Future challenges for the maturing Norwegian salmon aquaculture industry: An analysis of total factor productivity change from 1996 to 2008

Frank Asche a, Atle G. Guttormsen b,⁎, Rasmus Nielsen c

a Department of Industrial Economics, University of Stavanger, Ullandhaug N-4036, Stavanger, Norway
b UMB school of Economics and Business, Norwegian University of Life Sciences, P.O. Box 5903, N-1432, Aas, Norway
c Institute of Food and Resource Economics, University of Copenhagen, DK-1958 Frederiksberg C, Denmark

ARTICLE INFO

Article history:
Received 4 November 2011
Received in revised form 22 August 2012
Accepted 13 February 2013
Available online 27 February 2013

Keywords:
Salmon aquaculture
Total factor productivity
Data envelopment analysis
Malmquist index

ABSTRACT

In this paper, we analyze total factor productivity change in the Norwegian salmon aquaculture sector from 1996 to 2008. During this period, the production has on average been growing with 8% per year. At the same time, the price of salmon has stabilized indicating that an increase in demand is driving the production growth rather than increasing productivity in the sector. A Malmquist index approach is used to calculate total factor productivity change applying data envelopment analysis to construct the underlying production frontier. Furthermore, the bootstrap approach has been applied to construct confidence intervals for the Malmquist change indices. The results show a total factor productivity change of 1–2% a year, where the contribution from technical efficiency change is between 0.2 and 1.2% and technological change is between 0.6 and 0.8%. The results show that productivity growth has slowed down over the years indicating that demand growth is the main driver of production growth. Furthermore, as productivity growth is slowing down production growth can only happen when the production area is increased. The scarcity of suitable production sites can potentially be the most limiting factor to future production growth in the salmon aquaculture industry.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Aquaculture has been the world’s fastest growing animal food producing industry during the last decades (Food and Agriculture Organisation of the United Nations, 2009). The main factor causing this development is widely recognized to be that control with the biological production process has led to a tremendous growth in this development is widely recognized to be that control with the Organisation of the United Nations, 2009). The main factor causing this development is widely recognized to be that control with the production process has allowed systematic R&D at all levels in the supply chain from input providers (Asche, 2008; Tweteras and Heshmati, 2002), production and quality control (Forsberg and Guttormsen, 2006) and downstream due to improvements in logistics and sales (Asche et al., 2007b; Kvaløy and Tweteras, 2008; Larsen and Asche, 2011). However, the main focus when studying productivity growth in aquaculture has been on the production plants or farms (Sharma and Leung, 2003), as this is the key element in the successful aquaculture industry.

Salmon is one of the most successful aquaculture species, and productivity growth has been the main engine for the production growth (Asche, 2008). Productivity can be regarded as a performance measure, as more efficient firms produce more output with a set of inputs. Innovations increase productivity by influencing the output/input ratio. For instance, better breeds lead to increased productivity because they have better growth for the same input mix. In the case of Norwegian salmon production there is increasing evidence that productivity growth is slowing down. An indication of this feature is shown in Fig. 1. While the real price of salmon was rapidly declining until the late 1990s, indicating that productivity growth was faster than demand growth, the price of salmon stabilized in the late 1990s (Fig. 2). The relatively constant price during the last decade is an indication that productivity grows at a similar pace as demand. However, the production growth, which is the volume of output produced relative to the year before, has on average been growing with 8% per year from 1996 to 2008. With a fairly constant price, this implies a demand growth of 8%, which is very close to what is reported by Asche et al. (2011). This raises two interesting questions. Is it the demand growth that has picked up pace or is productivity growth that has slowed down? Moreover, if productivity growth is slowing down, the only way for production to increase is by the use of more inputs. That is...
straightforward if the inputs are available. However, in salmon farming, the main input is production sites, a factor that might be a limit to further growth. More than 95% of all farmed salmon is currently produced in four countries (Canada, Chile, Norway and the UK), and in all countries the access to production sites is tightly regulated.

A number of studies have investigated productivity growth in Norwegian salmon farming (Andersen et al., 2008; Asche et al., 2007a; Guttormsen, 2002; Tveteras, 2002). Other studies focus on more specific element such as agglomeration (Tveteras, 2002; Tveteras and Battese, 2006), production risk (Kumbhakar and Tveteras, 2003), inefficiency (Asche et al., 2009b) and learning by doing (Nilsen, 2010) using a parametric approach. This studies report productivity growth in the range of 3–15%, that technical change has been non-neutral, and that productivity growth is less when accounting for inefficiency, as reduced inefficiency shows up as productivity growth when not modeled explicitly.

In this study, we are using a Malmquist index to calculate total factor productivity (TFP) growth using data envelopment analysis (DEA) to construct the underlying production frontier. Even though, the Malmquist index and DEA are often used for productivity analysis, the application to aquaculture is still limited (Cinemre et al., 2006; Hassanpour et al., 2010; Vassdal and Holst, 2011; Vassdal and Roland, 1998) and with the exception of the early study by Vassdal and Roland (1998) and the recent study of Vassdal and Holst (2011), this approach has not been used to investigate productivity development in salmon aquaculture. The advantage of using the Malmquist index is that the TFP growth can be divided into both technical efficiency change and technological change. Our approach will add to the information provided by Vassdal and Holst (2011) as we calculate pure technical and scale efficiency and use the approach of Simar and Wilson (1999) to obtain standard errors. Moreover, we also explicitly account for the smolt input and the area used for production. Furthermore, the TFP growth and related change indices are calculated in two ways; first using a balanced data set estimating the year to year change; secondly by using a balanced data set only including firms operating in both 1996 and 2008 to estimate the change for the whole period. Finally, by assuming that the price has been varying around a constant mean since the late 1990s, we can separate the part of the production growth that is due to productivity change from the part that is due to increased input factor use.

The paper is organized as follows: We start by introducing the readers to the methodology, focusing on the Malmquist index and DEA. In Section 3, the data for the analysis are described together with some descriptive statistics before we present the results from our analysis, in Section 4. At last we conclude and discuss some possible policy implications.

2. Methodology

The Malmquist index can be used to estimate changes in total factor productivity (TFP) for a firm or an industry over time. The TFP index is defined (Coelli et al., 2005) as an index of the ratio of all output produced to all input used in the production. The Malmquist index is often used when price and cost data are not readily available. The index is based on non-parametric distance functions, which allows for a description of a multi-input and multi-output production technologies without the need to specify a behavioral objective function (Coelli et al., 2005). Furthermore, the index has the advantage that TFP changes can be separated into technical efficiency change (EFFCH) and technological change (TECHCH). The EFFCH can further be divided into pure technical efficiency change (PURE EFFCH) and scale efficiency change (SCALE EFFCH). Data envelopment analysis (DEA) can be applied to estimate the distance functions used to obtain the results of the Malmquist TFP index (Fare et al., 1994). The distance functions measure how far a firm is from its optimal production relative to other firms in a sample given the observed input and output.

An advantage of using the non-parametric methods, such as DEA and TFP indices, is that these do not require specification of a functional form for the production frontier. Furthermore, it is relatively easy to handle multiple inputs and outputs in these methods. On the other hand, the non-parametric approaches do not take statistical noise into account and all deviations from the frontier are considered as inefficiency. However, using the bootstrap technique suggested by Simar and Wilson (1998, 1999, 2000a), which can be used to analyze the sensitivity of nonparametric efficiency scores to sampling variation, it is possible to address this problem.

In this paper, the Malmquist TFP index is applied to estimate TFP changes in the Norwegian salmon aquaculture sector from 1996 to 2008.

Fare et al. (1994) specified an output oriented Malmquist productivity change index $m_o$ as follows:

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

Where $d_{oe}$ represents the distance function. The subscript o indicates the output-oriented approach and c refers to the use of constant returns to scale (CRS) technology. The index $m_o$ estimates the productivity change of a firm producing $(y_{t+1}, x_{t+1})$ in period $(t + 1)$ relative
The output-oriented DEA model can formally be written as (Coelli et al., 2005):

\[ \text{EFFCH} = \max_{\lambda, \phi} \left( \sum_{j=1}^{J} \lambda_j y_j - \sum_{i=1}^{I} \phi_i x_i \right) \]

Finally, the SCALE EFFCH can be calculated as (Coelli et al., 2005):

\[ \text{SCALE EFFCH} = \frac{\mu_{ov}^{d_{ov}}(y_{t+1}, x_{t+1})}{\mu_{ov}^{d_{ov}}(y_t, x_t)} \]

The bootstrap technique suggested by Simar and Wilson (1998, 1999, 2000a,b) is applied. Using this method, it is possible to address the problem of measurement errors estimating confidence intervals for DEA scores and Malmquist indices. The “smoothed” bootstrap procedure outlined in Simar and Wilson (1999) is performed 1000 times, which results in a sample of 1000 estimates of the Malmquist index and change indices for each individual firm. The smoothing parameter suggested by Silverman (1986) for the bivariate data is used in the present context. From these samples a confidence interval can be constructed. This makes it possible to evaluate whether the Malmquist TFP changes and decomposed change indices of a firm are subject to significant changes during the time period investigated, and if the reason for these changes can be allocated to EFFCH, TECHCH, PURE EFFCH or SCALE EFFCH.

For detection of outliers, which can have large influence on the estimated DEA frontier, the super efficiency test developed by Andersen and Petersen (1993) is used. The reason for removing outliers in this study is that the aim is to obtain representative average TFP changes that are not heavily influenced by a few extreme observations. For a more thorough evaluation on detection of outliers using the super efficiency test, see Wilson (1995), Banker and Chang (2006).

### 3. Data

The data used in the present analysis is based on a profitability survey for Norwegian aquaculture collected by the Norwegian Directorate of Fisheries. The survey collects annual account data at the farm level.
As can be seen from Tables 1–3, the average use of input per kilo of output is quite similar in the three samples. Even in the smallest sample with 57 firms data cover 12% of the total production and 18% of the total numbers of firms in 1996 and 22% of the total production and 54% of the total numbers of firms in 2008. Furthermore, all samples contain a mix of small, medium and large size firms. Altogether, this indicates that the samples are relative representative for the industry as a whole.

4. Empirical results

In this section, a general description of the development and the influence of the selected input variables are presented based on the data presented in Table 1. Furthermore, the estimated results from the calculation of the Malmquist index and the bootstrap analysis are presented.

Feed is one of the most important inputs in salmon production (Guttormsen, 2002). In the period 1996–2008 the use of feed has been relatively constant, as shown in Fig. 3. The area used for production has increased, which to some extent can be explained by the implementation of legislation on the use of production sites and the volume of fish in the cages. The regulation is introduced to control the volume of production and to protect the environment. Capital invested in tangible fixed assets has been increasing, due to investment in larger cages and feeding-boats using more advanced technology, such as, computer systems to monitor feeding, oxygen levels in the water and the growth in the cages (Asche and Bjørndal, 2011). The increased use of feed, area and capital for production of one kilo of fish indicates a decrease in productivity from 1996 to 2008.

### Table 2
Selected data for the year to year analysis 1996–2008.

<table>
<thead>
<tr>
<th>Firm</th>
<th>Year</th>
<th>Output 1000 tons</th>
<th>Feed 1000 tons</th>
<th>Smolt 1000 tons</th>
<th>Labor 1000 h</th>
<th>Area million cubic meters</th>
<th>Capital million NOK real value</th>
<th>% of total production of salmon and trout</th>
<th>Average use of input per kilo of output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Y X1 X2 X3 X4 X5</td>
<td>Y X1 X2 X3 X4 X5</td>
<td>Y X1 X2 X3 X4 X5</td>
<td>Y X1 X2 X3 X4 X5</td>
<td>Y X1 X2 X3 X4 X5</td>
<td>Y X1/X Y X2/Y Y X3/Y Y X4/Y Y X5/Y</td>
<td>Y X1/Y Y X2/Y Y X3/Y Y X4/Y Y X5/Y</td>
<td>Y X1/Y Y X2/Y Y X3/Y Y X4/Y Y X5/Y</td>
</tr>
<tr>
<td>173</td>
<td>1996_1</td>
<td>124 142</td>
<td>3</td>
<td>1463 4</td>
<td>738</td>
<td>39</td>
<td>1.15 0.024 0.012 0.030 5.95</td>
<td>124 142</td>
<td>3</td>
</tr>
<tr>
<td>163</td>
<td>1997_1</td>
<td>165 198</td>
<td>4</td>
<td>1736 5</td>
<td>1119 45</td>
<td>1.20 0.024 0.011 0.029 6.78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>161</td>
<td>1997_2</td>
<td>148 175</td>
<td>4</td>
<td>1487 4</td>
<td>898 40</td>
<td>1.18 0.027 0.010 0.028 6.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>148</td>
<td>1998_2</td>
<td>184 219</td>
<td>4</td>
<td>1434 6</td>
<td>1055 45</td>
<td>1.19 0.022 0.008 0.032 5.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>148</td>
<td>1998_3</td>
<td>197 235</td>
<td>5</td>
<td>1526 6</td>
<td>1114 48</td>
<td>1.19 0.025 0.008 0.031 5.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>148</td>
<td>1999_3</td>
<td>218 261</td>
<td>6</td>
<td>1655 7</td>
<td>1280 46</td>
<td>1.20 0.028 0.008 0.031 5.87</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>143</td>
<td>1999_4</td>
<td>241 287</td>
<td>6</td>
<td>1869 8</td>
<td>1480 51</td>
<td>1.19 0.025 0.008 0.031 6.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>143</td>
<td>2000_4</td>
<td>300 354</td>
<td>8</td>
<td>1919 8</td>
<td>1902 61</td>
<td>1.18 0.027 0.006 0.028 6.34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>2000_5</td>
<td>247 290</td>
<td>7</td>
<td>1542 7</td>
<td>1546 51</td>
<td>1.17 0.028 0.006 0.028 6.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>2001_5</td>
<td>273 320</td>
<td>6</td>
<td>1645 11</td>
<td>2013 54</td>
<td>1.17 0.022 0.006 0.039 7.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>116</td>
<td>2001_6</td>
<td>248 290</td>
<td>5</td>
<td>1456 10</td>
<td>1900 49</td>
<td>1.17 0.020 0.006 0.039 7.66</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>116</td>
<td>2002_6</td>
<td>276 330</td>
<td>6</td>
<td>1490 11</td>
<td>1849 51</td>
<td>1.20 0.022 0.005 0.039 6.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>2002_7</td>
<td>258 304</td>
<td>6</td>
<td>1388 10</td>
<td>1695 47</td>
<td>1.18 0.023 0.005 0.038 6.57</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>2003_7</td>
<td>255 322</td>
<td>5</td>
<td>1326 11</td>
<td>1565 44</td>
<td>1.26 0.020 0.005 0.045 6.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>2003_8</td>
<td>247 312</td>
<td>5</td>
<td>1286 11</td>
<td>1465 43</td>
<td>1.26 0.020 0.005 0.044 5.93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>2004_8</td>
<td>272 330</td>
<td>7</td>
<td>1426 13</td>
<td>1603 43</td>
<td>1.21 0.026 0.005 0.049 5.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2004_9</td>
<td>300 370</td>
<td>7</td>
<td>1643 15</td>
<td>1822 48</td>
<td>1.23 0.023 0.005 0.049 6.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2005_9</td>
<td>359 431</td>
<td>8</td>
<td>1693 18</td>
<td>1900 56</td>
<td>1.20 0.022 0.005 0.050 5.29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>2005_10</td>
<td>409 488</td>
<td>9</td>
<td>1881 20</td>
<td>2637 63</td>
<td>1.19 0.022 0.005 0.049 6.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>2006_10</td>
<td>502 588</td>
<td>10</td>
<td>2290 25</td>
<td>3041 72</td>
<td>1.17 0.020 0.005 0.050 6.06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>2006_11</td>
<td>425 511</td>
<td>9</td>
<td>2110 23</td>
<td>2419 61</td>
<td>1.20 0.021 0.005 0.055 5.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>2007_11</td>
<td>523 626</td>
<td>11</td>
<td>2207 33</td>
<td>3618 64</td>
<td>1.20 0.021 0.004 0.063 6.92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>2007_12</td>
<td>558 669</td>
<td>11</td>
<td>2332 34</td>
<td>3959 68</td>
<td>1.20 0.020 0.004 0.060 7.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>2008_12</td>
<td>597 756</td>
<td>12</td>
<td>2717 42</td>
<td>4577 73</td>
<td>1.27 0.020 0.005 0.070 7.67</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
On the other hand, the average use of smolts has decreased from an average of 0.025 in 1996–2000 to an average of 0.021 in 2001–2008 per kilo produced. The reason for this change can be explained by the fact that the smolts released in the pens are larger than in the beginning of the period, and that the vaccines and antibiotics have been improved in lowering the mortality rate. The average use of labor in terms of hours has been reduced by more than 50% from 1996 to 2008. The decreased input of smolts and labor indicates an increase in productivity.

In Fig. 4, a real price index for the selected input is shown from 1996 to 2008 for production of one kilo of fish. Only capital cost has increased over the period, whereas feed, labor, and smolts have decreased. The sum of the selected input cost decreased until 2005, but since then, the cost per kilo increased to a level just below the cost in 1996.

Table 4 shows the results from the calculation of the Malmquist index. The results show that the TFP changes have been positive in most years, except for 2008. Overall, the average yearly growth has been 1.9% from 1996 to 2008. However, the TFP change has been stagnating or falling since 2005. In the year to year analysis, the most important component has been the EFFCH with an average yearly growth of 1.2%, whereas TECHCH has contributed with an average yearly growth of 0.6%. The PURE EFFCH has been positive with an average growth of 1.4% a year, whereas the average SCALE EFFCH has been close to zero. Hence, the constant return to scale assumption of Vassdal and Holst (2011) does not seem to influence the results, despite the fact that increasing returns are reported in recent parametric studies (Asche et al., 2009b; Nilsen, 2010).

In general, the results seem plausible and are in line with those in Vassdal and Holst (2011), which also find a decline in the TFP growth from 2005. In contrast to these studies, Vassdal and Roland (1998), analyzed the years 1992–1995 and found an annual productivity improvement of 15–20%, which mostly could be attributed to TECHCH. Growth rates of that magnitude are not found in this analysis. In our analysis, the contribution to TFP growth from TECHCH has been negative in most years since 2002, which is also in line with the results in Vassdal and Holst (2011). This indicates that the most obvious technological improvements have been integrated by the industry and that the industry is becoming more mature. With TFP growth at 1.9%, productivity growth is lagging far behind a production growth at 8%, and increased input factor use do accordingly seem to be the main reason why salmon production continues to increase.

In order to test the result found in the year to year analysis the Malmquist index is calculated for a sample of 57 firms operating both in 1996 and 2008. Using this approach we are able to study the development for each individual firm operating in the whole period instead of looking at a year to year development. This way we can obtain more detailed information on the TFP changes at firm level and the importance of EFFCH and TECHCH. On the other hand, the sample is reduced due to the facts that firm stops operating and new ones are starting up. The exclusion of firm leaving or entering the sector over the time period can bias the results, because the ones leaving may be expected to have low productivity and the ones entering might have the opportunity to invest in new technology and have high productivity. This has to be born in mind when evaluating the results from the two analyses. Furthermore, to investigate if the changes are significant, confidence intervals are constructed using the bootstrap procedure suggested by Simar and Wilson (1999).4

In Table 5, the average result for the 57 firms is presented. The calculation of the Malmquist index shows a different trend than the results obtained by the year to year calculation. The average annual TFP growth is estimated to 1%, which is 0.9% less than the results from the year to year analysis. The contribution from EFFCH is 1% lower at a level of 0.2% a year, whereas the TECHCH has become slightly more important increasing from 0.6 to 0.8%.

An explanation for these differences could be that the firms that have managed to stay in the sector for the whole period of time have been close to the frontier from the beginning, due to good management, therefore, the catching up effect has been smaller than for other firms. However, this seems not to be the case here, because the average EFFCH is the same for the selected 57 firms as for the whole sample in both years.

Another explanation could be that within an industry characterized by a high rate of innovation, the producers tend to employ several different technologies at the same time, which can contribute to technical inefficiency. In other words, even though, the average producer experiences growth they are not catching up with the best using state of the art technology, and the distance to the frontier (inefficiency) decreases at a slower rate than if there have been no technical innovations. Furthermore, firms entering an industry which have a high rate of innovation may be able to leapfrog already established firms by avoiding large investments in older technologies, and taking advantage of best practice technologies that were previously unavailable (Nilsen, 2010).

In Table 6, the change index score is shown for the 57 selected firms in the sample. 38 experienced a positive TFP growth, whereas only 19 had negative growth. Using the bootstrap method 28 firms could be identified as having a significant positive growth, whereas only 12 had a significant negative growth. Furthermore, the most important contribution to TFP growth comes from TECHCH where 42 firms experienced positive growth (20 significant) and only 15 had negative growth (3 significant). Looking at EFFCH 32 firms had positive growth (9 significant) and 25 had negative growth (7 significant). These results are in line with Vassdal and Roland (1998) in

\[ \text{Index } 1996 = 100 \]

4 The original DEA estimates have not been bias corrected, because the bias corrected estimator had a higher standard deviation than the original estimator (Simar and Wilson, 1999). Furthermore, the analysis was also performed using “the normal reference rule” for the calculation of bandwidth (Simar and Wilson, 2000a). The changed bandwidth had no effect on the estimated confidence intervals (Simar and Wilson, 1998, 1999).
which they concluded that TECHCH was the most important driver of TFP growth. Furthermore, the results can also be related to the agriculture sector, where Rasmussen (2010) investigated TFP growth for three kinds of agricultural farming in Denmark. The overall result showed an average yearly growth of 2.1–3.3% from 1985 to 2006. TECHEFF was the most important factor with a yearly growth of 1.0–1.6%, whereas EFFCH was close to zero.

In Table 7, the average growth in input and output parameters from 1996 to 2008 is shown for the selected 57 firms divided into groups with a positive, neutral and negative changes in the Malmquist index, EFFCH and TECHCH indices at a 10% level of significance.

The firms experiencing a positive TFP change increased production 4.7 times, which equals the average level, but they used a lower than average input. For the firms that experienced positive EFFCH the output increased more than 6 times using a little more input than the average firm except for the input of labor hours and area. For the firms experiencing positive TECHCH the output increased 4.9 times using less input than the average firm except for the input of feed.

The overall average growth in production shows an increase in output of 4.8.

Of the 57 firms, 11 have a combined production of salmon and salmon trout. There is no indication that a combined production of salmon and salmon trout has any influence on TFP, thus, the firms having a combined production are represented in both the positive, neutral and negative groups above.

5. Concluding remarks

The results in this paper show that the yearly growth in the Norwegian salmon production has slowed down from yearly growth rates of 15–20% in 1992–1995 (Vassdal and Roland, 1998) to yearly growth rates of 1–2% over the period 1996–2008. The decomposition of the Malmquist index into EFFCH and TECHCH shows that the average change in EFFCH has been between 1.2 and 0.2%, whereas the TECHCH has been between 0.6 and 0.8%. Moreover, in contrast to what is the case in parametric studies, there is no evidence of increasing returns to scale. This may then be an artifact of the functional form.

This analysis clearly illustrates the development of a maturing industry; from an infant industry with high growth rates and technological development to a more mature industry with lower growth rate. Lower growth rate also means limited possibilities to increase productivity growth through technical development and more efficient production. The industry is then becoming more dependent upon external factors, such as demand and regulation, which they have less control over. With the limited productivity growth, this indicates that most of the production growth from the late 1990s has been possible primarily due to higher input use. This is also an indication that production sites have not been a strongly limiting factor. In Norway, this is partly due to more licenses and partly due to larger plants at each location (Asche and Bjørndal, 2011). Whether this can continue is a different question as production licenses are tightly regulated in all the large salmon producing countries, and environmental concerns are increasingly leading to regulations that can limit plant size.

The use of the main input, feed, has been slightly increasing from 1996 to 2008, which indicates a decrease in productivity. On the other hand, the cost and the relative importance of feed to other inputs in production have been decreasing, which is in contrast to the development from 1986 to 1998, where Guttormsen (2002) showed that the cost share and importance of feed were increasing even though the price was falling. Guttormsen (2002) also showed that there was evidence of very limited short-run substitution possibilities between feed and capital and feed and labor. A productivity increase in feed should, therefore, either be driven by a decrease in the consumption of feed or lower prices. Since the consumption of feed seems to have reached its minimum level, increased productivity is depending on lower prices. So far, the feed producing industry has been able to substitute between the more expensive fish meal and oil and cheaper vegetable alternatives to proteins, to cut prices, and this development is expected to continue. On the other hand, consumers demand for a more “healthy” product that can limit the substitution possibilities and possible price decrease, because the vegetable alternatives do not contain the healthy omega 3 and 6 fatty acids.

That the area used for production has been the input factor that has increased the most, this indicates a reduction in productivity over the period investigated. The spatial issue is important for several reasons. First, as the production has expanded in Norway the availability of good production sites has become more limited and the

<table>
<thead>
<tr>
<th>Year</th>
<th>Firm’s</th>
<th>EFFCH</th>
<th>TECHCH</th>
<th>TFPCH</th>
<th>PURE EFFCH</th>
<th>SCALE EFFCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996–1997</td>
<td>173</td>
<td>1.00</td>
<td>1.00</td>
<td>1.01</td>
<td>1.01</td>
<td>0.99</td>
</tr>
<tr>
<td>1997–1998</td>
<td>161</td>
<td>0.99</td>
<td>1.04</td>
<td>1.03</td>
<td>0.99</td>
<td>1.01</td>
</tr>
<tr>
<td>1998–1999</td>
<td>148</td>
<td>1.02</td>
<td>1.01</td>
<td>1.02</td>
<td>1.04</td>
<td>0.98</td>
</tr>
<tr>
<td>1999–2000</td>
<td>143</td>
<td>0.98</td>
<td>1.09</td>
<td>1.06</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>2000–2001</td>
<td>128</td>
<td>1.02</td>
<td>0.98</td>
<td>1.00</td>
<td>1.00</td>
<td>1.02</td>
</tr>
<tr>
<td>2001–2002</td>
<td>116</td>
<td>1.02</td>
<td>1.03</td>
<td>1.05</td>
<td>1.02</td>
<td>1.00</td>
</tr>
<tr>
<td>2002–2003</td>
<td>106</td>
<td>1.02</td>
<td>0.98</td>
<td>1.01</td>
<td>1.01</td>
<td>1.02</td>
</tr>
<tr>
<td>2003–2004</td>
<td>104</td>
<td>1.03</td>
<td>0.98</td>
<td>1.01</td>
<td>1.05</td>
<td>0.98</td>
</tr>
<tr>
<td>2004–2005</td>
<td>100</td>
<td>1.05</td>
<td>1.01</td>
<td>1.05</td>
<td>1.02</td>
<td>1.03</td>
</tr>
<tr>
<td>2005–2006</td>
<td>95</td>
<td>0.98</td>
<td>1.02</td>
<td>1.00</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td>2006–2007</td>
<td>81</td>
<td>1.04</td>
<td>0.96</td>
<td>1.00</td>
<td>1.02</td>
<td>1.03</td>
</tr>
<tr>
<td>2007–2008</td>
<td>87</td>
<td>0.94</td>
<td>0.99</td>
<td>0.99</td>
<td>1.05</td>
<td>0.99</td>
</tr>
<tr>
<td>Average yearly growth %</td>
<td>1.2</td>
<td>0.6</td>
<td>1.9</td>
<td>1.4</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>
aquaculture producers are competing for space with other users, such as fishermen and recreational use of the water. The same feature is important also in Chile as production is moving south, and lack of new sites has largely stopped the production growth in Canada and Scotland (Asche and Bjørndal, 2011). Secondly, agglomeration of the aquaculture industry can have positive effects on productivity, but a higher density of fish farms can have negative effects, because it increases the risk of spreading diseases between farms, and the negative effect seems to dominate (Asche et al., 2009a; Nielsen, 2011; Tveteras, 2002).

With more than 95% of the world’s salmon production located in only four countries, the limited productivity growth in the last decade raises questions with respect to how long farmed salmon production can continue to grow. It is certain that it is limited how much production can continue to grow if it can only happen with more sites. As technology is globally available (Asche and Bjørndal, 2011), our results can also go a long way to explain why production has not increased in Canada and Scotland, as new sites are not available in these countries. It also goes a long way to explain why price volatility has increased (Ogland and Skjervold, 2008). This development also gives stronger incentives for more radical technology development, where genetic modification may be the strongest candidate (Smith et al., 2010).

### References


