	3.04	1965	10.61
1988	913	5.21	242	1.38	1155	6.59
1989	727	4.05	712	3.96	1439	8.01
1990	840	5.28	339	2.13	1179	7.41
1991	418	2.81	568	3.82	986	6.63
1992	589	3.35	292	1.66	880	5.01
1993	668	3.58	375	2.01	1042	5.58
1994	934	4.91	894	4.70	1828	9.61
1995	1428	7.15	2416	12.10	3844	19.26
Total	9712		7969		17681	
Mean	883	4.98	724	4.01	1607	8.98

6. Conclusions

In this paper we estimated technical and scale efficiency of Icelandic fish processing firms and calculated structural measures of efficiency for the industry as a whole. For this purpose, DEA was applied, and Tobit regressions were then used to analyse the determinants of efficiency at firm level.

Technical efficiency is positively related to firm size, and firms producing fish meal and fish oil appear to be more efficient than others. Diversity of operation, i.e., whether the firms produce more than one of the following product groups; frozen products, salted and dried products, and fish meal and fish oil, hampers efficiency. Furthermore, capital intensity encourages efficiency. The message from this is quite clear: In order to achieve maximum efficiency, firms should be large and produce few outputs, rather than indulge in the production of many, different goods. Firms in South and West Iceland are less efficient than their counterparts in the North and East. This rather strange result is probably due to the geographical distribution of the fish meal and fish oil producing firms. In our sample, most of these firms are located in North and East Iceland, and, as mentioned earlier, these firms are generally found to be more efficient than others. Finally, technical efficiency has been decreasing over time.

The results for scale efficiency are not as statistically significant. Still, we find that inefficiency is a positive function of both the capital-labour ratio and output diversity, as well as a positive function of time. These results indicate that capital-intensive firms are unable to take full advantage of their existing scale economies, and that the firms' capacity is larger than needed.

Structural technical and scale efficiency fell in 1994 and 1995 after remaining fairly stable for the other periods, and this fall can probably be attributed mainly to falling cod catches. Changes in the economic environment of firms between the 1980s and 1990s, e.g., lower inflation, the establishment of domestic auction markets for fish, and less direct and indirect government aid, do not appear to have affected structural efficiency, although they may have affected the efficiency of individual firms.

The analysis conducted in this study shows that there is ample scope for firms in the fish processing industry to improve their efficiency, and that the rewards for doing so are quite high. In all, it is estimated that the total revenue loss during the period 1985-1995 amounted to almost 18 billion Icelandic kronur, just over one-third of total sales of the industry in 1990. Policies aimed at improving the economic performance of the industry should therefore pay special attention to increasing the efficiency of firms that are farthest away from the production frontier.

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Appendix

Table A1
Ranking of firms according to their level of technical inefficiency. The most inefficient firm is denoted by 1 etc., while F indicates the firm was on the frontier. na denotes missing observation

Firm	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1	4	1	2	5	5	2	3	1	1	na	4
2	F	na	na	na	na	F	F	na	F	F	F
3	F	F	F	na	F	6	F	F	F	11	23
4	14	20	15	1	F	5	15	11	4	2	1
5	6	5	5	13	1	na	F	F	F	na	F
6	F	F	F	F	F	na	na	na	na	na	F
7	F	17	F	22	4	19	F	18	12	5	13
8	16	19	14	16	8	21	7	9	6	9	14
9	na	na	na	na	na	na	na	na	na	na	F
10	10	23	9	na	6	16	17	13	F	16	12
11	F	7	6	4	F	8	F	14	16	12	6
12	11	na	F	na	na	1	2	6	2	F	19
13	na	na	na	na	na	na	na	na	na	F	10
14	F	F	22	F	F	F	F	21	14	F	na
15	22	F	17	23	13	24	F	17	F	F	F
16	F	F	F	F	F	23	F	F	F	F	F
17	12	21	12	17	9	7	F	F	18	18	F
18	25	na	F	na	na	9	F	F	F	F	F
19	27	22	18	18	19	F	F	F	13	7	11
20	7	10	7	2	12	22	4	4	5	na	3
21	24	12	F	24	2	F	F	19	10	13	na
22	F	F	F	F	F	25	F	F	F	F	24
23	2	F	na	na	na	F	F	na	na	na	na
24	1	F	F	na	F	3	12	F	3	3	22
25	na	na	na	na	F	15	na	2	7	19	15
26	19	F	16	12	16	13	F	F	17	17	21
27	15	na	10	3	15	18	8	5	na	10	17
28	13	8	20	10	10	12	5	12	na	15	5
29	8	11	11	25	11	F	F	F	8	6	16
30	26	15	3	11	14	F	9	20	F	21	18
31	18	9	1	9	18	17	16	8	15	8	9
32	F	F	F	F	F	F	14	F	F	F	F
33	3	2	8	6	3	4	6	7	F	14	7
34	F	F	F	F	F	F	1	F	na	na	F
35	21	6	13	na	17	11	11	16	11	4	8
36	9	F	4	14	20	F	F	F	F	20	F
37	F	F	F	F	F	F	F	F	F	F	F
38	F	14	21	15	F	na	na	na	na	na	na
39	23	F	F	21	21	20	F	F	F	F	F
40	5	4	23	7	F	10	13	3	9	1	2
41	20	3	F	19	7	14	10	10	F	F	20
42	17	18	19	20	F	26	F	15	F	F	F
43	F	16	F	8	na	F	F	F	F	F	F

Table A2
Ranking of firms according to their level of scale inefficiency each year. The most inefficient firm is denoted by 1, etc., while F indicates the firm was on the frontier. na denotes a missing observation

Firm	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
1	16	27	11	1	15	9	24	9	19	na	32
2	F	na	na	na	na	F	18	na	4	1	1
3	F	F	F	na	F	24	F	F	F	7	29
4	4	7	23	21	4	4	2	18	22	13	31
5	20	14	27	2	19	na	F	F	F	na	F
6	F	F	F	F	F	na	na	na	na	na	F
7	23	9	F	3	16	13	8	5	9	15	10
8	10	13	28	24	27	23	14	11	2	22	5
9	na	na	na	na	na	na	na	na	na	na	15
10	14	18	21	na	20	20	17	20	8	21	12
11	28	17	24	25	F	5	9	4	14	24	17
12	12	na	1	na	na	F	1	6	12	F	27
13	na	na	na	na	na	na	na	na	na	F	34
14	F	F	18	F	F	F	15	12	20	12	na
15	26	8	15	27	7	2	4	2	11	25	9
16	F	F	F	F	F	17	F	F	21	F	23
17	7	5	6	26	9	12	5	3	1	2	2
18	2	na	F	na	na	10	F	F	F	F	F
19	1	3	10	22	11	F	16	F	6	18	11
20	29	22	20	23	17	16	26	15	3	na	22
21	11	19	F	13	21	F	F	8	7	14	na
22	17	11	4	11	10	7	13	10	F	3	4
23	15	2	na	na	na	1	F	na	na	na	na
24	27	1	2	na	3	F	23	1	10	5	14
25	na	na	na	na	12	21	na	14	17	16	28
26	21	4	29	17	14	8	10	F	18	11	6
27	8	na	14	10	22	26	12	13	na	20	19
28	6	20	25	19	24	19	19	16	na	10	25
29	30	24	16	8	28	F	F	F	16	17	24
30	18	15	26	20	8	F	21	23	F	8	20
31	13	28	19	16	25	15	20	19	5	26	13
32	F	6	3	18	6	3	7	F	F	4	16
33	3	12	12	7	13	11	3	7	F	6	18
34	F	F	F	F	1	F	25	F	na	na	33
35	25	21	22	na	23	22	27	21	23	23	21
36	5	F	5	12	18	F	22	F	F	27	F
37	F	F	F	F	F	F	F	F	F	F	3
38	F	25	13	4	2	na	na	na	na	na	na
39	F	F	17	9	26	27	F	F	15	F	8
40	24	16	7	5	F	25	11	24	13	19	30
41	9	23	9	6	5	6	6	17	F	F	26
42	22	26	8	14	F	14	F	22	F	9	7
43	19	10	F	15	na	18	F	F	F	F	F

Figure A1
Technical efficiency and revenue of Icelandic fish processing firms in 1985

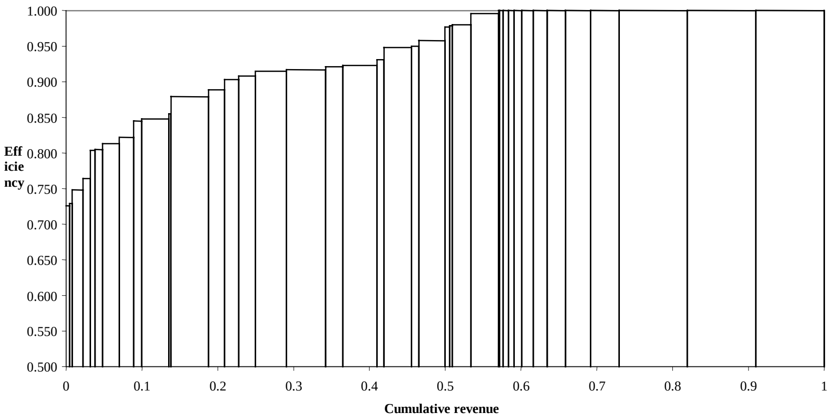

Figure A2
Technical efficiency and revenue of Icelandic fish processing firms in 1986

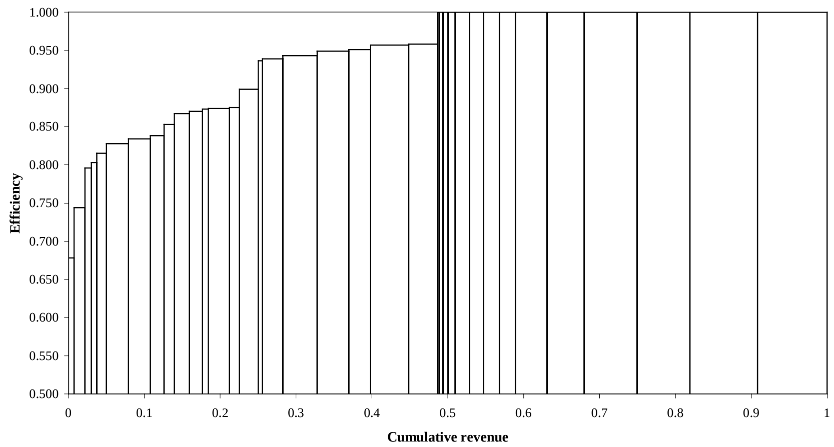

Figure A3
Technical efficiency and revenue of Icelandic fish processing firms in 1987

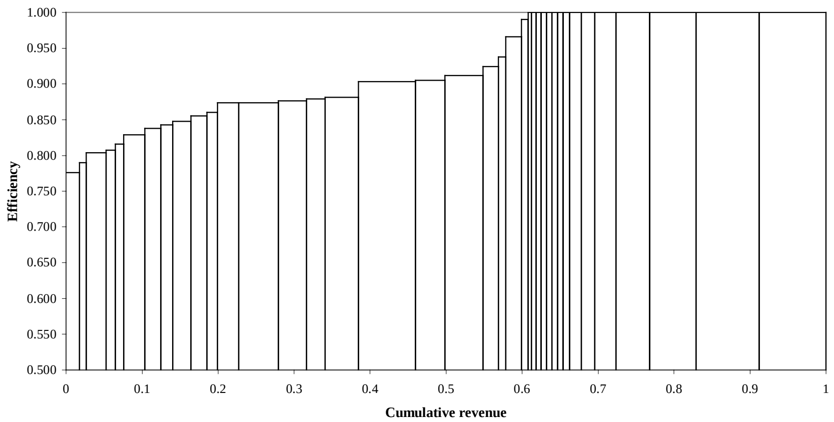

Figure A4
Technical efficiency and revenue of Icelandic fish processing firms in 1988

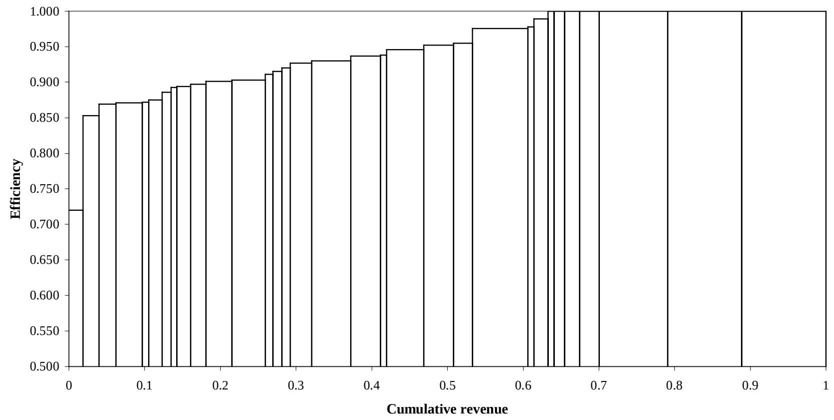

Figure A5
Technical efficiency and revenue in Icelandic fish processing firms in 1989

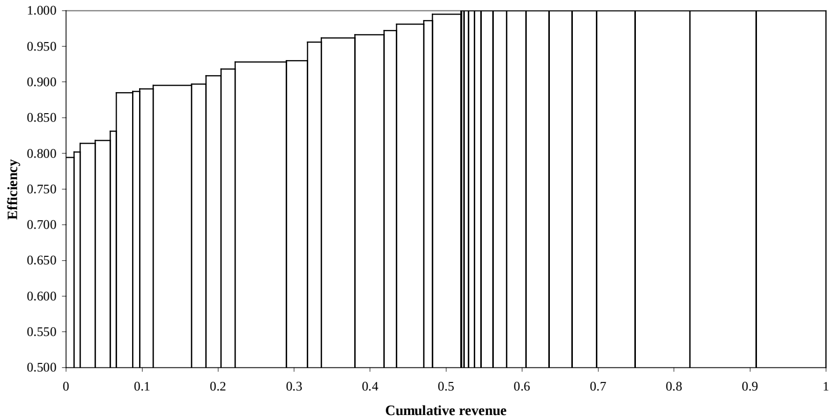

Figure A6
Technical efficiency and revenue in Icelandic fish processing firms in 1990

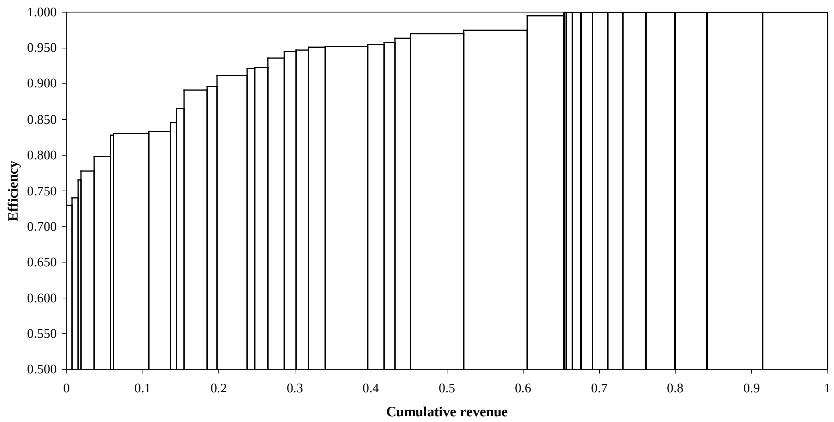

Figure A7
Technical efficiency and revenue in Icelandic fish processing firms in 1991

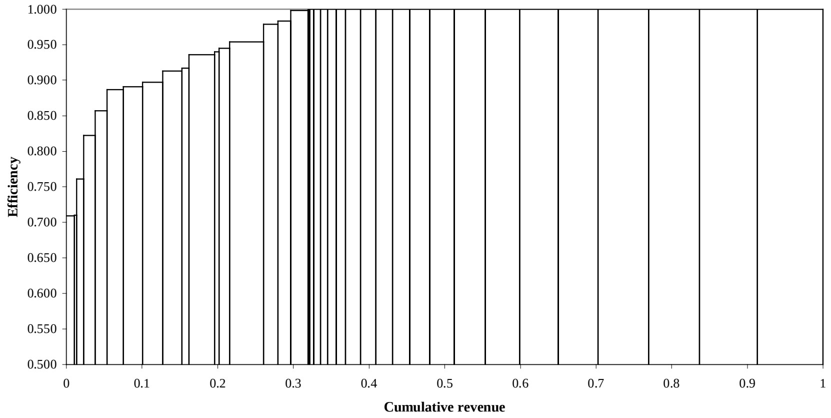

Figure A8
Technical efficiency and revenue in Icelandic fish processing firms in 1992

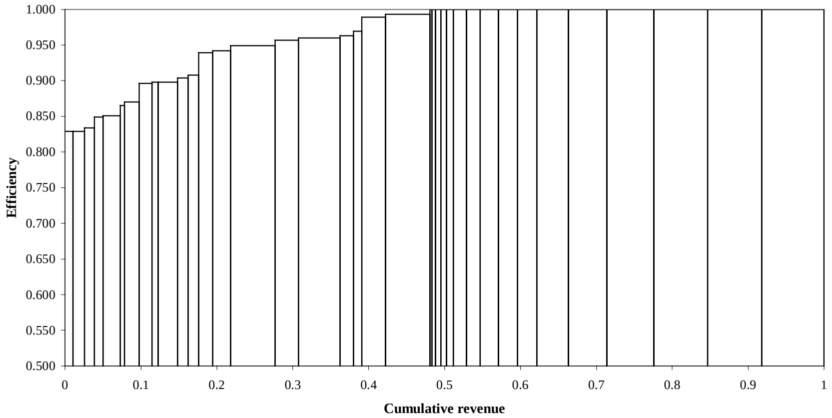

Figure A9
Technical efficiency and revenue in Icelandic fish processing firms in 1993

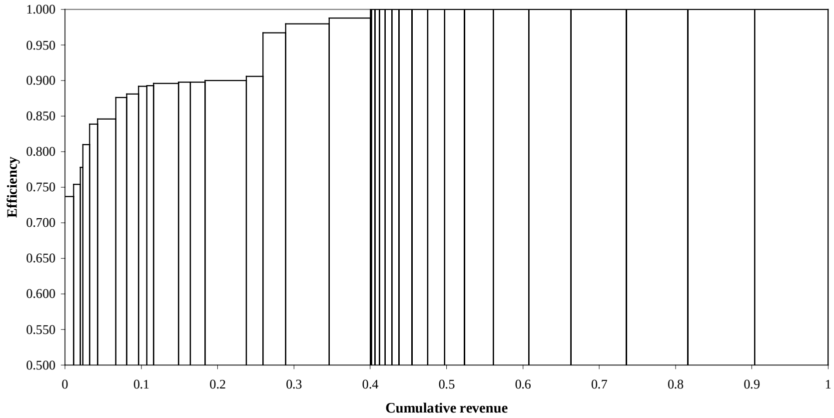

Figure A10
Technical efficiency and revenue in Icelandic fish processing firms in 1994

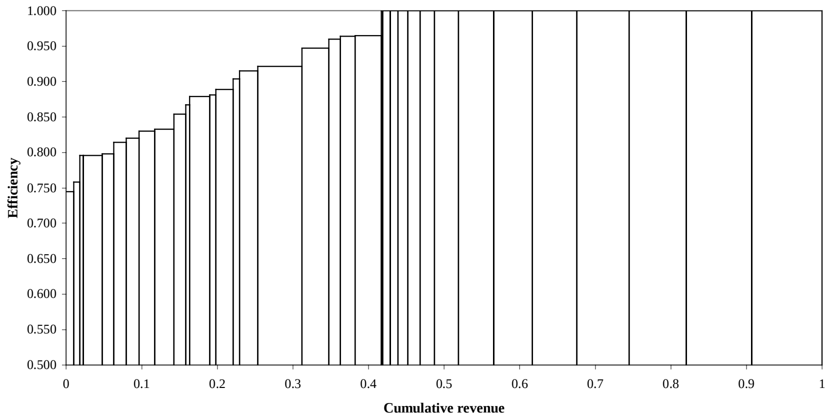

Figure A11
Technical efficiency and revenue in Icelandic fish processing firms in 1995

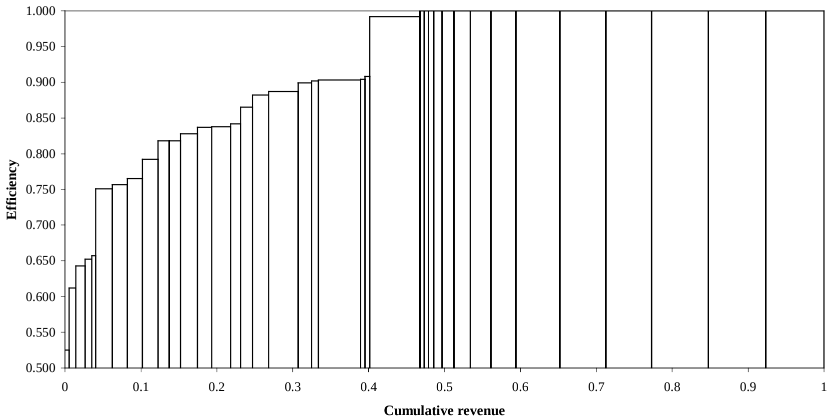

Figure A12
Scale efficiency and revenue of Icelandic fish processing firms in 1985

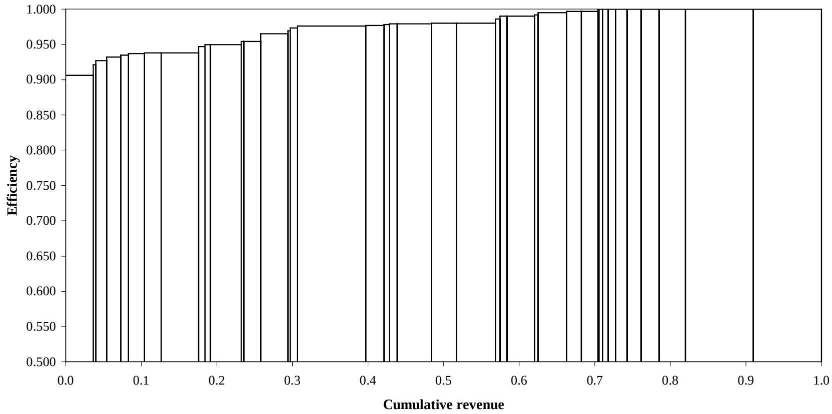

Figure A13
Scale efficiency and revenue of Icelandic fish processing firms in 1986

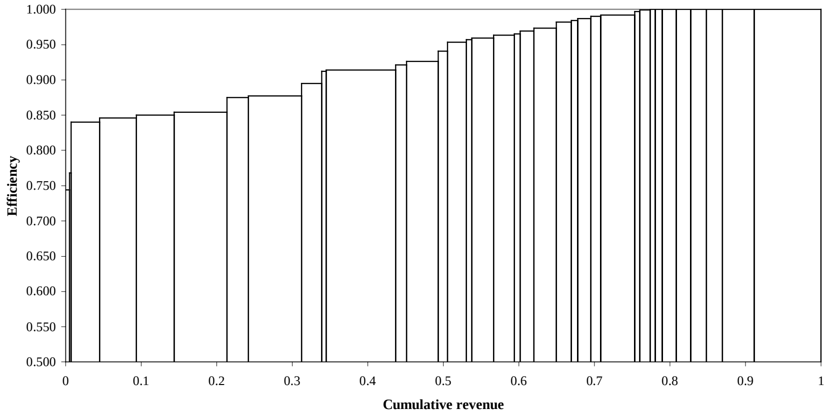

Figure A14
Scale efficiency and revenue of Icelandic fish processing firms in 1987

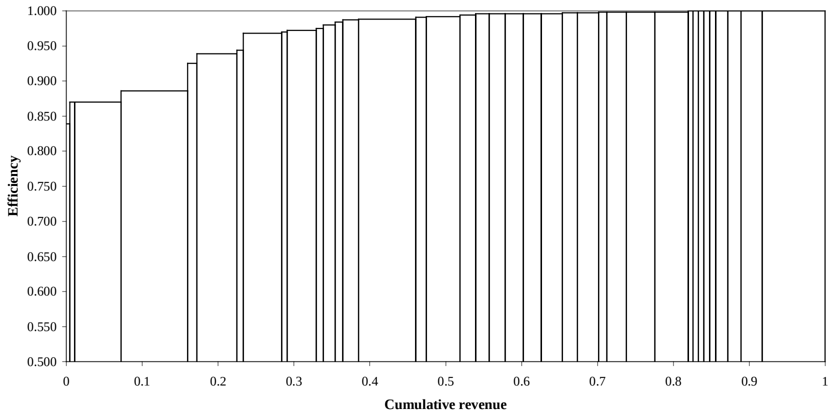

Figure A15
Scale efficiency and revenue of Icelandic firms in 1988

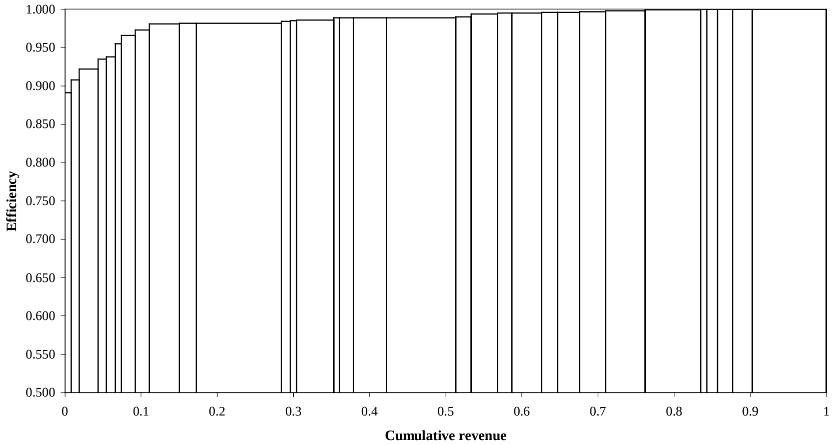

Figure A16
Scale efficiency and revenue of Icelandic firms in 1989

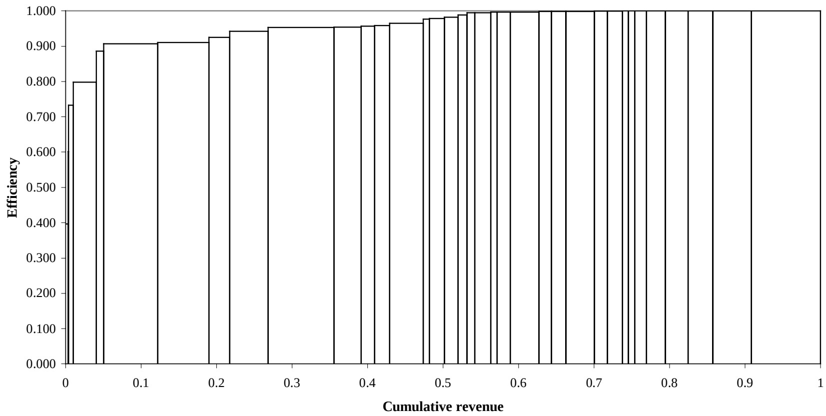

Figure A17
Scale efficiency and revenue of Icelandic fish processing firms in 1990

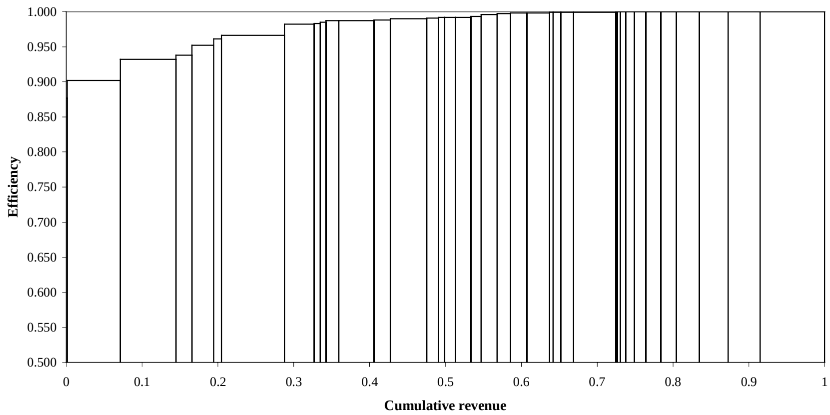

Figure A18
Scale efficiency and revenue of Icelandic fish processing firms in 1991

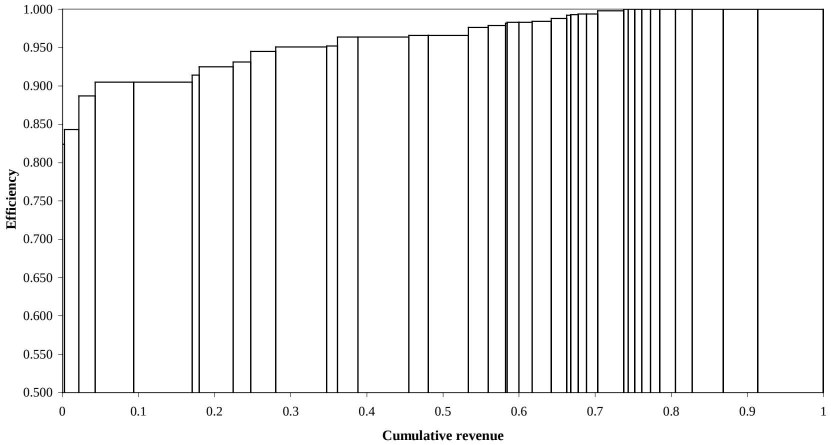

Figure A19
Scale efficiency and revenue of Icelandic fish processing firms in 1992

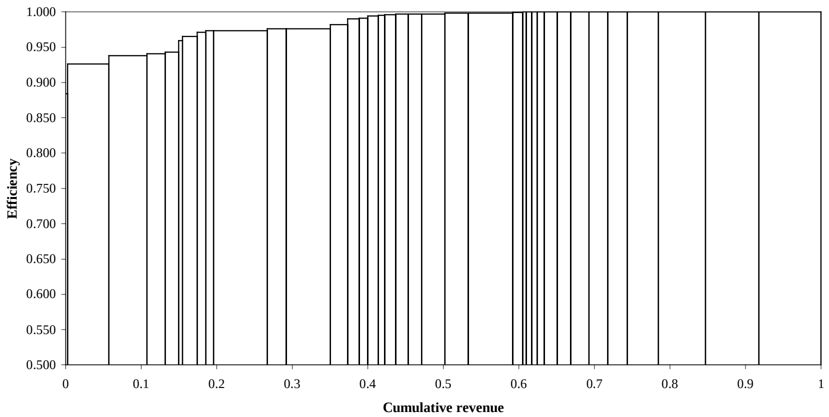

Figure A20
Scale efficiency and revenue of Icelandic fish processing firms in 1993

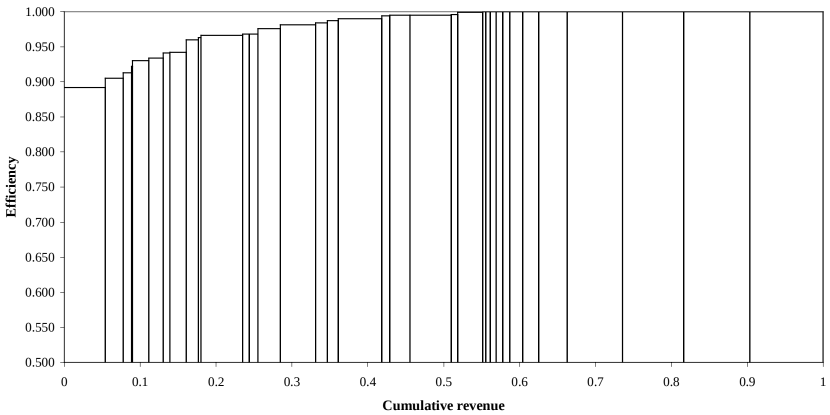

Figure A21
Scale efficiency and revenue of Icelandic fish processing firms in 1994

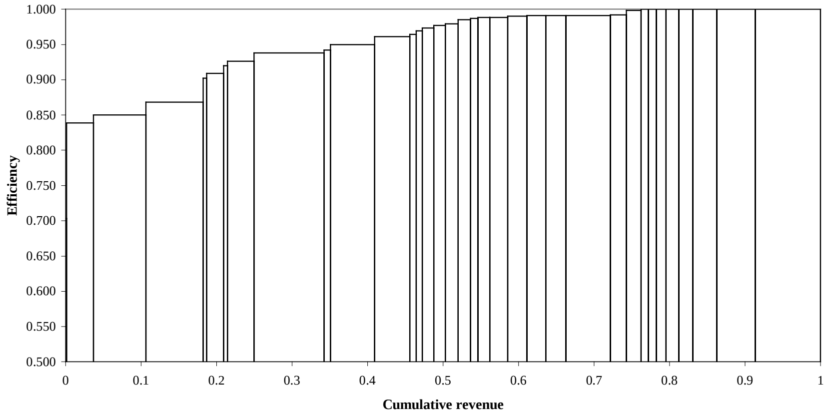

Figure A22
Scale efficiency and revenue of Icelandic fish processing firms in 1995

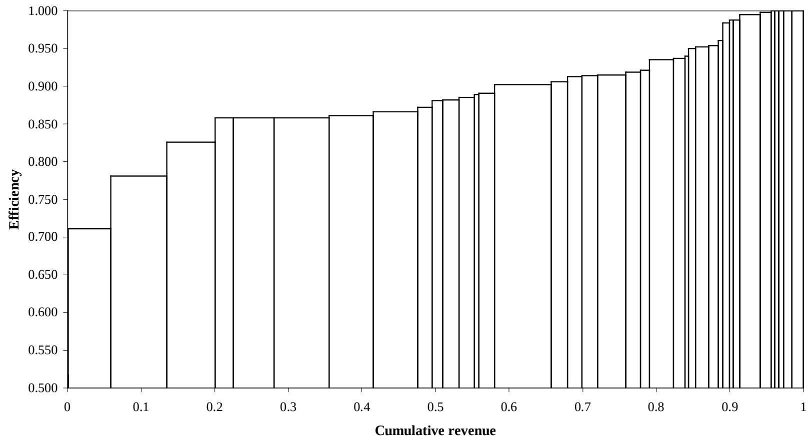

Table A3
Number of years each firm is on and below the production frontier

	Technical efficiency		Scale efficiency	
Firm	On frontier	Below frontier	On frontier	Below frontier
1	0	10	0	10
2	6	0	2	4
3	7	3	7	3
4	1	10	0	11
5	4	5	4	5
6	6	0	6	0
7	3	8	1	10
8	0	11	0	11
9	1	0	0	1
10	1	9	0	10
11	3	8	1	10
12	2	6	2	6
13	1	1	1	1
14	7	3	5	5
15	5	6	0	11
16	10	1	8	3
17	3	8	0	11
18	6	2	6	2
19	3	8	2	9
20	0	10	0	10
21	3	7	3	7
22	9	2	1	10
23	3	1	1	3
24	4	6	1	9
25	1	5	0	6
26	3	8	1	10
27	0	9	0	9
28	0	10	0	10
29	3	8	3	8
30	2	9	2	9
31	0	11	0	11
32	10	1	3	8
33	1	10	1	10
34	8	1	6	3
35	0	10	0	10
36	6	5	5	6
37	11	0	10	1
38	2	3	1	4
39	7	4	5	6
40	1	10	1	10
41	3	8	2	9
42	5	6	3	8
43	8	2	6	4
Sum	159	245	100	304

Table A4
Results from the Tobit efficiency regressions. Number of observations is 404

	Technical efficiency		Scale efficiency	
Variable	Parameter estimate	t-statistic	Parameter estimate	t-statistic
Constant	0.0667	2.235	0.0365	1.674
Sales	-0.0489	-6.166	-0.0006	-0.116
Capital/labour	-0.0009	-1.188	0.0005	2.063
Diversity	0.0403	3.424	0.0184	1.816
Fish meal and fish oil	-0.0513	-2.958	-0.0221	-1.457
South Iceland	0.0333	2.545	-0.0044	-0.438
West Iceland	0.0384	2.539	-0.0208	-1.517
Time	-0.0189	-2.509	-0.0188	-3.311
Time squared	0.0015	2.604	0.0018	4.217

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