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Abstract

The aim of this paper is to use micro data to estimate multifactor productivity (MFP) growth in the Icelandic fish processing industry 1985-1995. Four different methods are used; stochastic frontiers, Divisia index, and both single-output and multiple-output data envelopment analysis (DEA). Both the stochastic frontier production function and DEA reveal that technical efficiency has been deteriorating in the industry while progressive technical change has taken place. Estimates from the stochastic frontier production function also indicate that productivity growth has been boosted by a substantial price effect. The failure of Icelandic firms to take advantage of the small- scale economies found in the industry have on the other hand hampered productivity growth slightly. MFP-growth, as measured by the Divisia index, was on average 2.3%, far higher than that obtained from both the stochastic frontier and DEA. The results indicate that productivity estimates that do not take into consideration changes in technical efficiency – as earlier Icelandic studies have done – probably overestimate the true productivity growth. By the same token, results obtained using stochastic frontiers show that ignoring the effect of changes in relative prices will yield an incomplete picture of the development of productivity growth.

JEL classification: C14, C23, D24.

Keywords: Fish processing, stochastic frontier, DEA, efficiency, total factor productivity.

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1. Introduction

In the summer of 1809, a Danish adventurer named Jorgen Jorgensen seized control of Iceland in a bloodless revolution and held power for a number of weeks. One of his first acts was to suggest a national flag for Iceland that depicted salted cod against a sea-blue background. Jorgensen was neither the first nor the last person to realise the importance to Iceland of cod and other noble fish species. Fish products have remained Iceland's most valuable exports since the 13th century, although the importance of fisheries and fish processing industries has been declining in recent years. In 1985-1995, the fishing sector nevertheless still accounted for between 15-17% of GDP, while the share of fish products in total exported goods was 70-80% during the same period and generated about 50% of total export earnings. Just over 10% of the workforce was employed in the fishing sector, with the fish processing industries employing slightly more people than fishing. However, as noted by Arnason (1995), the national accounts probably understate the importance of fisheries in the economy, and the direct and indirect contribution of fisheries and fish processing industries to GDP could be as high as 35-40%.[1]

The fishing industry also plays a pivotal role in Icelandic regional policy. Iceland is characterised by a severe regional imbalance, with 2/3 of the population living in the capital, Reykjavik, or nearby.[2] Fishing is the main economic activity in most of the towns and villages outside the capital area, many of which would not survive the closure of the local fishing plant. As a consequence, the financial viability of the fishing and fish processing industries is important not only because of the export earnings they generate but also because of the regional significance of these activities. The government has therefore frequently been willing to lend these firms a helping hand, whether directly through loans and grants, or indirectly through the exchange rate policy.

Yet, despite the prominent place fishing commands in the Icelandic economy, relatively few studies have investigated productivity growth in the fish processing sector in any detail. A notable exception is Gunnarsson (1990), who estimated multifactor productivity (MFP) growth in Iceland 1945-1980, using aggregate data for

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[1] See Arnason (1995), pp. 81-86.
[2] The Icelandic population was 275,000 in 1999.

fishing and fish processing, as well as other sectors of the economy. Other studies have generally either estimated the productivity growth of certain inputs, such as capital and labour, and/or estimated MFP growth by indices, such as the Divisia index.[3] These studies have all been based on aggregate data.

This study, on the other hand, uses data on individual firms to assess MFP growth in fish processing during the years 1985-1995 using both parametric and non-parametric methods. In particular, a stochastic frontier production function with four inputs, capital, labour, materials and fuels, is used to decompose productivity growth into changes in technical efficiency, technical change and scale and price effects. Two non-parametric methods are applied, the Törnqvist approximation of the Divisia index and data envelopment analysis (DEA). The latter allows productivity changes to be decomposed into changes in efficiency and technical change.

This paper is organised in the following manner. A brief outline of the economic background and the Icelandic fish processing industry is given in Sections 2 and 3, respectively. Productivity measurements are discussed in Section 4, while the data used is presented in Section 5. Results are presented and compared in Section 6, and Section 7 concludes.

2. The economic background

After the fall of the Bretton-Woods system in 1973 and until 1990, Iceland followed an exchange rate policy that can be characterised as either a “managed float or [an] adjustable peg with heavy emphasis on adjustability”.[4] The frequent exchange rate adjustments of the period were above all intended to improve the competitiveness of the fishing sector, but also to maintain high employment, especially in the small coastal towns and villages. During this period, the Icelandic economy was engulfed in an inflation cycle, fuelled by indexed wages and the falling nominal exchange rate. Interest rates remained non-indexed until 1979, leading to rapid capital accumulation in many sectors, not least fisheries and fish processing industries. The period of cheap credit came to an end in 1984-1986 when interest rates were gradually liberalised and commercial banks allowed to determine their own lending rates.

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[3] See Institute of Economic Studies (1997, 1999), Danielsson (1997) and Valsson and Klemensson (1998)

From 1990 to date, the exchange rate policy has been much less accommodative. The central bank has followed a policy consisting of keeping the exchange rate within a certain fluctuation band, at present 9%. Still, external economic shocks forced devaluations of the Icelandic krona in 1992 and 1993. There is, however, no doubt that during the 1990s, much stronger emphasis was placed on exchange rate stability than in the previous two decades. This new stand, coupled with a path-breaking, moderate wage settlement in early 1990, lead to rapid deflation, and by 1992 inflation, as measured by the consumer price index (CPI), was down to 2.4%. This represented a sharp break with the inflationary era of the 1970s and 1980s, when inflation peaked at 76.1% in 1983. The general price level remained stable throughout the 1990s but inflationary pressure began building up again in 1999.

Two other important developments took place during the period under observation here. In 1986, a complex system of funds and transfers within the fishing sector was abolished. The main features of the system, which had been set up during the 1960s and 1970s, were an export tax levied on almost all fish products and reimbursement of sales tax from the government. Although this change had almost no effect on fish prices paid by the processing industry, price formation was made much more transparent and the "new" fish prices were also directly comparable to prices obtainable on foreign fresh-fish markets.

This simplification may be viewed as an important prerequisite for the introduction of domestic auction markets, which were established in Iceland a year later, in 1987. The Fisheries Price Determination Board (FPDB) had determined prior to that, the prices of all fish landed in Iceland. The emergence of the auction markets in effect put an end to the operation of the FPDB, although the board was not formally abolished until 1993.[5] During this transition period, the FPDB prices were generally viewed as bottom prices. The market prices for fish were either determined at the auction markets or set internally by vertically integrated firms that were engaged in both fishing and processing. The proportion of all landed fish sold at the auction markets rose rapidly during the first years the markets were in operation, and in 1995 almost one-third of all cod catches were sold at these markets.

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[4] Gudmundsson et. al (1999), p. 7.
[5] Law nr. 8/1993.

Firms in Iceland were thus confronted with a totally different economic reality in the 1990s than in previous decades. The days of loans bearing negative real interest rates were over. The government was committed to a stable exchange rate and much less willing than before to lend a helping hand to firms in the fishing sector, especially those located outside the capital area. In addition, many processing firms found themselves having to pay market prices for fish. This new economic reality, coupled with the introduction of the individually transferable quota system in fishing, has forced firms to pay closer attention to productivity and efficiency.

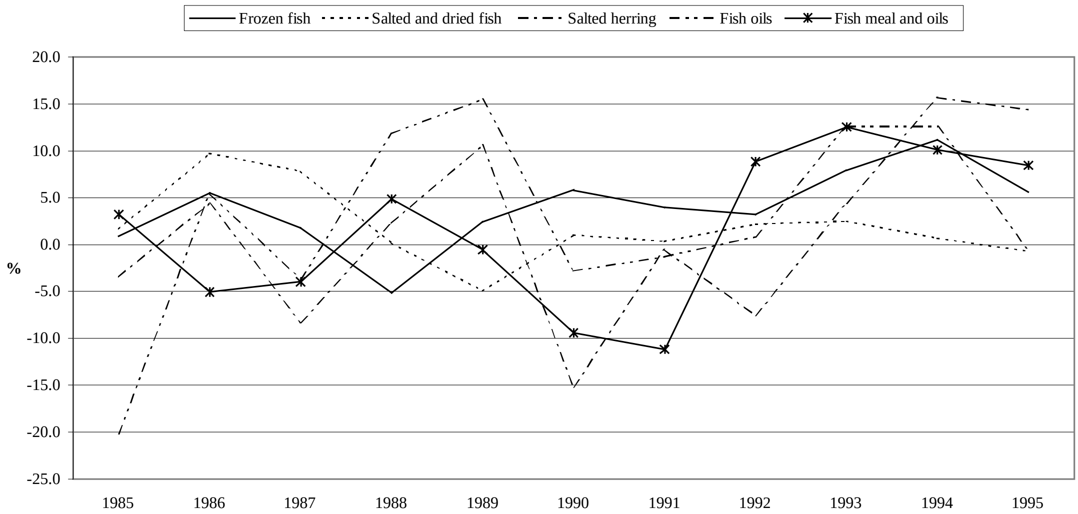
3. The fish processing industry

Most of the fish processing firms operated in Iceland are small. In 1989, about one-third of the companies only had the equivalent of one or two full-time employees on their books. Many of these were family firms. Close to 80% of the firms operated with less than 20 full-time employees, and only 30 firms had more than 60 full-time employees. However, these large firms produce the bulk of the fish products in Iceland.

The fish processing industry can be divided into firms engaged in the production of frozen products, salted and dried products, salted herring, fish meal and 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, while 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. Other important products include fish meal and fish oils, which are mainly produced from pelagic species, such as herring and capelin.

The Icelandic National Economic Institute (NEI) constantly monitors the profitability of Icelandic fisheries and fish processing industry. The profitability has been shown to be extremely volatile, mainly because of the stochastic nature of fisheries and price variations in international markets. As shown in Figure 1, profitability was increasing in the fishing industry as a whole during the early 1990s. This holds especially true for the freezing industry, where profits turned from being 5% of total revenues in 1988 to 11% in 1994. However, the profitability of all branches of the industry declined in 1995.

Figure 1.
Profitability of the Icelandic fish processing industries 1985-1995 as percentage of total revenue.



4. Productivity

In its simplest form, productivity is measured as the ratio between input and output. A more complicated measure allows for the fact that a multitude of inputs is usually employed to produce many outputs. In this paper, three different methodologies are employed to estimate multifactor productivity (MFP) growth in the Icelandic fish processing industry; Divisia indices, stochastic frontiers, and data envelopment analysis (DEA), all of which assume that many inputs are used in the production of a single output. In addition, a multi-output DEA is conducted.

4.1. Divisia index

Following Jorgenson and Griliches (1967), multifactor productivity (MFP) can be estimated using either Divisia quantity or price indices. Denoting the quantity of output l and input j as Y_l and X_i, respectively, the former may be written as

$$(1) \qquad \frac{M\dot{F}P}{MFP} = \sum_l v_l \frac{\dot{Y}_l}{Y_l} - \sum_{j=1}^{J} s_j \frac{\dot{X}_j}{X_j}$$

where v_l denotes the output share of output l, and s_j the input share of input j, and time derivatives are denoted by a dot.

Formally, $v_l = -\frac{W_l Y_l}{\sum_l W_l Y_l}$ and $s_j = -\frac{P_j X_j}{\sum_{j=1}^{J} P_j X_{j\,i}}$ where W_l and P_j denote the price of output l and input j, respectively.

Equation (1) thus defines MPF growth as the difference between the weighted average of the growth of output quantities and the weighted average of the growth of input quantities.

In a single output case, the Divisia quantity index takes the form

(1a) $$\frac{M\dot{F}P}{MFP} = \frac{\dot{Y}_i}{Y_i} - \sum_{j=1}^{J} s_i \frac{\dot{X}_j}{X_j}.$$

The Divisia index assumes that production is characterised by constant-returns-to-scale (CRS), that producers are in long-run equilibrium, perfect competition in both input and output markets, constant utilisation rate of all factors, and that all firms are on the efficiency frontier. As written in (1) the Divisia index is continuous, but it can be approximated using the Törnqvist formula:

(2) $$MFP_t - MFP_{t-1} = 0.5\sum_{i=1}^{I}(s_{it} + s_{it-1})Y_{it} - Y_{it-1} - 0.5\sum_{j=1}^{J}(v_{jt} + v_{jt-1})X_{jt} - X_{jt-1}.$$

As measured here, MFP is therefore a residual, what is left over when the use of all inputs has been accounted for in the production process. Productivity growth in the Divisia-sense is therefore synonymous with technical change.

4.2. Stochastic frontiers

The stochastic frontier production function is specified as

(3) $Y_{it} = f(X_{it};\beta)exp(V_{it} - U_{it})$

where *f()* represents the production technology and β a vector of parameters to be estimated, and other notations are as above. The V_{it} are assumed to be independent and identically normally distributed random errors with mean zero and variance σ_v^2, while the $U_{it}>0$ terms represent technical inefficiency and are assumed to be independent and identically distributed non-negative truncations of the $N(\mu,\sigma_u^2)$. If $\mu = 0$, the distribution takes the form of the half-normal distribution. However, there is no a priori reason to select any particular distributional form for the technical inefficiency effects. Instead, μ can be estimated along with other parameters of the model, and the hypothesis that $\mu = 0$ then tested. The random errors represent the effects of factors outside the firm's control, such as changes in the natural environment, access to raw material, measurement errors and left-out variables. The technical inefficiency terms, on the other hand, capture the effects of all factors that can be controlled by the firm. Technical efficiency of firm i at time t can be computed as

(4) $TE_{it} = exp(-U_{it})$.

In the case where $V_{it} = 0$, the function in (3) collapses to a deterministic frontier where all deviations from maximum output are related to technical efficiency and none to random error.

In this study, technical efficiency is estimated using the model proposed by Battese and Coelli (1992), hereafter called BC92. The technical inefficiency terms are allowed to vary over time and are defined as

(5) $U_{it} = \eta_{it}\, U_i = \{exp[-\eta(t - T)]\}U_i$.

where η is an unknown scalar parameter to be estimated, and T is the last year of the sample. In the case where $\eta > 0$, technical efficiency is increasing at a decreasing rate over time, but decreasing at an increasing rate when $\eta < 0$. Technical efficiency is time invariant when $\eta = 0$. The null hypothesis of no change in the technical efficiency over time can easily be tested. The BC92-model implies that the ordering of firms according to the magnitude of the technical efficiency effects remains the same throughout the period of study. The model therefore does not allow for situations where some firms are becoming relatively more or less efficient through time. Rather, the temporal pattern is the same for all firms and either increases or decreases exponentially. The model is estimated using maximum likelihood (ML).

4.3. Stochastic frontiers and MFP

Suppose the production technology can be represented by the following translog frontier production function

$$(6)\quad y_{it} = \beta_0 + \sum_j \beta_j x_{jit} + \beta_t t + 0.5\sum_j \sum_k \beta_{jk} x_{jit} x_{kit} + 0.5\beta_{tt} t^2 + \sum_j \beta_{jt} x_{jit} t + V_{it} - U_{it}$$

where y and x_j represent the respective output and inputs, denoted *k, l, m, f*, measured in logarithms.

Following Kumbhakar and Lovell (2000), MFP growth can be decomposed into

$$(7)\quad \frac{M\dot{F}P}{MFP} = TC - \frac{\partial U}{\partial T} + \sum_j \left[\frac{f_j x_j}{f} - s_j\right]\dot{x}_j$$

$$= (RTS - 1)\sum_j \lambda_j \dot{x}_j + TC - \frac{\partial U}{\partial T} + \sum_j \left[\lambda_j - s_j\right]\dot{x}_j$$

where *RTS* denotes returns to scale (elasticity of scale) and is measured as the sum of the input elasticities, $RTS = \sum_j \varepsilon_j = \sum_j \frac{f_j x_j}{f}$. In the translog case, *RTS* is defined as

$$(8)\quad RTS = \sum_j \left(\beta_j + \sum_k \beta_{jk} x_{kit} + \beta_{jt} t\right).$$

TC stands for technical change that is defined as the shift in the production frontier over time. *TC* is calculated as

$$(9)\quad TC = \beta_t + \sum_j \beta_{jt} x_{jit} + \beta_{tt} t\,.$$

$\frac{\partial U}{\partial T}$ measures the change in technical efficiency and can be obtained as the difference in estimated efficiency between two periods, i.e., $\hat{u}_{it} - \hat{u}_{it-1}$. It is assumed here that the efficiency effects are not a function of inputs.

Finally, $\lambda_j = \frac{\varepsilon_j}{RTS}$, and s_j denotes the share of input j in total costs, $s_j = \frac{P_j X_j}{\sum_j P_j X_j}$. As viewed here, the change in *MFP* can be decomposed into scale components ($(RTS-1)\sum_j \lambda_j \dot{x}_j$), technical change, technical efficiency change and price effects ($\sum_j [\lambda_j - s_j]\dot{x}_j$). The price effects can either capture the deviations of input prices from the value of their marginal products $(P_j \neq W_j f_j)$, or departure of the marginal rate of technical substitution from the ratio of input prices ($\frac{f_j}{f_k} \neq \frac{P_j}{P_k}$).

4.4. Malmquist productivity index

The Malmquist index was first presented in a consumer context by Malmquist (1953), but later developed into a proper productivity index by Caves et al. (1982) who expressed the index in distance functions. However, as shown by Färe et al. (1985), there is a simple relationship between distance functions and Farrell efficiency measures. Consequently, Färe et. al (1993) showed how the Malmquist index could be calculated using data envelopment analysis (DEA), and this issue was explored further in Färe et. al (1994). The Malmquist productivity index can be decomposed into changes in technical efficiency and technical change, thus enabling one to observe both a catching-up effect and a shift in the production frontier.

In this study, the Malmquist index is calculated using efficiency measures obtained from DEA. 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. The efficiency can be calculated either from the input or output side, i.e., the firms can either be regarded as minimising the inputs used in the production of a certain amount of output, or maximising the output obtainable from a certain mix of inputs. Here, the output-oriented measure is used, as it is my belief that the aim of the fish processing firm is to maximise output, and that the firms are in no way output-constrained. Furthermore, since the output-oriented measure corresponds to the conventional production function, it seems logical to use this approach to obtain productivity estimates comparable with those obtained from the stochastic production frontier.

The Malmquist index has two important advantages over other indices, such as the Fisher ideal index and the Törnqvist index. First, no assumption regarding the economic behaviour of the production units, e.g., cost minimising or revenue maximising, needs to be made. Second, the index requires no information on prices and can therefore be applied in cases where the price of outputs is unknown, such as in the production of various public services.

The index is based on pair-wise comparisons consisting of calculating the ratio between Farrell technical efficiency measures for a production unit relative to two different frontiers at two points in time. In the original paper by Färe et al. (1993), the Malmquist productivity index was calculated relative to a constant-returns-to-scale (CRS) technology. Later, Grifell-Tatjé (1995) showed that the index does not correctly measure changes in productivity in the presence of changes in returns to scale. As shown in Bjurek (1994, 1996), these shortcomings can be overcome if the Malmquist productivity index is defined as the ratio of a Malmquist output quantity and input quantity indices. In the present study, the traditional, CRS Malmquist index is used.

Using Farrell measures of technical efficiency, the output-oriented Malmquist multifactor productivity index can be defined as

$$(10) \quad M_o^{t+1}(X^{t+1}, Y^{t+1}, X^t, Y^t) = \left[\frac{F_o^t(X^t, Y^t \mid C, S)}{F_o^t(X^{t+1}, Y^{t+1} \mid C, S)} \frac{F_o^{t+1}(X^t, Y^t \mid C, S)}{F_o^{t+1}(X^{t+1}, Y^{t+1} \mid C, S)} \right]^{0.5} .$$

where $F_o^t(X^t, Y^t|C,S)$ and $F_o^{t+1}(X^{t+1}, Y^{t+1}|C,S)$ denote the output-oriented measures of efficiency of each firm at time *t* and *t+1*. The C and S indicate that the efficiency measures are calculated relative to CRS technology and strong disposability, respectively. $F_o^{t+1}(X^t, Y^t|C,S)$ denotes the output-oriented measures obtained assuming that inputs used to produce output at time *t* are used with the technology of time *t+1*. Likewise, $F_o^t(X^{t+1}, Y^{t+1}|C,S)$ is the efficiency measure obtained from assuming that the technology at time *t* is used to produce output from inputs at time *t+1*.

As mentioned above, the Malmquist productivity index may be decomposed into two components,

(11) $M_o^{t+1}(X^{t+1}, Y^{t+1}, X^t, Y^t) =$

$$\frac{F_o^t(X^t, Y^t \mid C,S)}{F_o^{t+1}(X^{t+1}, Y^{t+1} \mid C,S)} \left[\frac{F_o^{t+1}(X^{t+1}, Y^{t+1} \mid C,S)}{F_o^t(X^{t+1}, Y^{t+1} \mid C,S)} \frac{F_o^{t+1}(X^t, Y^t \mid C,S)}{F_o^t(X^t, Y^t \mid C,S)} \right]^{0.5}$$

where the ratio outside the bracket measures the change in technical efficiency between periods *t* and *t+1*, and the ratio inside the bracket is the geometric mean of the shift in technology as observed at time *t+1* (the first ratio) and time *t* (the second ratio).

Improvements in productivity will show up as Malmquist indexes with values greater than unity, while values less than unity will indicate deterioration of productivity. The efficiency change and technical change components have the same interpretation. The Malmquist productivity index does not require that changes in efficiency and technology move in the same direction; thus, efficiency could be improving, while regressive technical change was taking place. The net effect on productivity will then depend on which of the two components is dominant.

5. Data

The data used in this study comes from the Icelandic National Economic Institute (NEI) and consists of observations on 51 firms engaged in fishing and/or fish processing during the period 1985-1995. Most of the firms operate both boats and processing plants, but for our purposes, all firms engaged solely in fishing have been excluded from the sample. The database at hand therefore consists of an unbalanced panel.

NEI classifies the output of fish processing firms into six categories; frozen fillets, salted and dried products, salted herring, frozen shrimp, frozen scallop and fish meal and fish oil. We use three different output definitions, depending on the estimation method used. For the Divisia index, which consists of taking logdifferences of all weighed outputs and inputs, it proved necessary to group all outputs together as many firms only produced a single output, making it impossible to calculate the log-difference of the other outputs. Two different output definitions were used in DEA, single output (DEA1) and multiple-output definitions (DEA3). The former is the same as used for the Divisia index. In the latter, three output categories were defined; frozen products (frozen fillets, shrimp and scallop), salted and dried products (salted and dried fish, salted herring) and fish meal and fish oil. A slightly different definition of output was used for the stochastic frontiers. Since the technology involved in producing fish meal and fish oil differs greatly from that used for the production of frozen and salted products, the production technology of the latter was modelled separately. Consequently, all outputs except fish meal and fish oil were added together in the parametric model, and firms specialised in the production of fish meal and fish oil were excluded from our sample. Furthermore, all costs associated with the production of fish meal and fish oil were subtracted from total costs in multi-output firms. However, the small number of fish meal and fish oil firms in our sample made it unfeasible to estimate stochastic frontiers for these firms separately.

The data is taken from the tax records of firms, and all variables, both inputs and outputs, are therefore measured in millions of Icelandic kronur. Four inputs are used in the analysis; materials, wages, fuels and capital. 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 both production workers and administrative employees as well as employers' contributions and payroll taxes. Fuel and heating costs include all expenditures on oil and other fuels as well as on electricity and heating. The tax records also contain information on the value of the capital stock each year. However, 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

$$(12)\quad K_t = K_{t-1}(1+b_t)(1-\partial) + I_t$$

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, measured as the change in the building construction index from December of the previous year to December of the current year, 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. As the labour, material and fuel inputs are all cost concepts and thus measured in kronur, it was decided to measure the capital in a similar fashion and use capital cost as input rather than the capital stock itself. Capital cost, U_k, is measured as

$$(13) \quad U_k = K_t(\partial + r_t + b_t)$$

where r_t is the real interest rate at time t.

All variables used are deflated using appropriate indices. Thus, in the case of output a price index for exported fish products is used; materials and fuels are deflated using the consumer price index; labour is deflated using an index of hourly paid wages in fish processing plants, and capital is deflated using the building construction index.

Because of the different data needs of the stochastic frontiers, on the one hand, and the Divisia index and DEA, on the other, the number of observations is not the same in both cases. Thus, 385 observations were used for the parametric methods and 376 for the non-parametric. Most of the observations, 215, are on firms specialising in the production of one of the three outputs used in DEA3. Of these, only one firm is engaged solely in the production of fish meal and fish oil, and that firm is observed for nine years. There are a substantial number of observations, 93, on firms producing both frozen and salted products, and quite a few firms appear to produce all three outputs (52 observations).

Although the production of the firms included in our sample amounted to 30-35% of total revenues in the fish processing industries during the period under observation, the sample is biased. Most of the firms included in the sample are large, but small and medium-sized firms are underrepresented. No attempt is made to correct for this sample selection bias.

Summary statistics of the observations used for the stochastic frontier and Divisia indices and DEA are given in Tables 1 and 2, respectively. As mentioned in

Section 2 above, firms in the fish processing industries vary a great deal in size, and this is well reflected in the data at hand. Total sales of the smallest firms thus only amount to a few million kronur, while the largest firms register sales close to 2000 million kronur. On the input side, raw material makes up the largest share of costs, on average around one-half, while fuel costs only represent a small proportion of total costs.

Table 1.
Summary statistics of variables used for stochastic frontier.
Real millions Icelandic kronur. Number of observations is

	Mean	Std. dev.	Min.	Max.
Total sales	432.1	342.3	4.1	1799.1
Inputs:				
Capital	125.8	166.1	1.4	1380.1
Labour	99.3	83.4	1.0	406.9
Materials	249.7	189.2	1.6	996.2
Fuels	7.6	6.3	0.1	38.6
Total cost	482.4	313.3	21.7	1503.0
Cost shares:				
Capital	0.2497	0.2082	0.0023	0.9849
Labour	0.1983	0.0671	0.0053	0.3199
Materials	0.5366	0.1624	0.0079	0.8270
Fuels	0.0154	0.0079	0.0012	0.0621

The table also clearly shows that during these 11 years, fish processing firms were on average run at a loss. The total value of average outputs is 430 million kronur, but average total costs amount to 10 or 40 million more, depending on which data set is used.

Table 2.
Summary statistics of variables used for Divisia indices and DEA.
Real millions Icelandic kronur. mber of observations is 376.

	Mean	Std. dev.	Min.	Max.
Ouputs:				
Total sales	428.2	402.7	19.6	2008.7
Frozen products	297.2	335.9	0.0	1918.1
Salted products	72.7	86.5	0.0	364.3
Fishmeal and fish	58.2	163.1	0.0	1029.3
Inputs:				
Capital	91.8	97.0	1.0	658.8
Labour	90.1	84.2	4.4	463.1
Materials	247.3	227.9	13.3	1097.8
Fuels	11.8	4.9	0.1	101.4
Total cost	441.0	337.7	24.0	1629.7
Cost shares:				
Capital	0.2339	0.1957	0.0020	0.9430
Labour	0.1933	0.0638	0.0100	0.3180
Materials	0.5504	0.1576	0.0420	0.8880
Fuels	0.0224	0.0207	0.0010	0.1290

6. Development of productivity

In this section estimates of productivity growth using the different approaches outlined above, e.g., stochastic frontiers, the Malmquist index and the Törnqvist approximation of the Divisia index, are presented and discussed.

6.1. Stochastic frontier results

As mentioned above, the stochastic frontier production function was estimated using the BC92 model. The likelihood function and its derivatives with respect to the parameter of the model are presented in Battese and Coelli (1992). As shown there, the likelihood function can be expressed in terms of the variance parameters $\sigma_s^2 \equiv \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{\sigma_s^2}$. γ is therefore confined to the [0,1] interval, with a value of zero indicating the absence of any technical inefficiency effects. The model is then equivalent to the traditional average response function. A γ value of unity would on the other hand imply that the inefficiency effects would account for all deviations from the production frontier. The model would then correspond to a deterministic frontier.

The null hypothesis, that γ = 0, can be tested using likelihood ratio tests. Because the test value (γ = 0) lies on the boundary of the parameter space for γ, the test statistic has an asymptotic distribution, which is a mixture of two chi-square distributions, see Coelli (1992). This implies that for a test of size α, the critical value is equal to the value $\chi^2(2\alpha)$ instead of $\chi^2(\alpha)$.

The stochastic frontier model contains the 21 parameters of the translog production function defined in (6), as well as the four parameters associated with the distribution of the two random variables, U_{it} and V_{it}. The model is estimated using maximum likelihood and restrictions on both the production function parameters and the random variable parameters γ, η and μ can therefore be tested using likelihood ratio tests.

Table 3.
Hypothesis testing of the random variable parameters in the BC92-model.

	Null hypothesis, H_0	Log likelihood	χ^2-statistic	χ^2-value	Decision
Model 1	-	319.488	-	-	-
Model 2	μ=0	318.286	2.404	3.841	Accept H_0
Model 3	η=0	311.820	15.336	3.841	Reject H_0
Model 4	μ=η=0	311.718	15.540	5.991	Reject H_0
Model 5	μ=η=γ=0	291.379	56.218	7.814	Reject H_0

Results from testing various hypotheses on the random variable parameters are presented in Table 3. Model 1 is the unconstrained version where all of the three variables are allowed to take on a value different from zero. The hypothesis that μ=0 (the U_i's have half-normal distribution) is tested in Model 2; the restriction η=0 (time invariant efficiency) is imposed in Model 3, and both of these restrictions are imposed on Model 4. Finally, all the random variable parameters are set at zero in Model 5.

The hypothesis that the technical inefficiency effects can be represented by a half-normal distribution (Model 2) is the only one not rejected by the likelihood ratio tests. It thus seems that the traditional average production function is not appropriate here, as γ is clearly not zero, and that the firm-specific effects are time variant, since η takes on a value different from zero. These same conclusions are reached even if the analysis is based on the assumption that a half-normal distribution is appropriate for the inefficiency effects. The χ^2-statistic for the null hypothesis that η=0, given that μ=0, is 12.932, far higher than the 5% critical value of 3.841, and the χ^2-statistic for the null hypothesis that η=γ=0 is 13.136, which also exceeds the 5% critical value (5.991).

Table 4.
Parameter estimates of the stochastic translog production function using the BC92-model and assuming a half-normal distribution for the efficiency effects. Standard errors in parentheses.

Intercept	-1.8497		Fuels*Materials	0.0200	
	(1.3806)			(0.0460)	
Fuels	0.3954		Capital*Labour	0.0733	**
	(0.2361)			(0.0241)	
Capital	0.1671		Capital*Materials	-0.0734	**
	(0.1218)			(0.0219)	
Labour	-1.0309	*	Labour*Materials	0.0221	
	(0.5080)			(0.1222)	
Materials	1.9010	**	Fuels*Time	0.0074	
	(0.5029)			(0.0048)	
Time	0.0121		Capital*Time	0.0065	**
	(0.0155)			(0.0019)	
Fuels*Fuels	0.1232	**	Labour*Time	-0.0002	
	(0.0359)			(0.0080)	
Capital*Capital	0.0002		Materials*Time	-0.0135	**
	(0.0077)			(0.0060)	
Labour*Labour	0.1210				
	(0.1356)		$\sigma_s^2 \equiv \sigma_v^2 + \sigma_u^2$	0.0650	*
Materials*Materials	-0.0516			(0.0303)	
	(0.1234)		$\gamma \equiv \frac{\sigma_u^2}{\sigma_s^2}$	0.8580	**
Time*Time	0.0058	**		(0.0699)	
	(0.0020)		η	-0.1620	**
Fuels*Capital	-0.0126			(0.0599)	
	(0.0130)				
Fuels*Labour	-0.1417	**			
	(0.0488)				

** and * denote significance at the 1% and 5%, respectively.

The parameter estimates for the stochastic frontier translog production function using the BC92-model are presented in Table 4. Following the test results discussed above, the inefficiency effects are assumed to have a half-normal distribution. The parameter estimates of the production function are not very precise, with only nine of the 21 parameters significant at the 5% level or better. The estimate of γ (0.858) indicates that a substantial part of the errors in the production function can be attributed to the inefficiency effects. Note also that η is negative, implying that technical inefficiency was increasing during the period of study.

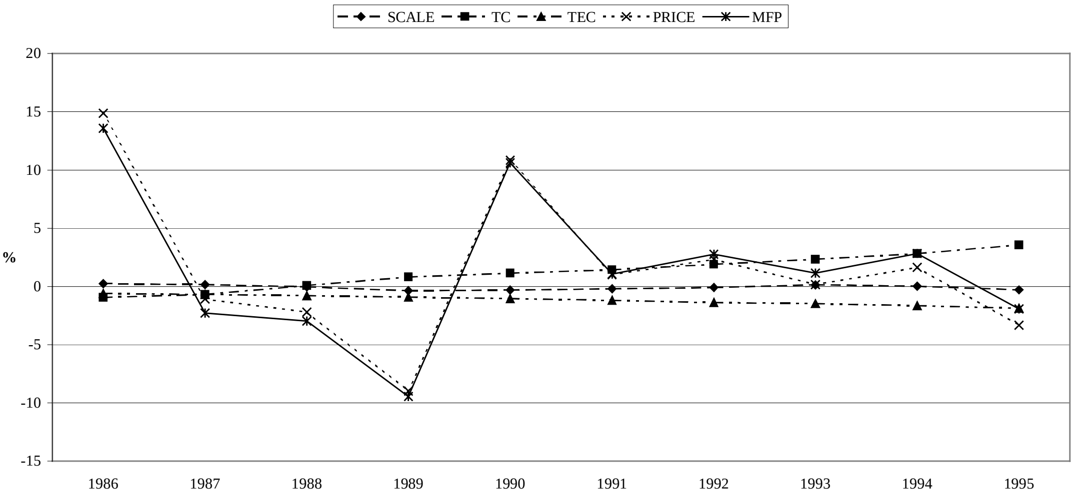
Multifactor productivity, weighted by the share of each firm in total revenue, grew on average by 1.5% between 1985 and 1995, boosted by progressive technical change and positive price effects (see Figure 2 and Table A1 in Appendix). Technical change can be further decomposed into neutral and biased technical change. The former is a linear trend, rising from 2.1% in 1986 to 7.3% in 1995 (see Table A2 in Appendix). The latter shows how time has affected relative input-use. Here, the biased component is negative and has on average declined by 3.4% per year.

The price component has varied tremendously, from 14.9% in 1986 to –9.0% in 1989, and these swings have, as is clearly revealed in Figure 2, completely determined the development of the multifactor productivity growth. As explained earlier, the price effects can either reflect how input prices diverge from the value of their marginal products, or how the marginal rate of technical substitution differs from the ratio of input prices. This departure from optimising behaviour is especially likely to happen during an inflationary period, when relative prices can easily become distorted. This is well reflected in the development of the price effects, which varied much more during the first five years of our sample when inflation in Iceland averaged 20.3%. By comparison, average inflation was down to 3.6% in 1991-1995. The price effects have on average raised productivity by 1.2%.

The scale characteristic of the fish processing firms remained almost constant between 1985 and 1995, registering on average slightly increasing returns-to-scale (1.03). However, the firms have been unable to take full advantage of these positive scale economies, and this failure of the firms has consequently decreased productivity growth by 0.1% on average.

As noted earlier, technical efficiency has been declining, and this development has seriously hampered productivity growth. Thus, deteriorating efficiency decreased mean *MFP* growth by 1.2%.

Figure 2.
Development of productivity (MFP) in the Icelandic fishing industry decomposed into scale effects (SCALE), technical change (TC.), efficiency change (TEC) and price effects (PRICE). Weighted percentage changes from previous year.

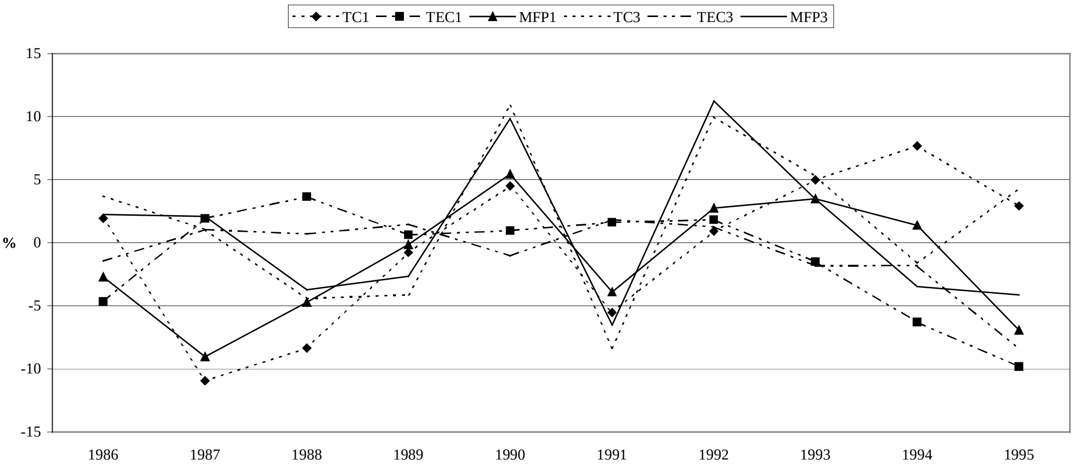


6.2. Malmquist index results

Two different estimates of *MFP* growth were calculated using the Malmquist productivity index. The first is based on a single-output DEA (DEA1), whereas the second is conducted using a multiple-output DEA (DEA3). The outputs in this case are three; frozen products, salted products and fish meal and fish oil.

The DEA estimates are depicted in Figure 3, with *MFP*1, *TC1* and *TEC1* denoting the DEA1 measures, and *MFP3*, *TC3* and *TEC3* the DEA 3 measures. The two specifications reveal similar productivity patterns, but average *MFP* growth is negative in DEA1, -1.4%, but positive under DEA3, 0.8% (see also Table A3 in the Appendix). According to the single-output DEA, technical change was regressive, and diminished productivity grew on average by 0.3%, while the rate of progressive technical change was on average 1.7% in the multiple-output DEA case. However, both methods reveal that technical efficiency has been deteriorating, thus curtailing productivity growth. The technical efficiency decrease amounted to 1.2% and 0.8% in the single- and multiple-output cases respectively.

Figure 3.
DEA productivity measures (MFP) decomposed into technical (TC) and technical efficiency changes (TEC). Single- and multiple-output DEA measures are denoted by the suffices 1 and 3 respectively. Weighted percentage changes from previous year.

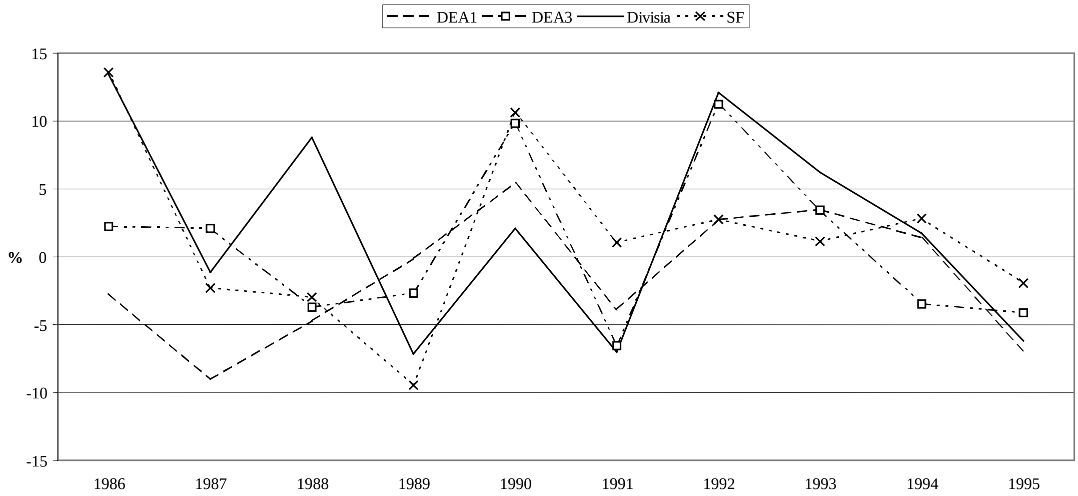


6.3. Comparison and discussion

The productivity measures obtained from the stochastic frontier, Malmquist index and Törnqvist approximation of the Divisia index are presented in Figure 4 and in Table A4 in the Appendix. The Törnqvist approximation of the Divisia index yields the highest average productivity growth estimates, 2.3%, which is considerably higher than the average growth rate obtained from the stochastic frontier (1.5%). The two DEA estimates are lower still, indeed the average, single-output DEA is negative. However, the four productivity estimates are in step, as clearly shown in Figure 4. All measures fluctuate a great deal, especially in the first years of the sample period, and all also point to a negative productivity growth trend starting in 1992.

The variations in productivity are probably mostly the result of the stochastic nature of fisheries, and the resulting fluctuations in the availability of raw material. During 1984-1989, the Icelandic demersal fisheries were controlled by a system of individual quotas and limits on effort, but in 1990 a system of individually transferable quotas (ITQ) was introduced in all fisheries. The ITQ system should in the long-run increase productivity in fisheries and the fish processing industry, as many of the drawbacks of open-access fishing will be eliminated. The system should, for instance, lead to a steadier flow of raw materials to the fish processing plants, resulting in reduced idle time and increased capacity utilisation, as well as better quality of the raw material. In this study, however, no attempt is made to assess the effects the ITQ system has had on the fish processing industry, as the data available do not allow any such judgement.

Figure 4.
Comparison of productivity estimates from single- (DEA1) and multiple-output DEA (DEA3), Divisia indices (Divisia) and stochastic translog frontier production function (SF). Weighted percentage changes from previous year.



Estimates from the stochastic frontier and DEA indicate that technical efficiency has been deteriorating, and simple productivity measures, such as those obtained from calculating a Divisia index, may therefore overestimate *MFP*-growth. The question that therefore must be addressed is: Why has technical efficiency fallen during 1985-1995 period? At present, I can give no certain answers but only point to the likely culprits. First, the establishment of the fresh-fish auction markets in Iceland has reduced the competitiveness of firms not operating their own boats, as these firms are often forced to pay higher prices for the raw material than the vertically integrated firms. Second, the competition with freezing-trawlers may have limited the available raw materials in some cases. This has a twofold effect. Firms may not be able to take full advantage of their potential scale economies, and the relative scarcity may also raise market prices. Third, firms which previously depended - at least partly - on government aid and received loans with low nominal rates, are now having to service more expensive loans without the hope of government intervention. Fourth, the establishment of a stock market in Iceland and the subsequent registration of several fish processing firms on the market has opened the door to less expensive venture capital for the largest firms. In return, these firms now have to adhere more strictly to the laws of the market, where profitability is the key word. Consequently, these firms are more likely to pay greater attention to opportunities to increase productivity and efficiency.

The productivity growth estimates presented here are similar to or lower than those obtained in previous Icelandic studies. Thus, Gunnarsson (1990) finds that productivity grew on average by 2.7% in the fish processing sector during the period 1945-1980. The productivity estimates are similar regardless of whether a translog cost function is used or the traditional Divisia index. In a more recent study, *MFP* is estimated to have grown on average by 2.0% between 1985 and 1996.[6]

Norway, especially the northernmost regions, is also very dependent on fishing, and the technology involved in the production processes is similar to that employed in Iceland. It may therefore be worthwhile to compare results from Norwegian productivity studies with those obtained here.

Using a short-run variable cost function, Kim and Bjorndal (1990) estimated productivity in the Norwegian fish processing industry in 1985-1987. Average *MFP*-growth declined by 5.8% for conventional plants, while productivity growth increased on average by 3.2% in freezing plants.[7] The productivity growth in the freezing plants is though very different in the two years in the sample, and improves from -17.3% in 1985/86 to 23.8% in 1986/87. Toft and Bjorndal (1993) used a hybrid translog cost function to analyse technical change in the Norwegian fish processing industry in 1985-1990. For conventional plants, the shift in the cost function amounted to 9.4% per year and 3.8% for the freezing plants. The two Norwegian estimates of productivity in freezing plants are therefore considerably higher than those obtained for the Icelandic firms when the Divisia index is used (2.3%).

7. Conclusions

The fisheries and fish processing sectors are vitally important to the Icelandic economy and, according to some estimates, constitute 35-40% of the country's GDP. Understanding the development of productivity in these sectors is therefore of utmost importance.

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[6] Institute of Economic Studies (1999).

The principal aim of this paper was to estimate productivity growth in the Icelandic fish processing sector using micro-data from individual firms in the period 1985-1995. Four different methods were used; stochastic frontiers, Divisia index, and both single-output and multiple-output DEA.

The stochastic frontier production function was estimated using the Battese and Coelli (1992) model, and, following Kumbhakar and Lovell (2000), productivity growth was decomposed into technical change, change in technical efficiency, and scale and price effects. Technical change boosted productivity on average by 1.3% and the price effects accounted for 1.5% on average. Declining technical efficiency and the scale effect decreased productivity by 1.2% and 0.1% on average.

The DEA results tell a similar story of deteriorating technical efficiency, but the two DEA models yield different estimates of average technical change. In the single-output case productivity declined on average by 1.4%, with efficiency falling by 1.2% and regressive technical change amounting to 0.3% on average. In the multiple-output case, productivity rose on average by 0.8%, with technical change increasing productivity by 1.7% on average and efficiency shrinking by 0.8%. *MFP*-growth, as measured by the Divisia index, was on average 2.3%, far higher than that obtained from both the stochastic frontier and DEA.

The Divisia productivity estimates obtained are similar to those obtained in previous Icelandic studies and also close to estimates of productivity in Norwegian fish processing plants.

The results indicate that productivity estimates not taking into consideration changes in technical efficiency – as earlier Icelandic studies have done – probably overestimate the true productivity growth. By the same token, results obtained using stochastic frontiers show that ignoring the effect of changes in relative prices will yield an incomplete picture of the development of productivity growth. The results therefore demonstrate the added insight that can be gained by utilising different methods to estimate productivity.

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[7] The main difference between the two types of plants is that freezing plants are equipped with freezing facilities, while the conventional plants are not.

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Appendix

Table A1.
Estimates of changes in multifactor productivity (MFP) from the stochastic translog frontier production function decomposed into scale effects (Scale), technical change (TC), technical efficiency change (TEC) and price effects (Price).
Percentage changes from previous years.

	Scale	TC	TEC	Price	MFP
1986	0.241	-0.942	-0.598	14.886	13.588
1987	0.152	-0.675	-0.683	-1.083	-2.289
1988	-0.036	0.074	-0.796	-2.210	-2.969
1989	-0.372	0.812	-0.915	-8.976	-9.451
1990	-0.304	1.135	-1.044	10.833	10.620
1991	-0.194	1.428	-1.190	1.015	1.060
1992	-0.091	1.901	-1.379	2.320	2.751
1993	0.139	2.329	-1.476	0.150	1.142
1994	0.017	2.821	-1.640	1.640	2.838
1995	-0.294	3.563	-1.877	-3.322	-1.930
Mean	-0.074	1.245	-1.160	1.525	1.536

Table A2.
Estimates of technical change (TC) from the stochastic translog frontier production function decomposed into neutral and biased technical change.
Percentage changes from previous year.

	Neutral	Biased	TC
1986	2.075	-3.017	-0.942
1987	2.652	-3.327	-0.675
1988	3.228	-3.154	0.074
1989	3.805	-2.993	0.812
1990	4.381	-3.246	1.135
1991	4.958	-3.529	1.428
1992	5.534	-3.633	1.901
1993	6.111	-3.782	2.329
1994	6.687	-3.866	2.821
1995	7.264	-3.701	3.563
Mean	4.670	-3.425	1.245

Table A3.
Productivity growth (MFP) in the Icelandic fish processing industry decomposed into technical change (TC) and changes in efficiency (TEC). Percentage changes from previous year. Single- (DEA1) and multiple-output (DEA3) DEA estimates.

	DEA1			DEA3		
	TC	TEC	MFP	TC	TEC	MFP
1986	1.938	-4.657	-2.718	3.705	-1.469	2.236
1987	-10.953	1.917	-9.035	1.050	1.050	2.101
1988	-8.365	3.655	-4.710	-4.424	0.706	-3.718
1989	-0.763	0.623	-0.140	-4.132	1.466	-2.666
1990	4.500	0.952	5.453	10.887	-1.043	9.844
1991	-5.517	1.624	-3.894	-8.361	1.828	-6.533
1992	0.911	1.827	2.739	9.977	1.256	11.233
1993	4.979	-1.503	3.476	5.273	-1.831	3.443
1994	7.686	-6.296	1.390	-1.636	-1.824	-3.459
1995	2.918	-9.835	-6.917	4.312	-8.433	-4.121
Mean	-0.267	-1.169	-1.436	1.665	-0.829	0.836

Table A4.
Comparison of productivity estimates obtained from the Malmquist index using single-output (DEA1) and multiple-output (DEA3) DEA, the Törnqvist approximation of the Divisia index (Divisia), and stochastic translog frontier production function (SF). Percentage changes from previous year.

Year	DEA1	DEA3	Divisia	SF
1986	-2.718	2.236	13.434	13.588
1987	-9.035	2.101	-1.147	-2.289
1988	-4.710	-3.718	8.786	-2.969
1989	-0.140	-2.666	-7.169	-9.451
1990	5.453	9.844	2.088	10.620
1991	-3.894	-6.533	-7.006	1.060
1992	2.739	11.233	12.087	2.751
1993	3.476	3.443	6.223	1.142
1994	1.390	-3.459	1.743	2.838
1995	-6.917	-4.121	-6.178	-1.930
Mean	-1.436	0.836	2.286	1.536

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W00:08 Eduard Hochreiter: "Exchange rate regimes and capital mobility: Issues and some lessons from central and eastern European applicant countries"

W00:09 Thorvaldur Gylfason: Fix or Flex? Alternative Exchange Rate Regimes in an Era of Global Capital Mobility

W00:10 Thorvaldur Gylfason: Natural Resources, Education and Economic Development

W00:11 Helgi Tomasson: Signal-noise Decomposition in Financial Markets: An Empirical Stochastic Process Analysis for Infrequent Trading

W00:12 Thorolfur Matthiasson: Changing Rules for Regulation of Icelandic Fisheries

W00:13 E. Tumusiime-Mutebile: Economic Reforms and their Impact in Uganda

W00:14 Sveinn Agnarsson: Productivity in Icelandic Fish Processing Industry 1985 – 1995: A Comparison of Methods