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# Deliverable 2.6

# Manuscript to a peer-reviewed journal on the economic performance of European seafood producers

## February 28th, 2019

# Executive Summary

The deliverable consists of a manuscript to the scientific journal, Aquaculture. The intended audience of the journal article is primarily the scientific community.

The primary aim of the empirical analysis was to compare the economic performance of salmon farming firms in Norway and Scotland which are the first and third important salmon production countries in the world.

The Norwegian data used in this study was provided by Kontali while the UK data comes from Orbis which maintains a data resource on private companies. Norwegian data from Kontali and other sources has been used for several earlier empirical studies on salmon farming in Norway, but data on Scottish salmon farming has been limited. The data employed here underlines this data poverty, as the data on the Scottish salmon farms extracted from the Orbis database only allows for a rather simple analysis, using current and fixed assets as the only inputs, and revenue as output. As such, current assets may be regarded as a crude proxy for variable costs and fixed assets a proxy for capital stock. As the intention in this paper is to compare the economic performance of Scottish salmon farms to Norwegian salmon farms, corresponding variables have been extracted from the Kontali in-house database. The Norwegian data spans 30 years for the period 2006-2015, while the Scottish data covers eight firms observed during the years 2008-2015. Both datasets therefore consist of balanced panels.

This analysis was conducted in two stages. In the first stage, an output-oriented DEA model was used to calculate the technical and scale efficiency of Norwegian and Scottish salmon farms for two years, 2008 and 2015. For this purpose, the two data sets are pooled together resulting in a total of 38 observations for each year. The year 2008 was the earliest time period for which data is available for salmon farms in both countries, and the year 2015 the latest year. Applying the DEA models to the pooled data made it possible construct a frontier composed of both Norwegian and Scottish firms and determine the number of firms for each country that are right on the frontier.

In the second stage, the Malmquist productivity change index was applied to each data set. This comparison yielded information on how total factor productivity (TFP) has developed in each country and how much of the changes can be attributed to changes in technology and how much to changes in pure technical efficiency and scale efficiency.

The technical efficiency calculated under the assumption of variable returns to scale, of the Norwegian firms averaged 0.671 in 2008, while the Scottish firms had on average an efficiency score of 0.824. Four of the seven firms on that year's production frontier were Scottish and three Norwegian. The Norwegian firms were however better in taking advantage of their economies of scale, as borne out by their slightly higher scale efficiency, 0.713 as opposed to 0.679 for the Scottish firms. By 2015, the gap in technical efficiency of the firms from both countries had narrowed considerably, although the Scottish firm were on average found to be more efficient.

During the period 2006-2015, the 30 Norwegian firms experienced on average a 0.1 decrease in productivity. This was mostly due to declining pure technical efficiency, that declined on average by 0.4%. Scale efficiency, on the other hand, grew by 0.3% but there was on average no technical change. On average, TFP declined by 6.3% for the Scottish firms, mostly due to large technical regress, as observed by the average decline of 11.2%. Large improvements in scale efficiency (8.9%), however, compensate partly for the adverse technical change effects.

The comparison between Norwegian and Scottish farms revealed that although Scottish salmon producers may be more efficient, the regressive technical change experienced by the Scottish fish farmers has led to a negative TFP growth, and thus a widening gap between the economic performance of salmon producers in the two countries.

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# Development of productivity and efficiency of salmon farming in Norway and Scotland: A Malmquist productivity index approach

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**Abstract**

The objective of this study is to examine and understand the economic performance of Atlantic salmon farmed in the Norway and Scotland, which are the first and third important salmon production countries in the world. This analysis is conducted in two stages. In the first stage, an output-oriented DEA model is used to calculate the technical and scale efficiency of Norwegian and Scottish salmon farms in two years, 2008 and 2015. In the second stage, the Malmquist productivity change index is applied to each data set. This comparison will yield information on how total factor productivity (TFP) has developed in each country and how much of the changes can be attributed to changes in technology and how much to changes in pure technical efficiency and scale efficiency. Norwegian firms averaged 0.671 in 2008, while the Scottish firms had on average an efficiency score of 0.824. Four of the seven firms on that year's production frontier were Scottish and three Norwegian. The Norwegian firms were however better in taking advantage of their economies of scale, as borne out by their slightly higher scale efficiency, 0.713 as opposed to 0.679 for the Scottish firms. By 2015, the gap in technical efficiency of the firms from both countries had narrowed considerably, although the Scottish firm were on average found to be more efficient. During the period 2006-2015, the 30 Norwegian firms experienced on average a 0.1 decrease in productivity. This is mostly due to declining pure technical efficiency, that declined on average by 0.4%. Scale efficiency, on the other hand, grew by 0.3% but there was on average no technical change. On average, TFP declined by 6.3% for the Scottish firms, mostly due to large technical regress, as observed by the average decline of 11.2%. Large improvements in scale efficiency (8.9%), however, compensate partly for the adverse technical change effects. The comparison between Norwegian and Scottish farms reveals that although Scottish salmon producers may be more efficient, the regressive technical change experienced by the Scottish fish farmers has led to a negative TFP growth, and thus a widening gap between the economic performance of salmon producers in the two countries.

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## 1. Introduction

Atlantic salmon (*Salmo salar*) is one of the most important species produced in aquaculture. In 2016, world production of Atlantic salmon amounted to 2.2 million tonnes, or 2.8% of the global aquaculture production of fish, crustaceans, mollusk, etc. [1], making Atlantic salmon the ninth most important farmed species. In terms of value, however, Atlantic salmon ranked second behind white leg shrimp (*Penaeus vannamei*), with a total value of 14.4 billion $, or 6.3% of the value of the world aquaculture production. The Atlantic salmon industry has grown excessively in the last quarter century, with production almost doubling every decade. World production was 500 thousand tonnes in 1996, reached a million tonnes in 2003 and 1.5 million tonnes in 2011 before breaking the 2 million tonnes barrier in 2013. However, the growth in salmon production has stalled in recent years associated among others with fish health disorders and environmental challenges.

Norway is the undisputed world leading producer of farmed salmon [2]. The country produces around half of the Atlantic salmon sold in the world, with main markets being Japan, the EU and North America. In recent years, Norwegian production has exceeded one million tonnes. Other main producers are Chile, the UK (Scotland), Canada, the Faroe Islands and Australia. Whereas salmon production in Norway has increased dramatically in the last decade, the development in Scotland has been more modest. Scottish salmon production actually decreased in the first years of the new millennium but has since increased slightly. The compounded annual growth rate of Norway was 7% in 1998-2018, but only 2% in the UK [3]. However, while the supply Norwegian farmed salmon is only expected to grow by 4% annually in 2018-2021, production of farmed salmon in the UK is projected to rise by 7% over the same period. The salmon sector has undergone substantial consolidation since the 1990s [4][5] . This development has been especially strong in Norway and Chile, with the number of Norwegian firms producing 80% of the production decreasing from almost 70 firms in 1997 to 23 firms in 2017, and the number of firms in Chile decreasing from more than 30 to 12 over the same period [3]. In the other main producing countries – Scotland, Canada, Australia, and the Faroe Islands – the market is dominated by only a handful of firms. In Scotland and Canada only five firms produce 95% of all farmed salmon, while in the Faroe Islands and Australia only two firms produced 80% of all salmon [3].Atlantic salmon is the most highly developed form of large scale intensive aquaculture due to its productivity growth and technological change

[2]. Although salmon farming does carry considerable production risk [6–10], the risk has been deemed lower than is associated with the farming of other important species [3]. The combination of relatively low risk and high level of industrialization allows salmon farming to enjoy considerable competitive advantage.

Most of the empirical studies on salmon aquaculture have employed Norwegian data, not only because Norwegian firms have been at the forefront of the industry, but also because Norwegian data have been easier to come by. The economic performance of Norwegian salmon farming has been thoroughly researched, with early studies analysing returns to scale and factor substitution [11] the cost inefficiency of public regulation of input factors [12], the restrictions imposed on productivity by government regulations [13], and trade disputes and the relationship between long-run production cost and price [14]. Other studies have focused on the impact of risk on productivity growth and input usage [15,16], the relationship between industry cost-price margin and productivity growth [17] and what consequences changes in technology have had on the input substitution possibilities for Norwegian salmon farmers [18]. More recent studies have analysed the relationship between innovations and productivity growth [19], the relationship between input-factor prices and cost-driven output prices and how output prices will go from being driven by productivity to being driven by falling input costs [20]. Agglomeration externalities have sometime been represented as primal productivity or reduced cost, but [21] test for agglomeration effects using a profit function approach, arguing that revenue effects can be equally important as productivity and cost effects.

Fewer economic studies have dealt with the salmon farming in Scotland. [22] compared the growth of salmon farming in Norway, the UK, Chile and Canada, [23] analysed the development of Scottish salmon farming in relation to sustainable intensification and [24] modelled the growth of Scottish salmon production using a logistic population model.

Several studies have explicitly examined efficiency in salmon farming. [25] and [26] employ stochastic production frontiers to examine the influence of regional agglomeration externalities on the productivity in Norwegian salmon aquaculture, where a distinction is made between the effects on the production possibility frontier and technical inefficiency. [27] use a shadow cost model based on a system consisting of a translog cost function and its factor share equations to decompose overall cost inefficiency into its technical and allocative components. The stochastic frontier approach has also been used to separate the sources of inefficiency into temporary shocks, i.e. the outbreak of diseases, and factors that lead to permanent efficiency differences [28]

A couple of non-parametric studies have focused on the Norwegian salmon farming. [29] measure total factor productivity growth (TFP) from 2001 to 2008 using the Malmquist productivity index, and [30] employ the same methodology to analyse productivity growth during 1996-2008.

This paper presents a more recent analysis of the economic performance of the Norwegian salmon industry and presents the first estimates of efficiency and TFP growth in Scottish salmon farming. The Norwegian data covers 30 firms observed in the years 2006-2015, while the Scottish data spans eight firms operating in 2008-2015. The Scottish data is, however, rather limited and includes only information on revenue and current and fixed assets, and to make the comparison between the two countries meaningful it was decided to limit the Norwegian analysis to the use of these same variables. Although this does, naturally, affect the level and depth of the analysis, the comparison does still provide valuable insights into the relative performance of the salmon producing countries.

## 2. Methodology

Data envelop analysis (DEA) is a well-known non-parametric approach to measure the efficiency of an organization (e.g., firm, hospital, school) that uses multiple inputs to generate multiple outputs [31]. DEA was first introduced by Charnes, Cooper and Rhodes in 1978 [32] who extended Farrell's [33] methodology of estimating technical efficiency by comparing the most efficient decision making unit (DMU) with the efficiency frontier. In this paper, DEA is both used to calculate the efficiency of salmon firms in Norway and Scotland at a certain specific time, as well as to estimate changes in total factor productivity (TFP) for these same firms over time. DEA can be applied to estimate distance functions that measure how far a firm is from its optimal production relative to other firms in the same sample, given the observed inputs and outputs. As DEA is a non-parametric method, it does not require specification of the functional form of the production frontier.

Following [34], the output-oriented DEA model can be formally written as

(1) $[d_o^t(y_t, x_t)]^{-1} = max_{\varphi\lambda}\varphi$

s.t.

(2) $\varphi y_{(t)f,k} \leq \sum_{n=1}^{F} \lambda n y_{(t)n,k} \qquad k = 1, \dots, K,$

(3) $x_{(t)f,m} \geq \sum_{n=1}^{F} \lambda n x_{(t)n,m} \qquad m = 1, \dots, M,$

(4) $\lambda n \geq 0,\ \sum_{n=1}^{F} \lambda n = 1 \qquad n = 1, \dots, F.$

Here $d_o^t$ represents the output orientated distance function at time *t*, *y* is a vector of *K* outputs and *x* a vector of *M* inputs. The scalar $\phi$ measures the radial expansion in the output necessary to make the farm technically efficient. In the case where $\phi$ takes a value of unity, the farm in question is technically efficient, i.e. it is on the frontier. The vector λ is made up of F weights and identifies the extent to which the technically efficient observations are used to construct that part of the piecewise linear frontier approximation that envelops the $f^{th}$ data point. The subscripts *f = 1, … F* refer to the $F^{th}$ farm. The output orientated model examines how much output can be increased by keeping input usage fixed. The restrictions in eq. (2) and (3) ensure that each farm stays within the production possibility set for the sector when output is expanded, while eq. (4) imposes variable returns to scale (VRS) on the underlying technology. Removal of the restriction in (4) imposes constant returns to scale (CRS) on the model. The scale efficiency of the decision-making unit (DMU) can then be calculated as the ratio of the efficiency scores calculated under CRS and VRS. The scale efficiency can be interpreted as the degree to which firms are operating at optimal scale.

The model set out in eq. (1)-(4) can be employed to generate the necessary distance functions to estimate changes in TFP for individual firms using the Malmquist index. As shown by [35], an output oriented Malmquist productivity change index $m_o$ may be defined as:

(5) $m_o(y_t, x_t, y_{t+1}, x_{t+1}) = \left[\frac{d_{oc}^t(y_{t+1}, x_{t+1})}{d_{oc}^t(y_t, x_t)} \cdot \frac{d_{oc}^{t+1}(y_{t+1}, x_{t+1})}{d_{oc}^{t+1}(y_t, x_t)}\right]^{1/2}.$

Here, c refers to the CRS technology.

Eq. (5) may be rewritten to decompose changes in TFP into changes in efficiency and change in technology:

(6) $$m_o(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{d_{oc}^{t+1}(y_{t+1}, x_{t+1})}{d_{oc}^{t}(y_t, x_t)} \cdot \left[\frac{d_{oc}^{t}(y_{t+1}, x_{t+1})}{d_{oc}^{t+1}(y_{t+1}, x_{t+1})} \cdot \frac{d_{oc}^{t}(y_t, x_t)}{d_{oc}^{t+1}(y_t, x_t)}\right]^{1/2}.$$

Here, the first part of the Malmquist index estimates changes in efficiency (EC) and the second part technical change.

EC may be further disaggregated into local pure efficiency change (PEC) and scale effect (SEC), where $EC = PEC \cdot SEC$. Following [34], the changes in pure technical efficiency may be calculated as

(7) $$PEC = \frac{d_{ov}^{t+1}(y_{t+1}, x_{t+1})}{d_{ov}^{t}(y_t, x_t)},$$

and the scale effects as

(8) $$SEC = \left[\frac{d_{ov}^{t+1}(y_{t+1}, x_{t+1}) / d_{oc}^{t+1}(y_{t+1}, x_{t+1})}{d_{ov}^{t+1}(y_t, x_t) / d_{oc}^{t+1}(y_t, x_t)} \cdot \frac{d_{ov}^{t}(y_{t+1}, x_{t+1}) / d_{oc}^{t}(y_{t+1}, x_{t+1})}{d_{ov}^{t}(y_t, x_t) / d_{oc}^{t}(y_t, x_t)}\right]^{1/2},$$

where v denotes the VRS technology.

In what follows, the output-oriented model laid out in eq. (1) to (4) is employed to analyse efficiency in Norwegian and Scottish salmon farming at the beginning and end of the sample period, and the Malmquist index set out in eq. (5) to (8) used to study changes in TFP and decompose the year-to-year differences into technical change, changes in pure technical efficiency and scale effects.

## 3. Data

The Norwegian data used in this study is provided by Kontali (https://www.kontali.no/) while the UK data comes from Orbis which maintains a data resource on private companies (https://www.bvdinfo.com/en-us/our-products/data/international/orbis). Norwegian data from Kontali and other sources, has been used for several earlier empirical studies on salmon farming in Norway, but data on Scottish salmon farming has been limited. The data employed here underlines this data poverty, as the data on the Scottish salmon farms extracted from the Orbis database only allows for a rather simple analysis, using current and fixed assets as the only inputs, and revenue as output. Current assets refer to all assets of a company that can be conveniently sold, consumer, utilized or exhausted through the standard business operations, and thus converted into a cash value of the course of the next one-year period. Current assets include cash and cash equivalents, accounts receivable, stocks, liquid and marketable securities, pre-paid liabilities and other liquid assets. By contrast, fixed assets represent assets such as land, facilities, equipment and other illiquid investments, that cannot be turned into cash within a year. As such, current assets may be regarded as a crude proxy for variable costs and fixed assets a proxy for capital stock. As the intention in this paper is to compare the economic performance of Scottish salmon farms to Norwegian salmon farms, corresponding variables have been extracted from the Kontali in-house database. The Norwegian data spans 30 firms observed for the period 2006-2015, while the Scottish data covers eight firms observed during the years 2008-2015. Both datasets therefore consist of balanced panels.

**Table 1 Descriptive statistics of the Norwegian and Scottish salmon aquaculture data. EUR million (2015 prices).**

| | Mean | St.dev. | Min. | Max. |
|---|---|---|---|---|
| *Norway* | | | | |
| Revenue | 73.2 | 64.8 | 5.9 | 369.3 |
| Current assets | 47.1 | 39.4 | 4.9 | 213.1 |
| Fixed assets | 44.0 | 46.4 | 0.8 | 237.8 |
| | | | | |
| *Scotland* | | | | |
| Revenue | 68.5 | 73.5 | 1.6 | 309.3 |
| Current asssets | 46.5 | 43.8 | 0.9 | 151.1 |
| Fixed assets | 22.5 | 21.1 | 0.1 | 88.5 |

Source: Kontali and Orbis.

As shown in Table 1, firms in Norway and Scotland are on average quite similar in size, with annual revenue close to EUR 70 million, although the Norwegian firms are generally somewhat larger. In both data sets there is a considerably difference in size between the smallest and largest firms. The smallest Norwegian firm had revenue of EUR 5.9 million observed in 2009, while the largest had a revenue of EUR 369.3 million observed in 2015. The smallest Scottish aquaculture firm had a revenue of EUR 1.6 million observed in 2008 and the largest a revenue of EUR 309.3 million observed in 2015. All variables used in the analysis were deflated using the CPI in each country.

This difference in size is brought out even further in Figure 1, which shows the size distribution of the Norwegian salmon firms, for each year included in the sample. As the figure clearly reveals, the firms have on average become larger. Thus, whereas the largest firm had an operating revenue of EUR 131 million in 2006, the largest firm had sales of EUR 369 million in 2015. It is also clear from Figure 1 that firms have become more divergent in size.

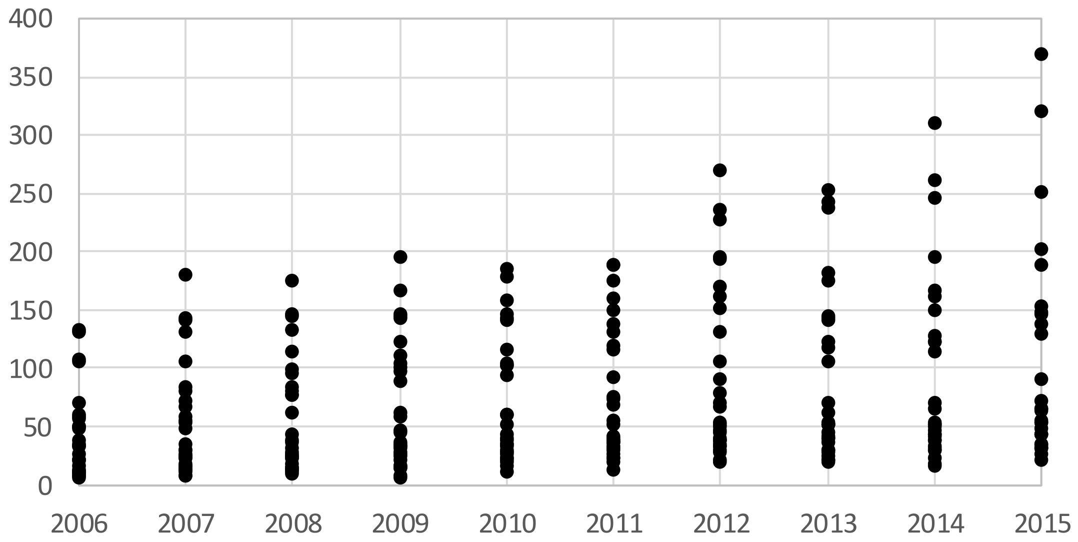


**Figure 1 Size distribution of Norwegian salmon firms 2006-2015. Operating revenue in EUR million (2015 prices). Source: Kontali.**

The size development of the eight Scottish firms included in this study is depicted in Figure 2. Although the largest firm appears to have grown larger over time, there are clear deviations from that trend, e.g. in years 2012 and 2014. While the relatively big firms have become larger, the smallest firms appear to have maintained a similar level of operation.

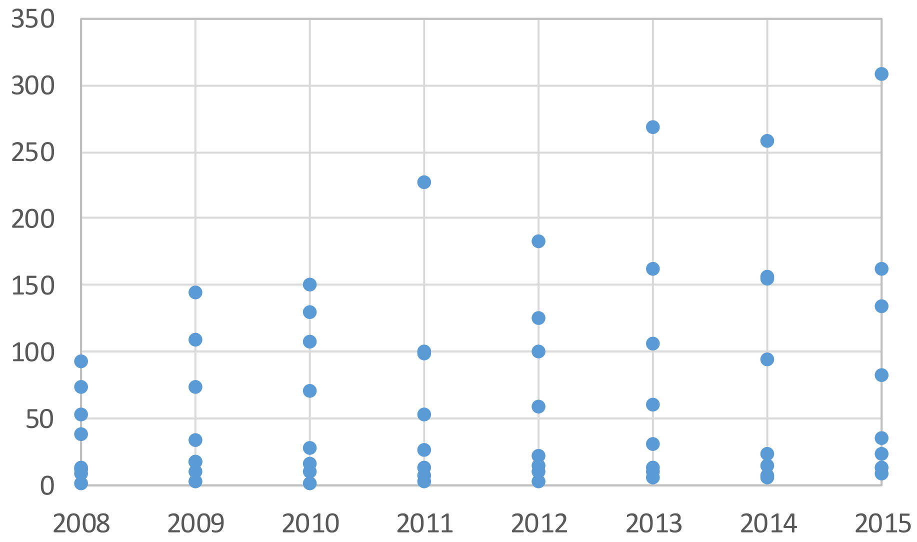


**Figure 2 Size distribution of UK salmon firms 2008-2015. Operating revenue in EUR million (2015 prices). Source: Orbis.**

## 4. Empirical results

The primary aim of the empirical analysis is to compare the economic performance of salmon farming firms in Norway and Scotland. This analysis is conducted in two stages. In the first stage, the output-oriented DEA model outlined earlier is used to calculate the technical and scale efficiency of Norwegian and Scottish salmon farms in two years, 2008 and 2015. For this purpose, the two data sets are pooled together resulting in a total of 38 observations for each year. The year 2008 is the earliest time for which data is available for salmon farms in both countries, and the year 2015 is the latest year. Applying the DEA models to the pooled data makes it possible construct a frontier composed of both Norwegian and Scottish firms and determine the number of firms for each country that are right on the frontier.

In the second stage, the Malmquist productivity change index outlined in eq. (5) to (8) is applied to each data set. This comparison will yield information on how TFP has developed in each country and how much of the changes can be attributed to changes in technology and how much to changes in pure technical efficiency and scale efficiency.

As revealed in Table 2, the technical efficiency, calculated under the assumption of VRS, of the Norwegian firms averaged 0.671 in 2008, while the Scottish firms had on average an efficiency score of 0.824. Four of the seven firms on that year's production frontier were Scottish and

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three Norwegian. The Norwegian firms were however better in taking advantage of their economies of scale, as borne out by their slightly higher scale efficiency, 0.713 as opposed to 0.679 for the Scottish firms. By 2015, the gap in technical efficiency of the firms from both countries had narrowed considerably, although the Scottish firm were on average found to be more efficient. The mean efficiency score of the Norwegian firms had now increased to 0.737 while the technical efficiency of the Scottish firms had declined to 0.788. The scale efficiency of both sets of firms was quite similar. However, there were now five Norwegian and only two Scottish firms on the frontier.

**Table 2 Average technical efficiency (TE) and scale efficiency (Scale) scores for the Norwegian and Scottish salmon farms in the years 2008 and 2015.**

| | TE | | Scale | | On frontier | |
|---|---|---|---|---|---|---|
| | 2008 | 2015 | 2008 | 2015 | 2008 | 2015 |
| Norway | 0.671 | 0.737 | 0.713 | 0.964 | 3 | 5 |
| Scotland | 0.824 | 0.788 | 0.679 | 0.970 | 4 | 2 |

The Norwegian results from the Malmquist productivity in change index are shown in Table 3. Here, a score of less than unity indicates negative change, or declining growth, and a score of more than unity indicates a positive change or increasing growth. During the period 2006-2015, the 30 Norwegian firms experienced on average a 0.1 decrease in productivity. This is mostly due to declining pure technical efficiency, that declined on average by 0.4%. Scale efficiency, on the other hand, grew by 0.3% but there was on average no technical change. The average changes only tell part of the story and hide most of the fluctuations observed in both technology and efficiency. Thus, technical change is found to have increased by 35.3% in 2006-2007 and by 13% in 2011-2012 but declined by 16.5% in 2013-2014 and by almost 14% in 2009-2010. Technical regress is observed in most years. Efficiency increased by 20.8% in 2013-2014 and 13.2% in 2010-2011 but declined by 17.5% in 2006-2007 and by 12.8% in 2012-2013. These large swings in the level of technology and efficiency also manifest themselves in large variations in TFP which falls by 18.5% in 2014-2015 and 14.1% in 2009-2010 but increases by 11.6% in 2006-2007.

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Table 3 Changes in TFP of Norwegian salmon farms decomposed into technical change (TC), pure technical efficiency change (PEC), changes in scale efficiency (SEC) and changes in efficiency (EC).

| Year | TC | PEC | SEC | EC | TFP |
|---|---|---|---|---|---|
| 2006-2007 | 1.353 | 0.836 | 0.986 | 0.825 | 1.116 |
| 2007-2008 | 0.987 | 1.089 | 0.957 | 1.042 | 1.029 |
| 2008-2009 | 0.985 | 1.087 | 0.958 | 1.042 | 1.026 |
| 2009-2010 | 0.862 | 0.971 | 1.026 | 0.996 | 0.859 |
| 2010-2011 | 0.929 | 1.049 | 1.079 | 1.132 | 1.052 |
| 2011-2012 | 1.130 | 0.989 | 0.974 | 0.963 | 1.087 |
| 2012-2013 | 0.934 | 0.925 | 0.942 | 0.872 | 0.815 |
| 2013-2014 | 0.835 | 1.092 | 1.106 | 1.208 | 1.009 |
| 2014-2015 | 1.072 | 0.956 | 1.014 | 0.970 | 1.039 |
| Average change in % | 0.000 | -0.400 | 0.300 | -0.100 | -0.100 |

Of the 30 Norwegian firms in the sample, 17 showed on average a positive TFP growth, but for the other 13 firms TFP declined on average. Most of the difference in performance can be traced to variations in pure technical efficiency; with the 17 firms registering positive TFP growth moving closer to the frontier, but those experiencing negative TFP growth moving away from the frontier.

Table 4 Number and performance of Norwegian firms with average negative and positive TFP growth.

| TFP | Firms | TC | PEC | SEC | EC | TFP |
|---|---|---|---|---|---|---|
| TFP > 0 | 17 | 0.1 | 2.3 | 0.4 | 2.7 | 2.8 |
| TFP < 0 | 13 | -0.3 | -3.8 | 0.3 | -3.5 | -3.8 |

The development of TFP and its components of the Scottish firm is outlined in Table 5. On average, TFP declined by 6.3% for these firms, mostly due to large technical regress, as observed by the average decline of 11.2%. Large improvements in scale efficiency (8.9%), however, compensate partly for the adverse technical change effects.

Table 5 Changes in TFP of Scottish salmon farms decomposed into technical change (TC), pure technical efficiency change (PEC), changes in scale efficiency (SEC) and changes in efficiency (EC).

| Year | TC | PEC | SEC | EC | TFP |
|---|---|---|---|---|---|
| 2008-2009 | 0.673 | 0.89 | 1.355 | 1.205 | 0.811 |
| 2009-2010 | 0.873 | 1.055 | 1.058 | 1.115 | 0.974 |
| 2010-2011 | 0.798 | 0.885 | 1.257 | 1.112 | 0.887 |
| 2011-2012 | 1.001 | 0.794 | 0.926 | 0.734 | 0.735 |
| 2012-2013 | 1.202 | 0.972 | 0.988 | 0.961 | 1.155 |
| 2013-2014 | 0.837 | 1.338 | 1.078 | 1.443 | 1.208 |
| 2014-2015 | 0.926 | 0.936 | 1.021 | 0.955 | 0.884 |
| Average change in % | -11.2 | -3.1 | 8.9 | 5.5 | -6.3 |

Not all the Scottish firms performed poorly during the period of observation. Three of them registered on average TFP growth of 2.2%, but TFP grew on average for the firms by 10.7%.

Table 6 Number and performance of Scottish firms with average negative and positive TFP growth.

| TFP | Firms | TC | PEC | SEC | EC | TFP |
|---|---|---|---|---|---|---|
| TFP > 0 | 3 | -9.3 | 0.5 | 12.2 | 12.7 | 2.2 |
| TFP < 0 | 5 | -12.1 | -5.1 | 7.1 | 1.5 | -10.7 |

The development of TFP for the Norwegian and Scottish salmon farms in 2008-2015 is traced out in Figure 3. During this period, productivity of the Norwegian firms declined on average by 1.6% and productivity of the Scottish firms declined by 6.3%. The year-to-year variations are quite extreme, with the firms experiencing large swings in productivity growth between years. It is also noteworthy that the observed productivity cycles in the two countries are out of sync and that the groups of firms do not experience good or bad productivity performance in the same years.

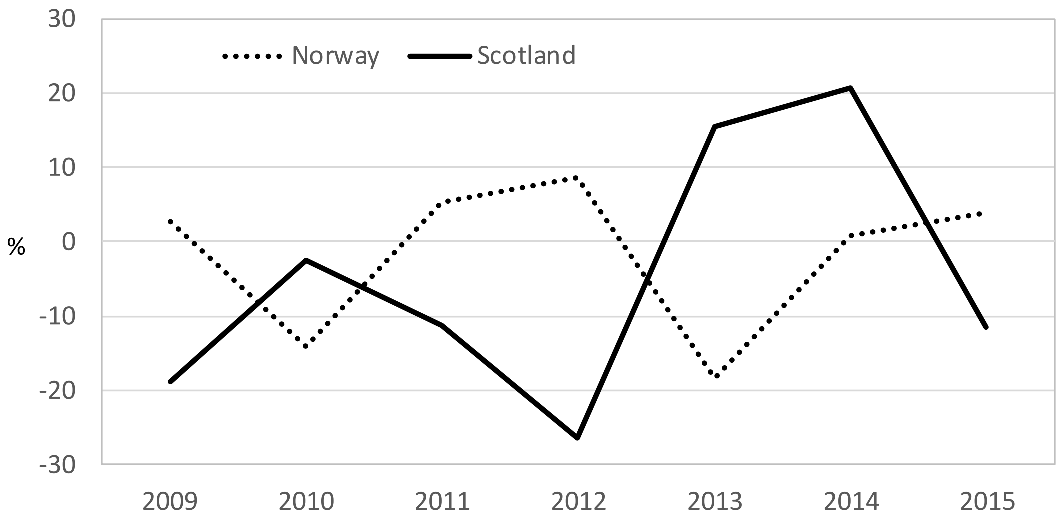


Figure 3 Development of TFP for the Norwegian and Scottish salmon farms. Percentage change from the previous year.

## 5. Discussion and conclusion

Although the empirical results clearly reveal large year-to-year fluctuations in productivity, technical change and efficiency, the overall picture looks more plausible. In the years 2006-2015, the Norwegian firms included in the sample experienced a slight annual decrease in productivity, brought about primarily by changes in technical efficiency. The Scottish firms performed significantly worse; TFP declined on average by 6.3% in 2008-2015, mostly because of regressive technical change. During this period, TFP of the Norwegian firms declined on average by 1.6%.

It is interesting to compare these results to earlier studies of the Norwegian industry that also apply the Malmquist productivity index in a DEA setting. [36] observed an annual productivity improvement of 15-20%, which mostly could be attributed to technical change. In a later study, [29] show that TFP grew from 2001 to 2005, but thereafter declined from 2005 to 2008, mostly due to a regress in the technical change component of the MPI. Finally, [30] find that TFP in the Norwegian aquaculture industry grew on average by 1.9% in 1996-2008, with changes in efficiency explaining two thirds of that growth. As noted by [29] and [30], these results are consistent with the development of a maturing industry that in its infancy shows considerable growth, but later develops into a more mature industry with lower growth rate. Indeed, the results from this study indicate that Norwegian salmon farms may be moving towards an era of declining productivity.

The comparison between Norwegian and Scottish farms reveals that although Scottish salmon producers may be more efficient, the regressive technical change experienced by the Scottish fish farmers has led to a negative TFP growth, and thus a widening gap between the economic performance of salmon producers in the two countries.

It is though worth noting, that the analysis undertaken in this paper is based on a limited number of inputs and that these inputs are accounting variables and not the kind of inputs generally used in productivity studies of the salmon industry, such as feed, smolt, labor, area and capital. Furthermore, the Scottish data only includes eight firms which also restrict the analysis. Although these data deficiencies may undermine the results a little bit, they should not alter the main conclusions that Norwegian firms have outperformed their Scottish counterparts in recent years.

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