This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 635761

Deliverable No. 2.3

Project acronym:

PrimeFish

Project title:

"Developing Innovative Market Orientated Prediction Toolbox to Strengthen the Economic Sustainability and Competitiveness of European Seafood on Local and Global markets"

Grant agreement No: **635761**

This project has received funding from European Union´s Horizon 2020 research and innovation program.

Start date of project: **1st March 2015**

Duration: **48 months**

Due date of deliverable:	31/05/2016
Submission date:	17/08/2017
File Name:	PrimeFish_Deliverable2_3 Economic performance of farmed species
Revision number:	01
Document status:	Final[1]
Dissemination Level:	PU[2]

Revision Control

Role	Name	Organisation	Date	File suffix[3]
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[1] Document will be a draft until it was approved by the coordinator
[2] PU: Public, PP: Restricted to other programme participants (including the Commission Services), RE: Restricted to a group specified by the consortium (including the Commission Services), CO: Confidential, only for members of the consortium (including the Commission Services)
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Deliverable 2.3

Report on the economic performance of selected European and Vietnamese farmed species

August 2017

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Executive Summary

Global production of the main farmed species consumed in the EU has increased drastically in recent years. Production of Atlantic salmon is estimated to have grown by 157% during 2000-2016 and exports of pangasius from Vietnam increased from 700 tonnes in 2000 to 660 thousand tonnes a decade later, with a quarter of those exports finding its way to EU markets. Production of sea bass and bream increased by 259% between 2003 and 2016. But not only has the volume increased, prices of salmon and sea bass and bream have become higher, up approx. 100% and 10%, respectively, while pangasius prices have fallen.

Fish farmers within the EU face competition from many directions. They must compete with wild capture fisheries within and outside the EU, aquaculture firms from outside Europe, as well as other food products.

The aim of this deliverable is to use firm level data to analyse and compare the economic performance of aquaculture firms within and outside the EU. For this purpose, it was decided to base the analysis on two key fish farming activities within the EU - Scottish salmon firms and Mediterranean sea bass and sea bream firms – and two important international competitors – Norwegian salmon firms and Vietnamese pangasius firms.

The economic performance of firms is here gauged in terms of changes in efficiency and productivity. Using Data Envelopment Analysis (DEA), an efficiency frontier, which is made up of the most efficient firms, is constructed for each of the four case studies. The position of each firm relative to the frontier is then used to calculate efficiency scores, which are then decomposed into pure technical efficiency and scale efficiency. Technical efficiency indicates how well firms update existing production technology and how they improve their production management, whereas scale efficiency is an indication of how well firms have managed to take advantage of the existing economies of scale. DEA also makes it possible to estimate shifts in the efficiency frontier which are taken to represent changes in technology. An outward shift will then signify technical progress and an inward shift technical regress. Productivity growth is then analysed in terms of these two factors, changes in technical efficiency and technology.

The data at hand differs slightly between case studies, both in regard to the input variables available and time dimension. The output variable is the same for all cases, output revenue. The Norwegian study uses costs of employment and materials, current and fixed assets and shareholders' funds as

inputs, while the Scottish data includes observations on current and fixed assets, current liabilities and the number of employees. The Vietnamese data includes current and fixed assets as well as current and non-current liabilities, and the data on the EU sea bass and bream industry has information on these same four variables as well as the number of employees. For Norway, the data covers the period 2006-2015, for Scotland 2008-2015, and for the EU sea bass and bream and Vietnamese pangasius firms the study covers the years 2009-2014. Despite these differences, there is both sufficient overlap in time period and in information available, to compare the four different sectors.

The salmon firms in Norway and Scotland were on average more efficient than the other aquaculture firms, in regard to both technical efficiency and the ability to take advantage of the scale efficiency at hand. Technical efficiency under the assumption of variable-returns-to-scale averaged 0.962 for Scottish salmon firms and 0.947 for their Norwegian counterparts, but was only 0.794 for Vietnamese pangasius firms and 0.72 for sea bass and bream firm in the EU. Firms on the efficiency frontier are assigned a score of 1.0. The results thus show that Scottish salmon firms could on average reduce their input utilization by 3.8% (1-0.962) without reducing their level of output, and Norway could produce the same amount of salmon while using 5.3% less inputs. By contrast, Vietnamese firms could reduce their input utilization by 20.6% and Mediterranean firms by 28%.

Salmon firms in Norway and Scotland enjoyed scale efficiencies of 0.949 and 0.933, while the estimated scale efficiency of Vietnamese firms was 0.855 and only 0.605 for EU sea bass and bream firms.

However, comparison of productivity performance yields a completely different picture. Here, Vietnamese pangasius firms show a remarkable performance, with average productivity of 16% per year, with the EU sea bass and bream firms also showing strong productivity growth of 9% per year. Both Norway and the UK experienced a productivity decline during this period. The productivity growth of the Vietnamese firms can both be attributed to improvements in technical efficiency and improved technology, while better efficiency explains most of the growth of the EU firms. The UK salmon firms have also become more technically efficient, but technical regress has a negative impact on their productivity growth. Norwegian firms have seen their technical efficiency decline slightly and have also experienced a slight technical regress.

Using data at firm level has advantages for understanding the competitiveness of EU aquaculture, as it provides valuable insight into the industry structure; that enables us to understand better the overall trends in productivity and efficiency of the entire sector as well as also for individual firms, and to compare the performance between sectors as regards of utilisation of specific inputs at firm level. The results of this deliverable therefore are useful for discussion with industries regarding areas for improvement, and of course for the development of the simulation model and DSS tool within the project, i.e. in WP5 and WP6, respectively. However, the analysis provided in this deliverable is based on limited data, and the number of firms, period of data, and input variables used in analysis for four case sectors are not identical. In addition, the results are based on the application of a single method, DEA, and may not be robust to the use of different methodological approach. The interpretation and implications of the results should acknowledge those limitations.

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1 Introduction

Farmed seafood products constitute an important part of the diet of EU citizens. In 2015, per capita consumption of seafood in the EU 28 averaged 25.5 kg (Eumofa, 2016). Tuna and cod were the most popular seafood, but salmon ranked third, with an average per capita consumption of 2.09 kg. EU citizens also consumed on average 0.6 kg of freshwater catfish, mostly pangasius, and 0.42 kg of trout. Sea bass and bream is also quite popular, especially in southern Europe. Whereas most of the salmon and all of the pangasius is imported from Norway and Vietnam respectively, there are also important aquaculture sectors within the EU. Thus, salmon farming is a vital economic activity in rural Scotland and farming sea bass and bream is an important industry in the Mediterranean countries. Trout is farmed in many EU countries, including Italy, France, Denmark, Germany and Spain.

Fish farmers within the EU face competition from many directions. They must compete with the wild capture fisheries within and outside the EU, aquaculture firms from outside Europe, as well as other food products. In some cases, farmed products produced within EU face competition from the same products produced outside the common market. Salmon farmers in Scotland must, for instance, compete with aquaculture from Norway, the Faroe Islands and Chile, and firms producing sea bass and bream face competition mainly from firms in Turkey. In order for EU aquaculture firms to be profitable and sustainable, it is therefore important that the firms manage the competition and are well equipped to deal with the challenge from firms outside of EU which compete from a different context.

The aim of this deliverable is to use firm level data to analyse and compare the economic performance of aquaculture firms within and outside the EU. For this purpose, it was decided to base the analysis on two key fish farming activities within the EU - Scottish salmon firms and Mediterranean sea bass and sea bream firms – and two important international competitors – Norwegian salmon firms and Vietnamese pangasius firms.

Economic performance may be defined in various ways, but it is most common to focus either on financial indicators or productivity. Here, we follow the latter approach and examine economic performance using Data Envelopment Analysis (DEA) which allows productivity growth to be decomposed into changes in efficiency and technology. Efficiency here refers to how well firms manage to utilise their inputs to produce output, in this case farmed fish. Using DEA it is possible to construct an efficiency frontier, which is made up of the most efficient firms, and to calculate how far other firms are from that frontier. The method also makes it possible to analyse shifts in the frontier, which is taken to represent technical change. Firms can then either improve their productivity by moving close to the efficiency frontier at each point in time, and/or take advantage of the technical progress, which shifts the frontier out. DEA also makes it possible to decompose technical efficiency into pure technical efficiency and scale efficiency which measures how well firms are able to utilise the scale economies available.

The deliverable is the outcome of two tasks within work package (WP) 2 in PrimeFish; Task 2.1 Economic performance of selected individual sectors and Task 2.2 European seafood market.

2 Sector history and data

2.1 Global salmon market

Global supply of farmed Atlantic salmon is estimated to have grown by 157% over the period 2000-2016. Annual growth averaged 6% during this period, but varied from -4% to 22% annually. There is a clear connection between the level of output and prices, with the growth rate being the main determinant for variation in prices. Changes in annual prices have varied between EUR 2.42 in 2003 to EUR 6.61 in 2016. The production value of Atlantic salmon has increased on average by 11% annually since 2000, with output value in 2016 359 % larger than the value in 2000. Price per kg increased by about 110% over the same period, with price increasing on average by 5% each year.

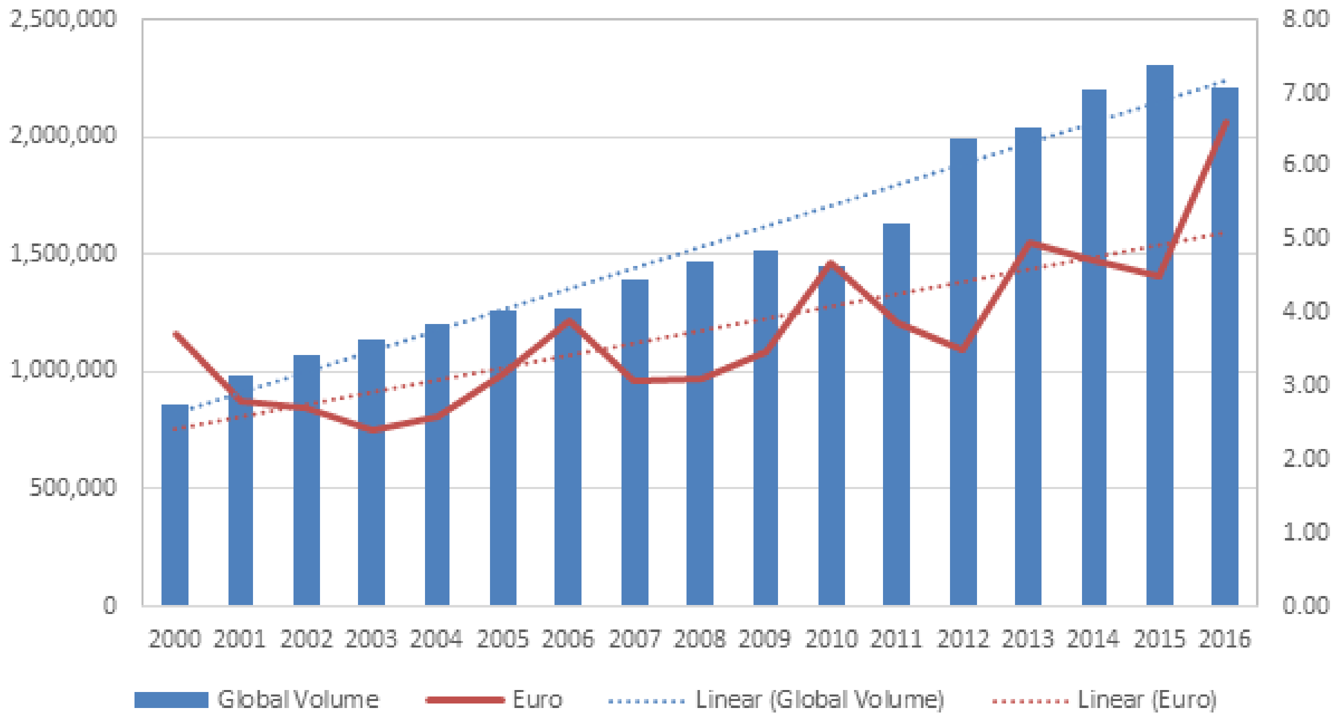

Figure 1. Global production of farmed salmon 2000-2016 in tonnes (left axis) and average price (EUR per kg) (right axis) (Kontali Analyse AS).

The salmon industry is led by Norway, which produces around half the Atlantic salmon sold in the world, with main markets in Japan, the EU and North America. In recent years, Norwegian production has exceeded one million tonnes. Other main producers include Chile, the UK, Canada, the Faroe Islands and Australia. Production in the UK, i.e. in Scotland, has been close to 150 thousand tonnes in recent years. 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

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first years of the new millennium, but has since increased slightly. The compounded annual growth rate of Norway has been 7%, but only half that or 3% in the UK.

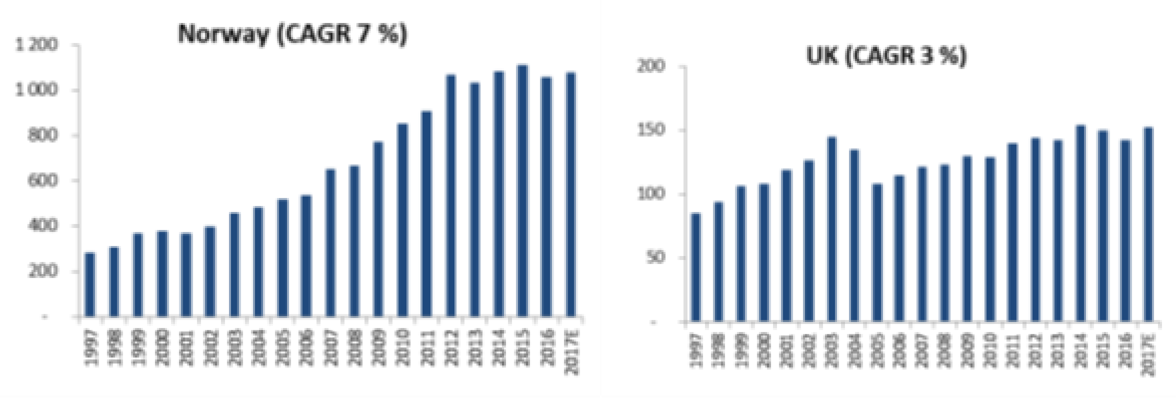

Figure 2. Production of farmed salmon in Norway (left) and the UK (right), as well as compounded annual growth rate (CAGR). Thousand tonnes. (Salmon industry handbook, Marine Harvest/Kontali Analyse AS)

The salmon sector has undergone substantial consolidation since 2000. 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 2016, and the number of firms in Chile decreasing from more than 30 to 13 over the same period. In the four 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 four firms produce 80% of all farmed salmon, while in the Faroe Islands only three firms produced 80% of all salmon and only two in Australia.

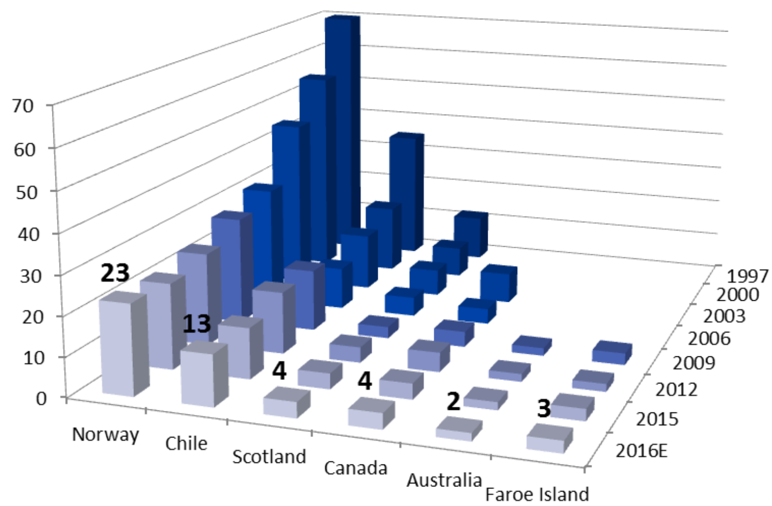

Figure 3. Market consolidation in salmon farming. Number of firms producing 80% of farmed salmon in Norway, Chile, Scotland, Canada, Australia and the Faroe Islands 1997-2016. (Salmon industry handbook, Marine Harvest/Kontali Analyse AS)

2.2 Salmon in Norway

The data on Norway salmon covers the period 2006-2015 and includes observations on operating revenue, employment costs, material costs, current assets, fixed assets and shareholders´ funds for 30 Norwegian firms. As shown in Table 1 the firms vary a great deal in size, with the largest firm having revenue of EUR 369 million and the smallest 6 EUR million. The average firms had sales of EUR 73.2 million, but the median firm was significantly smaller. The large standard deviation reflects well the variability of the firms in the sample.

Table 1. Descriptive statistics of Norwegian salmon data. EUR million (2015 prices).

	Average	Median	Std. dev.	Max	Min
Operating revenue	73.2	46.4	64.8	369.3	5.9
Employment costs	6.8	3.4	7.2	35.3	0.3
Material costs	40.5	27.9	34.0	176.4	0.5
Current assets	47.1	33.3	39.4	213.1	4.9
Fixed assets	44.0	22.9	46.4	237.8	0.8
Shareholders´ funds	36.9	23.1	38.7	229.1	0.7

This difference in size is brought out even further in Figure 4, which shows the size distribution of the Norwegian salmon firms, for each year included in the sample. As the figure clearly reveals, the firms become on average 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 the spread of the firms has also been increasing

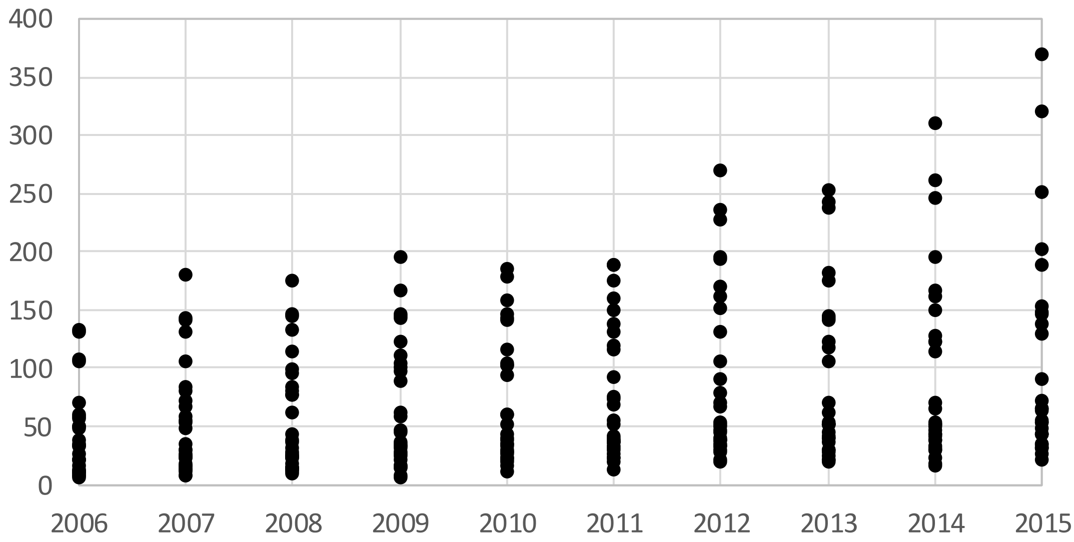

Figure 4. Size distribution of Norwegian salmon firms 2006-2015. Operating revenue in EUR million (2015 prices).

2.3 Salmon in the UK

The data on the salmon aquaculture in the UK covers eight firms observed during the period 2008-2015. Information was available on operating revenue, current assets, fixed assets, current liabilities and the number of employees. As in the other three cases, there is a large difference in the size of the firms. While the largest firm had sales of 309 EUR million, the smallest registered revenue of only EUR 1.6 million. On average, firms had revenue of EUR 68.5 million, but the median was only half as large, or EUR 34 million. The difference in size is also well reflected by the large standard deviation.

Table 2. Descriptive statistics of the UK salmon firms. EUR million (2015 prices).

	Average	Median	Std. dev.	Max	Min
Operating revenue	68.5	33.9	73.5	309.3	1.6
Current assets	46.5	31.2	43.8	151.1	0.9
Fixed assets	22.5	13.4	21.1	88.5	0.1
Current liabilities	29.8	17.7	32.3	149.9	0.6
Number of employees	192.3	95.0	172.5	578.0	12.0

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.

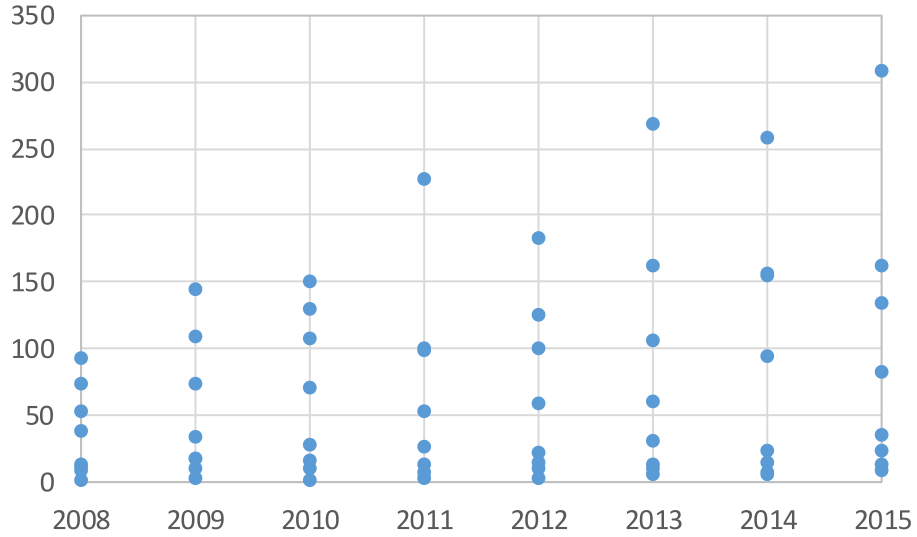

Figure 5. Size distribution of UK salmon firms 2008-2015. Operating revenue in EUR million (2015 prices).

2.4 Pangasius in Vietnam

Since 1990s, Pangasius catfish has been one of the fastest growing aquaculture species globally, with an annual production of over 1 million tonnes (FishStatJ, 2014). Vietnam is the major producer, representing more than 75% of the global production and 95% of global export value (EPA, 2014). In 2015, the production of Vietnamese pangasius was around 1.1 million tonnes (VASEP, 2016), slightly less than it was at its peak of 1.4 million tonnes in 2012.

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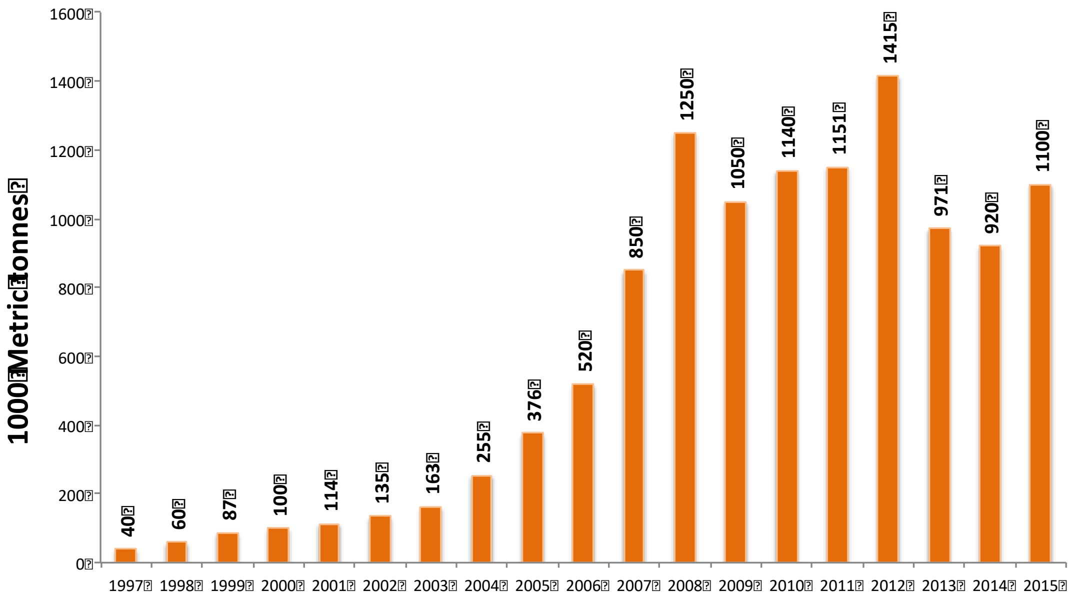


Figure 6. Vietnamese pangasius production (VASEP, 2016)

In Vietnam, pangasius farming is mostly organised within ten provinces in the Mekong Delta River; An Giang, Dong Thap, Tien Giang, Can Tho, Vinh Long, Ben Tre, Hau Giang, Soc Trang, Tra Vinh, and Kien Giang. In 2012, the total pangasius farming areas of Vietnam amounted to 3,586 ha, of which household farms accounted for 49%, farming companies for 49% and farmer collective 2% (Tung et al., 2014). The farming area has increased significantly in recent years, and had by 2015 grown to 5,900 ha (MARD, 2016). The Food and Agriculture Organisation (FAO) has categorized Vietnamese pangasius production as hyper-intensive. More than 97% of the pangasius production is processed further at the country's approximately 140 processing plants (EPA, 2014; VASEP, 2016). The vast majority of these processing establishments are located in the provinces in the Mekong River Delta. Most of the pangasius is sold in foreign markets, with the exports increasing in line with increases in production. Thus, while exports in 2000 only amounted to 700 tons, this volume has increased to 660,000 tonnes with a value of USD 1.4 billion only a decade later (CBI, 2012). In 2010, there were 291 pangasius exporters in Vietnam. Most were small, exporting less than 1,000 tons, but a third of the exporters operate on a large scale, and have a combined share of almost 75% of the total export volume.

Table 3. Number of pangasius processors per province in Vietnam.

Province	Processing unit	Export volume (1000 tonnes)	Value (USD million)
An Giang	15	159	342
Dong Thap	12	115	277
Can Tho	22	166	350
Tien Giang	13	97	202
Hau Giang	1	6	14
Ben Tre	3	14	32
Vinh Long	2	11	19
Ho Chi Minh	19	37	78
Tra Vinh	2	6	16
Kien Giang	1	3	6
Vung Tau	1	1	2
Da Nang	2	3	4
Others	>47	42	87
Total	>140	660	1,429

Source: CBI (2012).

The EU and the US are the most important markets for pangasius. In 2012, 24% of Vietnamese pangasius volume was exported to the EU and 21 % to the US, with exports to countries in Asia, Mexico, Brazil, China and others making up the remaining 55% (SFP, 2015). The US was initially the main market for pangasius from Vietnam, but trade measures imposed in 2002 led the Vietnamese industry to seek more diversified global markets. As a result, the exports have grown almost exponentially since this time (Belton et al., 2011) with the export value increasing several times.

Europe is the largest seafood market in the world, accounting for 20% - 25% of the global market, with pangasius one of the most important imported fish products for the EU markets. Although some other countries produce pangasius nowadays, more than 99% of frozen pangasius imported into Europe comes from Vietnam (CBI, 2015). The largest markets for pangasius in Europe, i.e. Spain, the Netherlands and Germany, all saw their import value go down in the period 2012 – 2014. Overall, the value of frozen pangasius fillets imported to the EU decreased from EUR 342 million in 2012 to EUR 275 in 2014 (CBI, 2015).

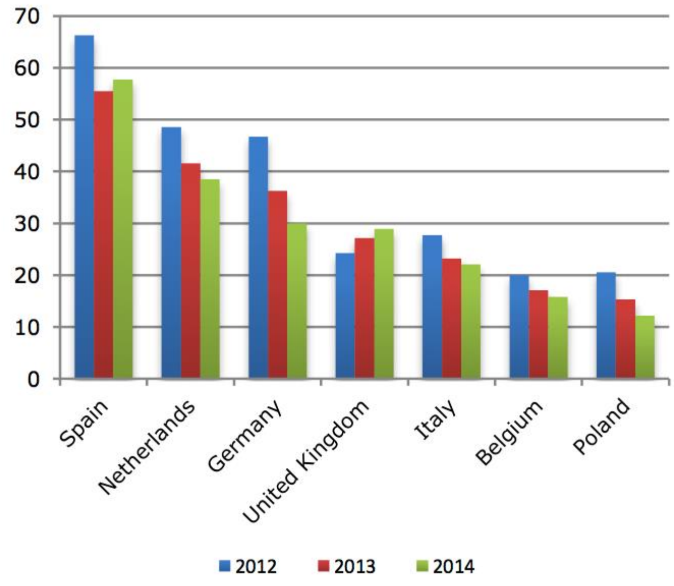


Figure 7. EU imports of frozen pangasius fillets in 2012-2014 (EUR million). Source: CBI, 2015.

Pangasius products exported to EU (and the world) are mainly frozen fillets, other products including fresh fillets, wholefish (fresh and frozen) account for less than 5% of total export volume (CBI, 2015). In 2014, imports to the EU amounted to EUR 270 million, down from EUR 340 million just two years earlier.

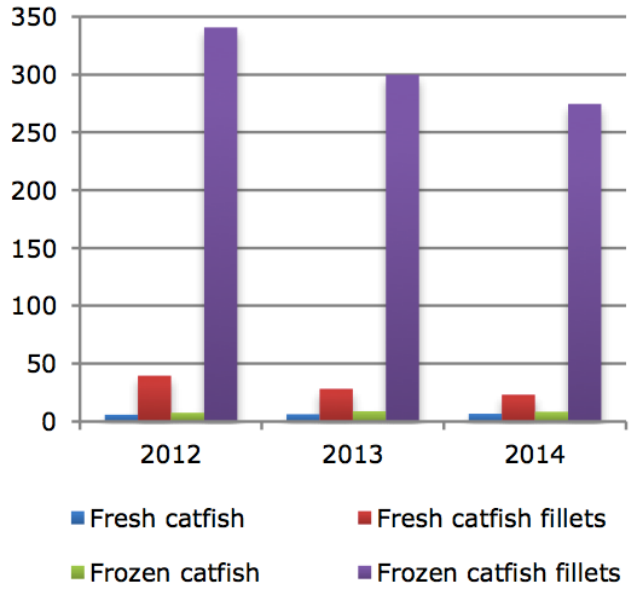


Figure 8 EU imports of pangasius in 2012 – 2014 (EUR million). Source: CBI, 2015.

Pangasius is a favoured substitute for other fish products in many EU countries because the fish processes similar quality (e.g. colour and convenient attribute) as other whitefish but is much lower priced than the whitefish, e.g. cod, pollack, and sole. However, in recent years the fish has faced strong competition in the EU market. Pangasius has been given an unfavourable reputation and mass media has reported negative aspects regarding safety and sustainability issues. The strong competitiveness in the European whitefish market during the past few years has put downward pressure on the export prices. The overall decline of pangasius imports is mostly attributed to competition with other white fish species, most importantly Alaska pollack and to some degree cod, in some markets, and maybe most significantly the negative perception of the product established among certain buyers and consumers (CBI, 2015).

As shown in Figure 9, pangasius prices ($/kg) in world markets have been declining during 2007-2014. The decline trend of pangasius price is present in all markets and markets over the period, including seven regions included in the figure ASEAN and Easters Asian (10 Asian countries, and China, Hong Kong, Japan, Taiwan, and Korea), North American (Canada and USA), Oceania (Australia and New Zealand), Russia and Eastern EU (Russia and former Soviet Union countries), South and Central America, Western EU, and Rest of the World (ROW) (Thong et al, 2017).

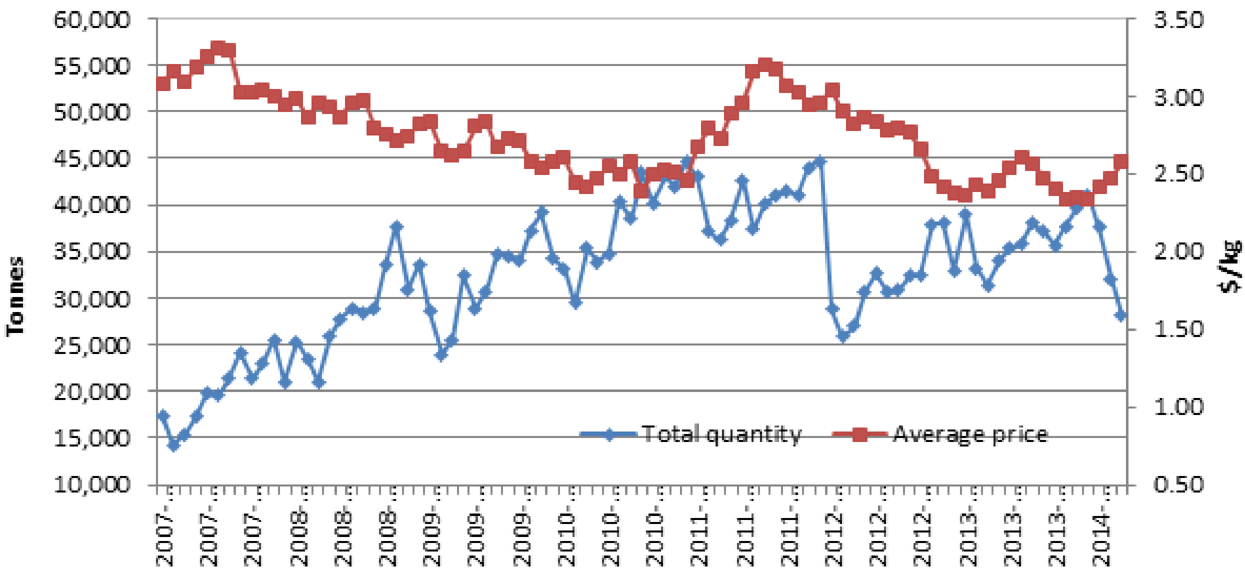


Figure 9. Average export prices of pangasius in period of 2007-2014. Source: ITC, 2015.

The data used in this study covers the period 2009-2014 and consists of observations on operating revenue, current assets, fixed assets, non-current liabilities and current liabilities for 20 firms. As revealed in Table 4 the firms vary somewhat in size. On average, the firms in the sample had revenue of EUR 37 million, but while the largest firms had sales of over EUR 224 million, the smallest firms had only sales of EUR 0.1 million. The median firm had sales of EUR 28 million.

Table 4. Descriptive statistics of the Vietnamese pangasius firms. EUR million (2015 prices).

	Average	Median	Std. dev.	Max	Min
Operating revenue	36.8	28.1	33.7	224.3	0.1
Current assets	26.5	22.8	18.2	111.2	1.3
Fixed assets	11.9	9.4	8.8	48.9	0.2
Non-current liabilities	2.3	1.2	2.7	13.9	0.0
Current liabilities	24.1	20.9	15.5	90.3	0.8

The largest firm included in the sample grew fast over the period of study, as shown by the fact that sales were only EUR 94 million in 2009 but had grown to EUR 224 million in 2014 (Figure 10). The figure also shows that other firms had also been growing during this period.

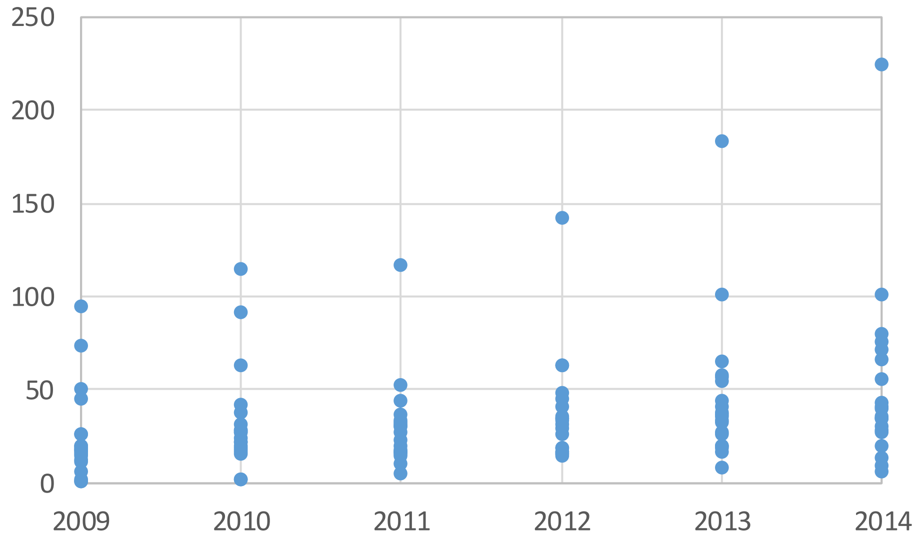


Figure 10. Size distribution of Vietnamese pangasius firms 2009-2014. Operating revenue in EUR million (2015 prices)

2.5 Sea bass and sea bream

The Mediterranean countries have considerably increased their production of sea bass in the last decade. Production was 259% higher in 2016 than it had been in 2003, representing an annual growth of 11%. Prices and revenue has also increased. Price per kg has increased from EUR 4.48 in 2009 to

EUR 5.73 in 2016, while the production value of farmed sea bass increased by 288% between 2003 and 2016. That represents an average increase in value of 12% per year. The value per kg produced has increased by about 8 % from 2000 to 2016, on average 1 % per year.

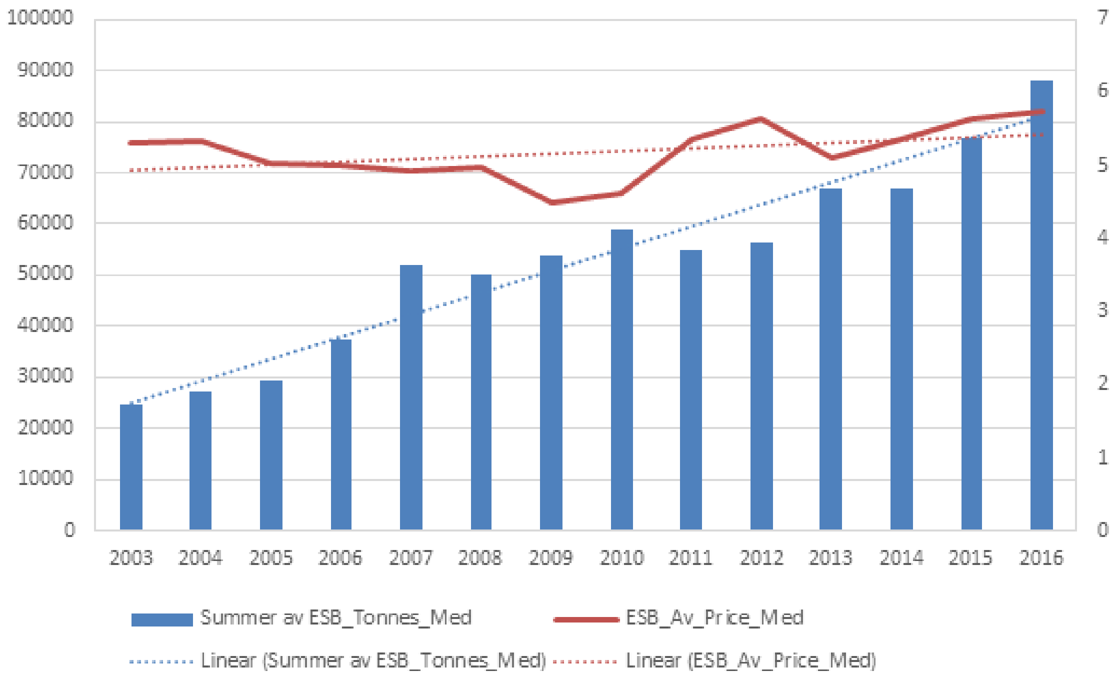


Figure 11. Production (left axis) and price per kg (right axis) of farmed sea bass in the Mediterranean countries 2003-2016. (Kontali Analyse AS)

Production of farmed sea bream increased on average by 10% in 2003-2016. The growth between years was though uneven, fluctuating between a decrease of 13% and growth of 29%. By 2016, sea bream production was almost 200% larger than it had been in 2003. Price per kg has on average grown by 2% per year, reaching a high of 5.32 euros in 2015, and a low of 3.49 euros in 2008. The value of sea bream supplies has on average increased by 10 % every year since 2003. Output value was 246% larger in 2016 than it had been in 2003.

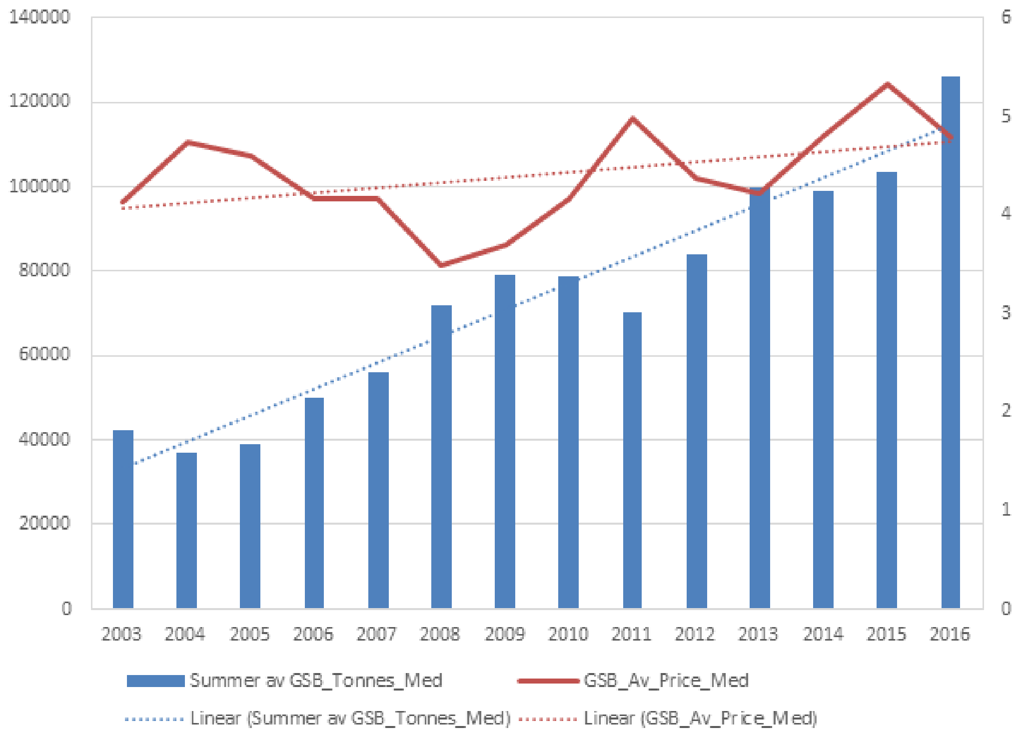


Figure 12. Production (left axis) and price per kg (right axis) of farmed sea bream in the Mediterranean countries 2003-2016. (Kontali Analyse AS)

The data on firms farming sea bass and sea bream covers 13 firms, where of seven are in Greece, three in Spain, two in Italy and one in Croatia, observed during the period 2009-2014. The annual data includes observations on operating revenue, current assets, fixed assets, non-current liabilities, current liabilities and the number of employees.

Table 5. Descriptive statistics of the European seabass and seabream firms. EUR million (2015 prices).

	Average	Median	Std. dev.	Max	Min
Operating revenue	42.9	23.6	50.9	222.9	2.4
Current assets	56.4	22.5	75.0	318.9	2.3
Fixed assets	37.0	9.0	60.1	242.8	0.2
Non-current liabilities	26.9	4.3	47.7	218.0	0.0
Current liabilities	46.6	15.9	66.8	284.6	0.9
Number of employees	283.9	134.5	389.6	1,797.0	6.0

The firms differ hugely in size. While the average firms had sales of EUR 43 million (2015 prices), the largest firm had an operating revenue of EUR 223 million and the smallest, revenue of EUR 2.4 million. The spread in the size distribution is well reflected by the difference between average size and median size, and by the fact that standard deviation of the sample was larger than the mean.

As shown in Figure 13, the 2-3 largest firms included in the sample are always much bigger than the other firms. There is, however, no clear trend in the size development of the firms in the sample. The smallest firm do not appear to have become larger, and the development of the largest firm is also not univocal.

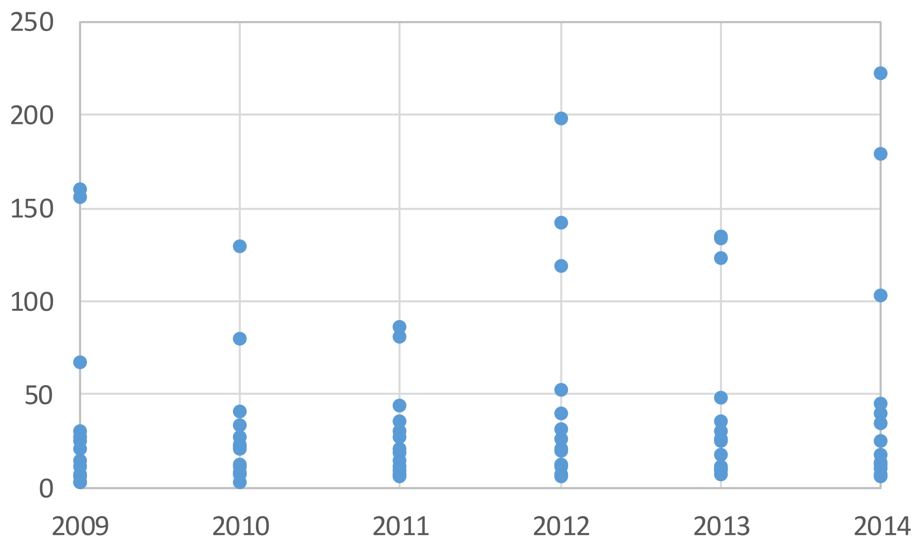


Figure 13. Size distribution of European seabass and seabream firms 2009-2014. Operating revenue in EUR million (2015 prices).

2.6 Summary

On average, the salmon aquaculture firms in Norway and the UK are similar in size, but the largest Norwegian firm is though substantially bigger than the largest UK firm.

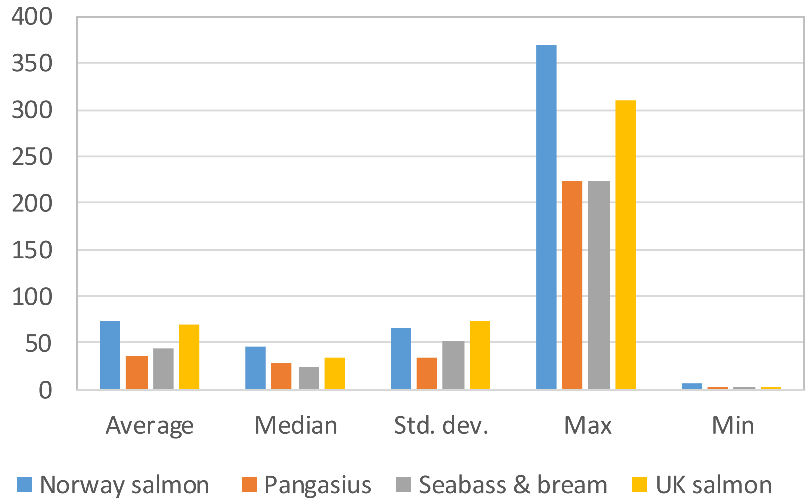


Figure 14. Comparison of the size of salmon firms in Norway and the UK, pangasius firms in Vietnam and seabass and seabream firms in Greece, Italy, Spain and Croatia. Operating revenue in EUR million (2015 prices).

Norwegian salmon firms and European seabass and seabream firms are on average the most capital intensive, as reflected by the high value of their fixed assets. At the opposite end, pangasius firms in Vietnam do not on average employ much fixed assets.

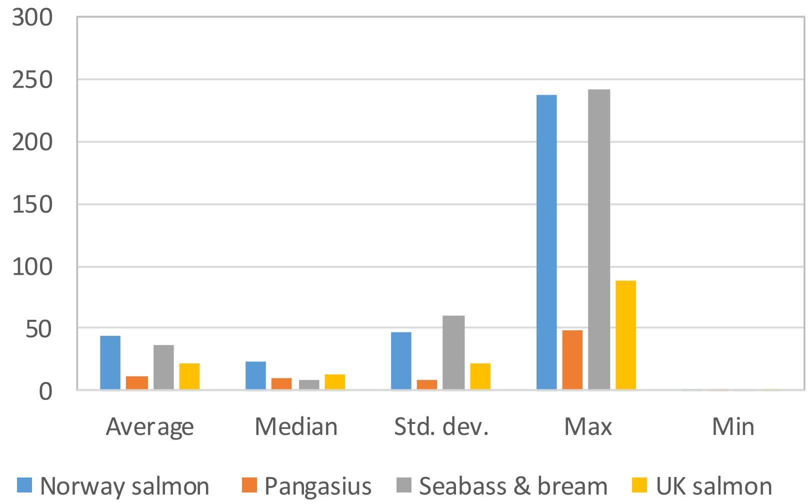


Figure 15. Comparison of the size of salmon firms in Norway and the UK, pangasius firms in Vietnam and seabass and seabream firms in Greece, Italy, Spain and Croatia. Fixed assets in EUR million (2015 prices).

Current assets are on average similar in the Norwegian and UK salmon firms, as well as the seabass and seabream firms in Greece, Spain, Italy and Croatia.

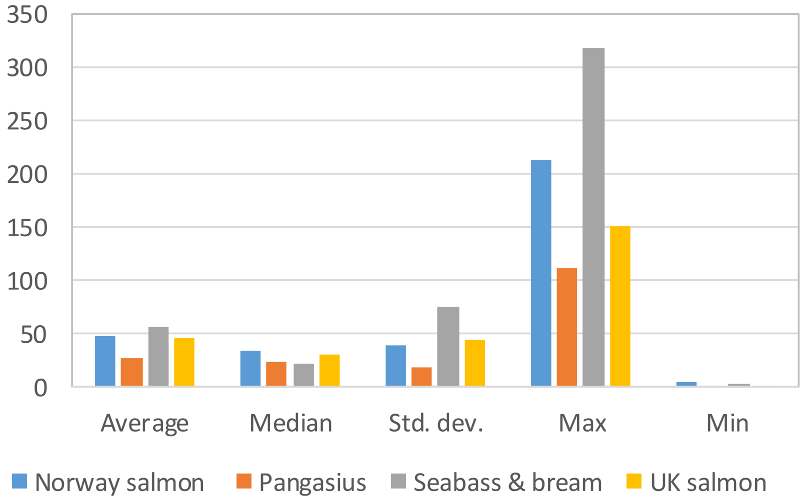


Figure 16. Comparison of the size of salmon firms in Norway and the UK, pangasius firms in Vietnam and seabass and seabream firms in Greece, Italy, Spain and Croatia. Current assets in EUR million (2015 prices).

Current liabilities of the Vietnamese pangasius firms, European seabass and seabream firms and UK salmon producers are similar, but the maximum is by far highest for seabass and seabream firms.

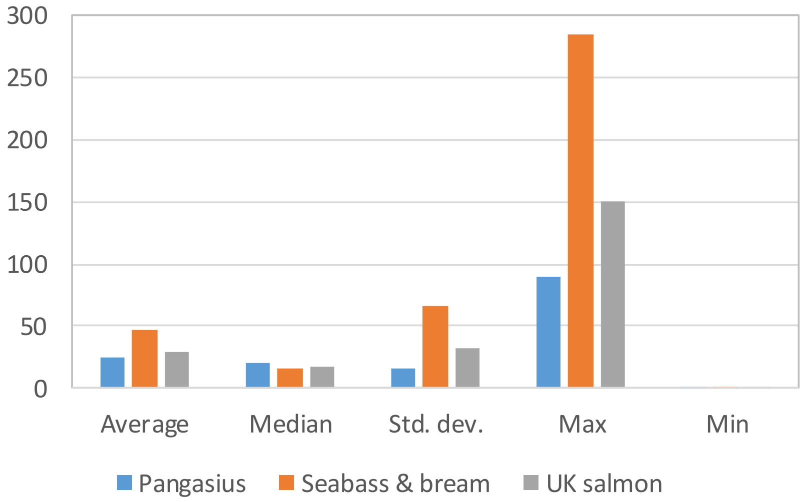


Figure 17. Comparison of the size of salmon firms in Norway and the UK, pangasius firms in Vietnam and seabass and seabream firms in Greece, Italy, Spain and Croatia. Current liabilities in EUR million (2015 prices).

Seabass and seabream producers in Greece, Spain, Italy and Croatia do on average employ slightly more labour than UK salmon firms. However, the largest seabass and seabream firm has almost 1800 employees, whereas the largest UK firm employees only around 580 people.

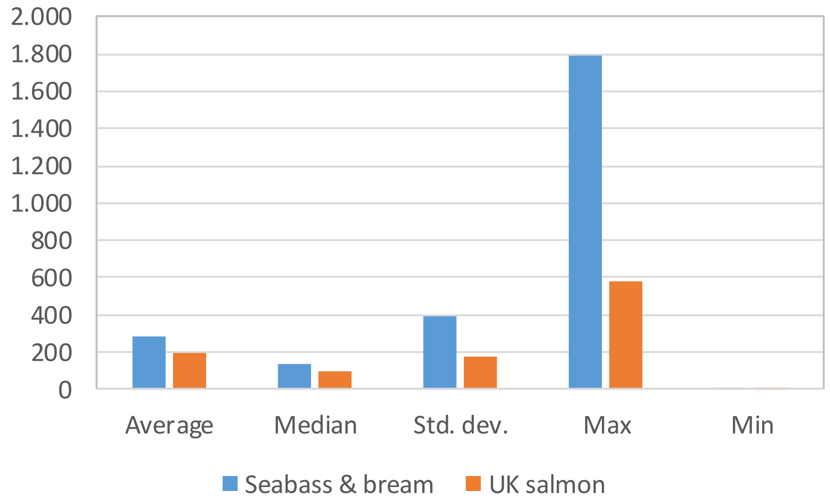


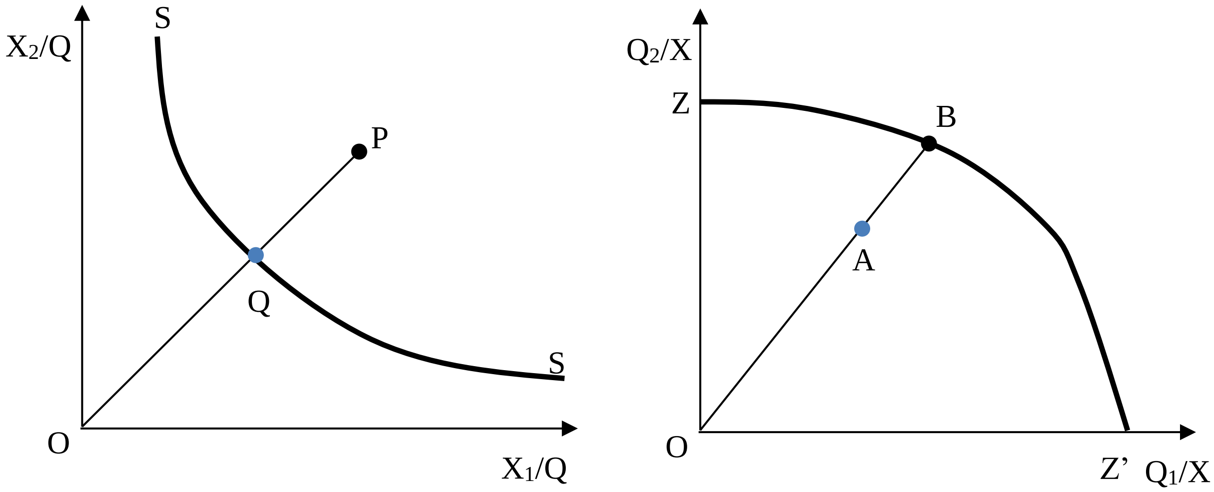
Figure 18. Comparison of the size of salmon firms in Norway and the UK, pangasius firms in Vietnam and seabass and seabream firms in Greece, Italy, Spain and Croatia. Number of employees.

3 Methods

The objective of this deliverable is to examine and understand the competitiveness of key EU aquaculture industries. For this purpose, it was decided to compare the performance of two key fish farming activities within the EU - Scottish salmon firms and Mediterranean sea bass and sea bream firms – with two important international competitors – Norwegian salmon firms and Vietnamese pangasius firms. The analysis is based on Data Envelopment Analysis (DEA) which is used to decompose estimated productivity into changes in scale efficiency and technical efficiency. Changes in scale efficiency reveal if firms are taken advantage of the scale economies open to them, while changes in technical efficiency indicate if the firms exploit their resources efficiently via technology updates and management improvements.

Technical efficiency is one component of overall economic efficiency, which is referred to as the ability of a firm to obtain either maximal output from a given set of inputs (output-orientation) or the optimal combination of inputs to achieve a given level of output (an input-orientation), given the production technology (Coelli et al., 2005, p.51-56). Both input and output measures can be used in order to compare technical efficiency between firms and over time (Kumbhakar and Lovell, 2000, Coelli et al., 2005).

Following Farrell (1957), the input-orientation can be illustrated using a firm producing a single output (*Q*) with two inputs (X_1 and X_2) under an assumption of constant returns to scale (CRS). The isoquant of a fully efficient firm is given by SS' in Figure 19a. If a given firm uses quantities of inputs, defined by the point P, to produce a unit of output, the technical inefficiency of that firm could be represented by the distance QP, which is the amount by which all inputs could be proportionally reduced without a reduction in output. This is usually expressed in percentage terms by the ratio QP/OP, which represents the percentage by which all inputs need to be reduced to achieve technically efficient production. The technical efficiency *(TE)* of a firm is most commonly measured by the ratio OQ/OP, which is equal to one minus QP/OP. It takes a value between zero and one, and, hence, provides an indicator of the degree of technical efficiency of the firm. A value of one implies that the firm is fully technically efficient. For example, the point Q is technically efficient because it lies on the efficient isoquant.



(a) (b)

Figure 19. Technical efficiency from input (a) and output (b) orientations.

Now consider a firm which uses a single input (X) to produce two outputs, Q_1 and Q_2.The production possibility curve is shown as ZZ' in Figure 19b. Given the current input employed by the firm, the current production (denoted by point A) can be expanded radially to point B. The output-orientated measure of *TE* is given by OA/OB. The output and input measures will be equivalent under constant returns to scale.

Scale efficiency is a simple concept that is easy to understand in a one-input, one-output case. Hence, a one-input, one-output variable return to scale (VRS) production technology is depicted in Figure 20, where the production set, S, is the area between the VRS production frontier, *f(x)*, and the X-axis, inclusive of these bounds. The technically inefficient firm operates at point D., It is clear that the productivity of firm D (as reflected by the slope of the ray from the origin) could be improved by moving from point D to point E on the VRS frontier (i.e., removing technical inefficiency), and it could be further improved by moving from the point E to the point B (i.e., removing scale inefficiency) – the technically optimal productive scale is at point B.

The ratio of the slope of the ray OD to the slope of the ray OE is equal to the ratio GE/GD, and the ratio of the slope of the ray OE to the slope of the ray OF (which also equals the slope of the ray OB) is equal to the ratio GF/GE. Thus, distance measures can be used to calculate these efficiency differences. In particular, it is possible to calculate the technical efficiency with respect to both CRS and VRS, and then specify scale efficiency as the ratio between these measures. The technical efficiency of firm D relates to the distance from the observed data point to the VRS technology and is equal to the ratio TE_{VRS} = GE/GD. Likewise, the distance from the observed data point to the CRS technology is defined as TE_{CRS} = GF/GD. Scale efficiency is then defined as:

$SE = TE_{CRS} / TE_{VRS}$ = (GF/GD)/(GE/GD) = GF/GE.

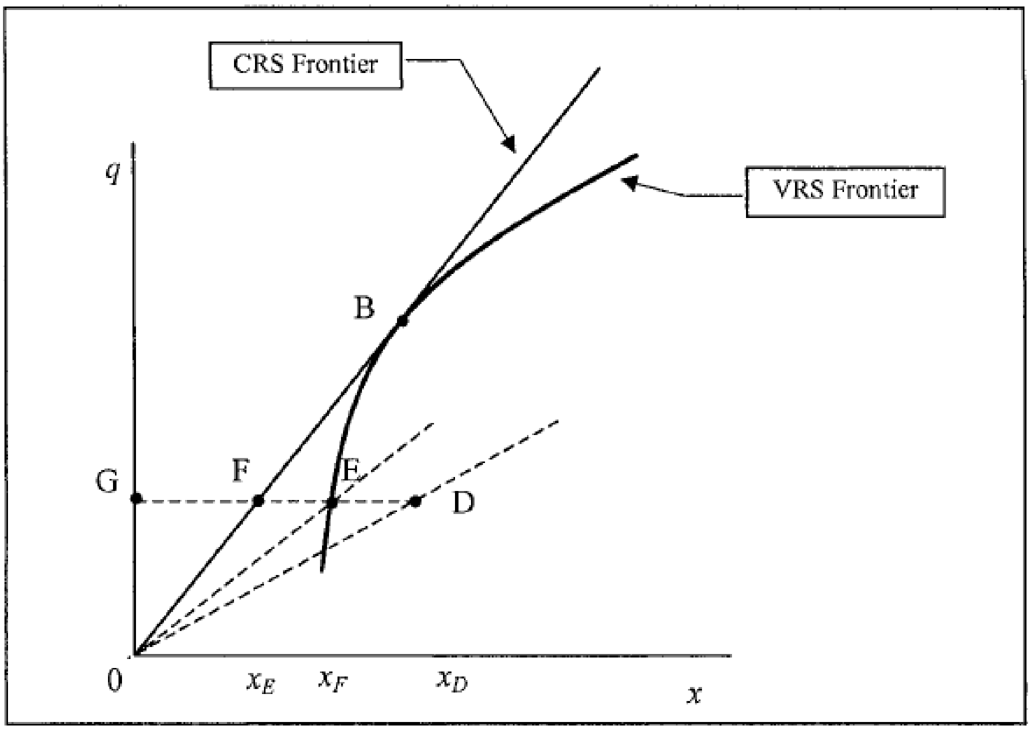


Figure 20. Scale efficiency. Source: Coelli et al. (2005).

The basic data envelopment analysis (DEA) model was defined by Charnes et al. (1978), based on Farrell (1957). DEA models can be formulated for input minimization or output maximization problems. As the calculations in this deliverable are all based on input minimization, we will in what follows only outline that approach.

TE scores of decision-making units (DMU) are derived by estimating each separate frontier for each year, by solving the following input-oriented DEA models:

Input-oriented DEA model under CRS assumption

$$
\begin{aligned}
&\text{TE} = \text{Min}_{\theta,\lambda} \quad \theta \\
&\text{Subject to} \quad \theta x_{ij} - \textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \geq 0, \qquad i = 1, \dots, M, \\
&\qquad -y_{rj} + \textstyle\sum_{j=1}^{n} \lambda_j y_{rj} \geq 0, \quad r = 1, \dots, N, \\
&\qquad \lambda_j \geq 0, \quad j = 1, \dots, n,
\end{aligned}
\tag{1}
$$

Input-oriented DEA models under VRS assumption

$$
\begin{aligned}
&\text{TE} = \text{Min}_{\theta,\lambda} \quad \theta \\
&\text{Subject to} \quad \theta x_{ij} - \textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \geq 0, \qquad i = 1, \dots, M, \\
&\qquad -y_{rj} + \textstyle\sum_{j=1}^{n} \lambda_j y_{rj} \geq 0, \quad r = 1, \dots, N, \\
&\qquad \textstyle\sum_{j=1}^{n} \lambda_j = 1, \\
&\qquad \lambda_j \geq 0, \quad j = 1, \dots, n,
\end{aligned}
\tag{2}
$$

where x_{ij} is the level of input *i* used by DMU_j, y_{rj} is output *r* of the DMU_j and n is the number of observed companies. The value of θ obtained is the efficiency score for the *j-th* firm. It satisfies: $\theta \leq 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient firm.

The Malmquist Index (MI) is used to measure the total factor productivity (TFP) change of a company or an industry over time, which is known as the Malmquist TFP index. If the MI equals one, it represents no change in productivity; a value greater than one indicates positive TFP growth; and an MI smaller than one indicates a TFP decline. The MI will be defined by distance functions. The input distance function, which involves the scaling of the input vector, is defined on the input set, L(**q**), as:

$$d_i(\boldsymbol{x}, \boldsymbol{q}) = \max\left\{\rho : \left(\frac{\boldsymbol{x}}{\rho}\right) \in L(\boldsymbol{q})\right\}, \tag{3}$$

where the input set L(**q**) represents the set of all input vectors, **x**, which can produce the output vector, **q**. The input distance function is illustrated using Figure 19a. The value of the distance function for the point, *P,* is equal to the ratio ρ=OP/OQ (Figure 19a). The input-orientated TE measure of a firm like (1) can be expressed in terms of input-distance function

$d_i(\boldsymbol{x}, \boldsymbol{q})$ as: $TE = 1/d_i(\boldsymbol{x}, \boldsymbol{q})$.

The input-orientated productivity measures focus on the level of inputs necessary to produce observed output vectors $\boldsymbol{q_t}$ and $\boldsymbol{q_{t+1}}$ under a reference technology. The input-orientated MI is defined as:

$$M_i(\boldsymbol{q}_t, \boldsymbol{q}_{t+1}, \boldsymbol{x}_t, \boldsymbol{x}_{t+1}) = [M_i^t(\boldsymbol{q}_t, \boldsymbol{q}_{t+1}, \boldsymbol{x}_t, \boldsymbol{x}_{t+1}) M_i^{t+1}(\boldsymbol{q}_t, \boldsymbol{q}_{t+1}, \boldsymbol{x}_t, \boldsymbol{x}_{t+1})]^{\frac{1}{2}}$$

$$= \left[\frac{d_i^t(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})}{d_i^t(\boldsymbol{q}_t, \boldsymbol{x}_t)} \times \frac{d_i^{t+1}(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})}{d_i^{t+1}(\boldsymbol{q}_t, \boldsymbol{x}_t)}\right]^{\frac{1}{2}} \quad (4)$$

The MI in (4) is defined in terms of four input distance functions, and a separate M_i will be calculated for every DMU. The MI formula can be decomposed in a common way as follow:

$$M_i(\boldsymbol{q}_t, \boldsymbol{q}_{t+1}, \boldsymbol{x}_t, \boldsymbol{x}_{t+1}) = \frac{d_i^{t+1}(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})}{d_i^t(\boldsymbol{q}_t, \boldsymbol{x}_t)} \left[\frac{d_i^t(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})}{d_i^{t+1}(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})} \times \frac{d_i^t(\boldsymbol{q}_t, \boldsymbol{x}_t)}{d_i^{t+1}(\boldsymbol{q}_t, \boldsymbol{x}_t)}\right]^{\frac{1}{2}} \quad (5)$$

or

$$MI = EC \times TC,$$

where

$$EC = \frac{d_i^{t+1}(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})}{d_i^t(\boldsymbol{q}_t, \boldsymbol{x}_t)} \quad (6)$$

$$TC = \left[\frac{d_i^t(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})}{d_i^{t+1}(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})} \times \frac{d_i^t(\boldsymbol{q}_t, \boldsymbol{x}_t)}{d_i^{t+1}(\boldsymbol{q}_t, \boldsymbol{x}_t)}\right]^{\frac{1}{2}} \quad (7)$$

The decomposition given in (5) identifies two sources of productivity change. The first part is technical efficiency change (EC) in (6). The second part is a measure of technical change (TC) in (7), the movements of the frontier technologies between the two periods, and its contribution to total productivity change.

Technical efficiency change (EC) be decomposed into scale efficiency change (SEC) and pure technical efficiency change (PEC). This can only be done when the distance functions in the above equations are estimated relative to a CRS technology (Fare et al.1994).

For the calculations, four different DEA models must be solved for each DMU. Assuming constant returns to scale (CRS) to start with, the following input-orientated linear programs are used:

$$[d_i^t(\boldsymbol{q}_t, \boldsymbol{x}_t)]^{-1} = \mathrm{Min}_{\theta,\lambda} \quad \theta$$
$$\text{Subject to} \quad \theta x_{ij,t} - \textstyle\sum_{j=1}^{n} \lambda_j x_{ij,t} \geq 0, \quad i = 1, \dots, M, \qquad (8)$$
$$-y_{rj,t} + \textstyle\sum_{j=1}^{n} \lambda_j y_{rj,t} \geq 0, \quad r = 1, \dots, N,$$
$$\lambda_j \geq 0, \quad j = 1, \dots, n,$$

$$[d_i^{t+1}(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})]^{-1} = \mathrm{Min}_{\theta,\lambda} \quad \theta$$
$$\text{Subject to} \quad \theta x_{ij,t+1} - \textstyle\sum_{j=1}^{n} \lambda_j x_{ij,t+1} \geq 0, \quad i = 1, \dots, M, \qquad (9)$$
$$-y_{rj,t+1} + \textstyle\sum_{j=1}^{n} \lambda_j y_{rj,t+1} \geq 0, \quad r = 1, \dots, N,$$
$$\lambda_j \geq 0, \quad j = 1, \dots, n,$$

$$[d_i^{t+1}(\boldsymbol{q}_t, \boldsymbol{x}_t)]^{-1} = \mathrm{Min}_{\theta,\lambda} \quad \theta$$
$$\text{Subject to} \quad \theta x_{ij,t} - \textstyle\sum_{j=1}^{n} \lambda_j x_{ij,t+1} \geq 0, \quad i = 1, \dots, M, \qquad (10)$$
$$-y_{rj,t} + \textstyle\sum_{j=1}^{n} \lambda_j y_{rj,t+1} \geq 0, \quad r = 1, \dots, N,$$
$$\lambda_j \geq 0, \quad j = 1, \dots, n,$$

$$[d_i^t(\boldsymbol{q}_{t+1}, \boldsymbol{x}_{t+1})]^{-1} = \mathrm{Min}_{\theta,\lambda} \quad \theta$$
$$\text{Subject to} \quad \theta x_{ij,t+1} - \textstyle\sum_{j=1}^{n} \lambda_j x_{ij,t} \geq 0, \quad i = 1, \dots, M, \qquad (11)$$
$$-y_{rj,t+1} + \textstyle\sum_{j=1}^{n} \lambda_j y_{rj,t} \geq 0, \quad r = 1, \dots, N,$$
$$\lambda_j \geq 0, \quad j = 1, \dots, n,$$

The first two linear programs in (8) and (9) are where the technology and the observation to be evaluated are from the same period, and the solution value is less than or equal to unity. The second two linear programs in (10) and (11) occur where the reference technology is constructed from data in one period, whereas the observation to be evaluated is from another period.

4 Results

4.1 Norwegian salmon firms

The DEA analysis of Norwegian salmon is undertaken by solving input-oriented DEA models, where operating revenue is selected as the output variable and five inputs: employment costs, material costs, current assets, fixed assets and shareholder funds. All variables are deflated using the year 2015 as baseline, with the consumer price index (CP) used to deflate the inputs and the Norwegian export salmon price index to deflate output. The data set includes 30 firms observed during the period 2006-2015.

4.1.1 Technical and scale efficiency

Under the assumption of variable-returns-to-scale (VRS), it was found that on average technical efficiency (TE) amounted to 0.947 (see Table 6), implying that the Norwegian salmon firms included in the study could have reduced inputs by 5.3% while maintaining the same level of output. As explained in Section 3 above, a fully efficient firm, i.e. a firm on the frontier, would have a technical efficiency score of unity. The calculated TE under the assumption of constant-returns-to-scale (CRS) was 0.899, slightly less than the TE calculated under the assumption of VRS. In general, though, the firms operate close to the frontier. The scale efficiency, calculated as the ratio of the TE under CRS and TE under VRS, was on average 0.949. This indicates that the actual scale of production had diverged from optimal scale; firms could on average decrease the input usage by operating at a more optimal scale. Ten of the firms were though found to have a scale efficiency score of unity, indicating that they were indeed operating at the most optimal scale.

As shown in Table 6, calculated TE is lowest in 2015 under both CRS and VRS, but both measures of TE show considerable variation. The calculated SE is more stable.

Table 6. Norwegian salmon firms. Average technical efficiency and scale efficiency.

Year	CRS-TE (1)	VRS-TE (2)	SE (3)=(1)/(2)
2006	0.879	0.930	0.945
2007	0.876	0.915	0.958
2008	0.869	0.930	0.934
2009	0.904	0.965	0.938
2010	0.909	0.966	0.942
2011	0.916	0.961	0.954
2012	0.943	0.970	0.972
2013	0.926	0.979	0.947
2014	0.894	0.940	0.952
2015	0.870	0.916	0.950
Mean	0.899	0.947	0.949

Note: CRSTE = technical efficiency from CRS DEA
VRSTE = technical efficiency from VRS DEA
SE = scale efficiency = CRSTE/VRSTE

Figure 21 graphically presents the TE scores obtained under the assumption of constant to scale and variable to scale during the period under consideration. The former is designated as CRS-TE and the latter as VRS-TE. Apart from scores for the year 2011, annual average score of TE under the assumption of VRS generally showed an increasing trend during 2007–2013, but decreased in 2013–2015. A similar development is observed for VRS-TE.

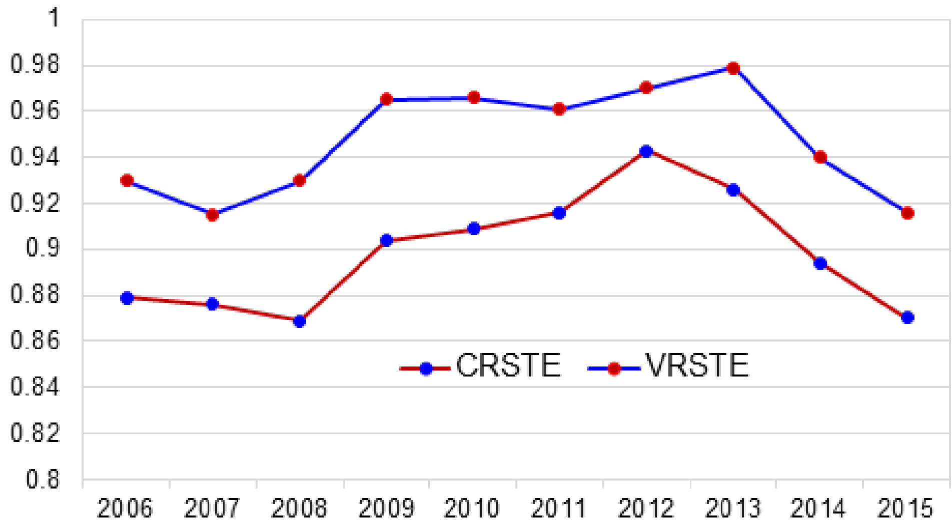


Figure 21. Norwegian salmon firms. Development of technical efficiency under VRS and CRS.

Table 7 compares the mean levels of actual and (projected) frontier inputs. Based on these results, the companies could, on average, by operating on the frontier reduce their fixed assets by 15.3%, shareholders´ funds by 13.4%, current asset by approximately 9%, employment costs by 8.3%, and material costs by 5.6%.

Table 7. Norwegian salmon firms. Comparison of actual and projected input usage (EUR 1000 per year).

	Employment	Materials	Current assets	Fixed assets	Shareholders' funds
Actual value	6,779	40,458	47,127	43,953	36,882
Projected value on frontier	6,216	38,206	42,797	37,239	31,951
Difference (%)	-8.3	-5.6	-9.2	-15.3	-13.4

Figures 22-26 compare actual and projected (frontier) input usage over the period of study. In general, the largest gains could be achieved by reducing the utilisation of fixed assets and shareholders´.

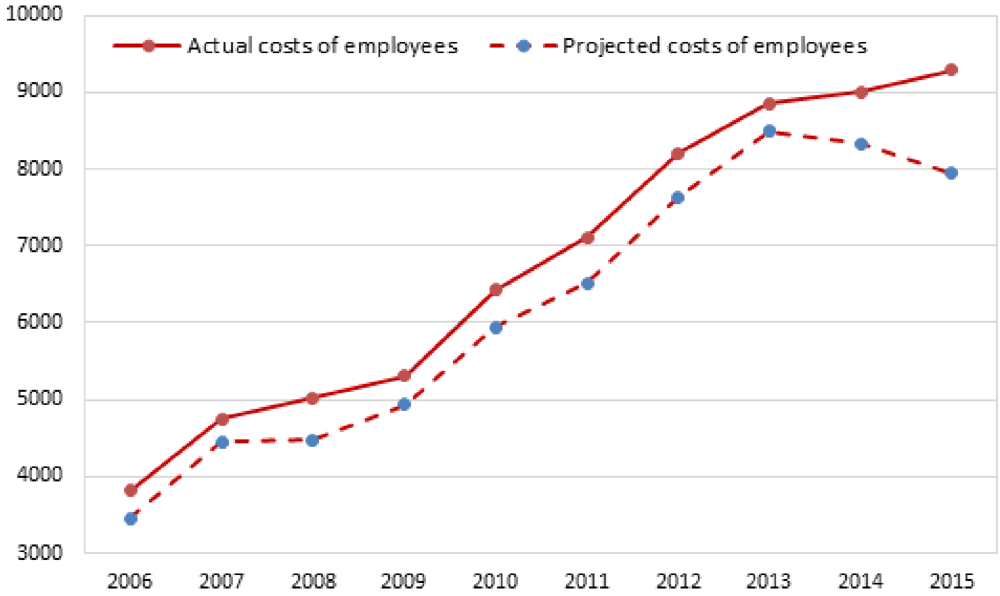


Figure 22. Norwegian salmon firms. Comparison of actual and projected usage of employees.

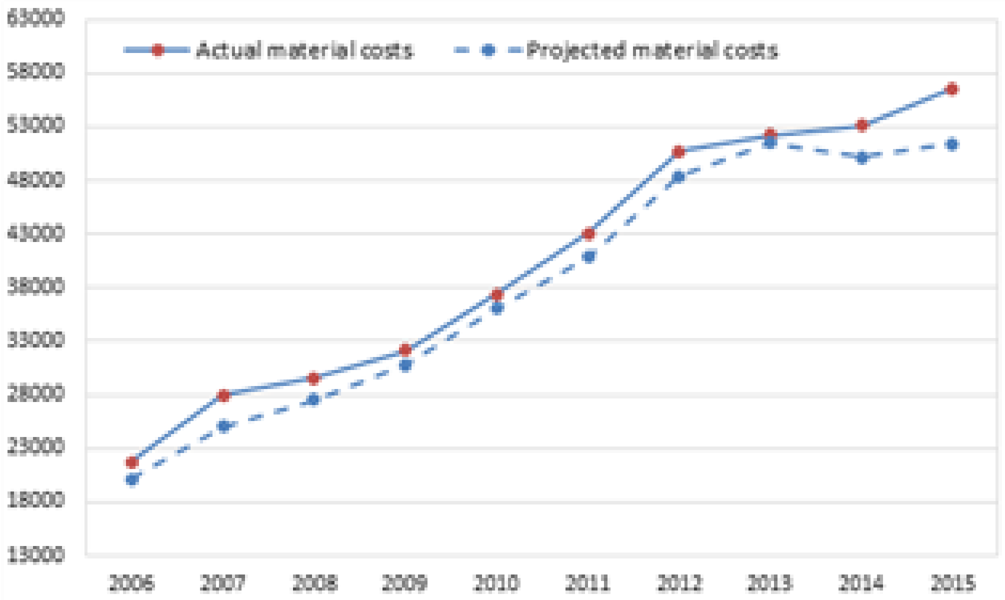


Figure 23. Norwegian salmon firms. Comparison of actual and projected usage of materials.

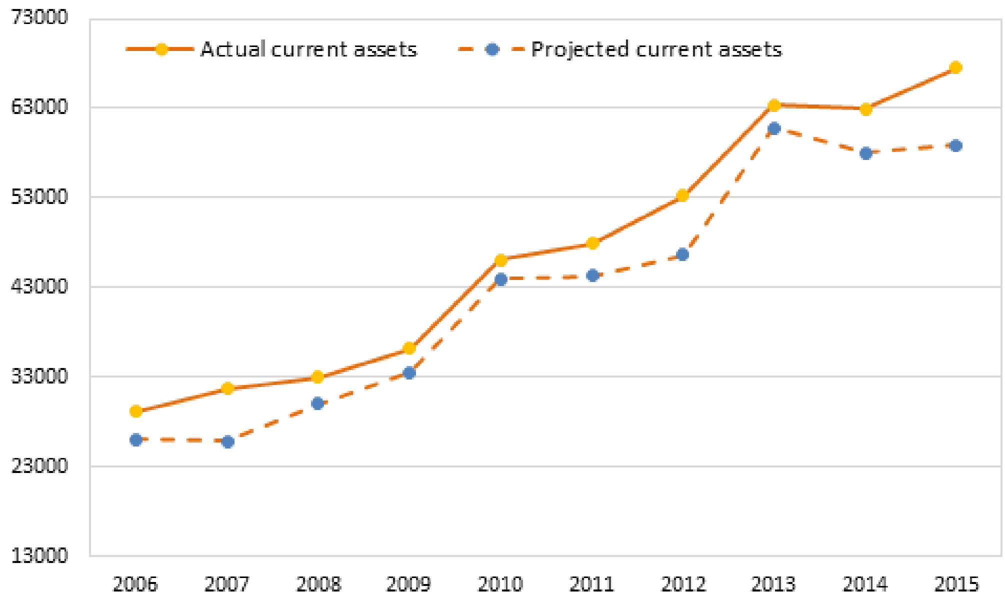


Figure 24. Norwegian salmon firms. Comparison of actual and projected usage of current assets.

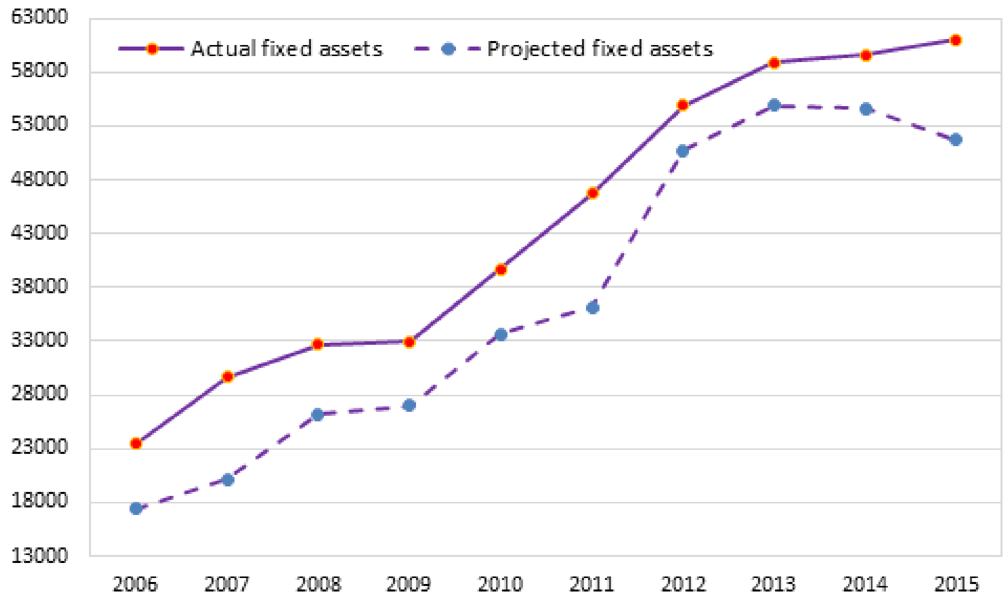


Figure 25. Norwegian salmon firms. Comparison of actual and projected usage of fixed assets.

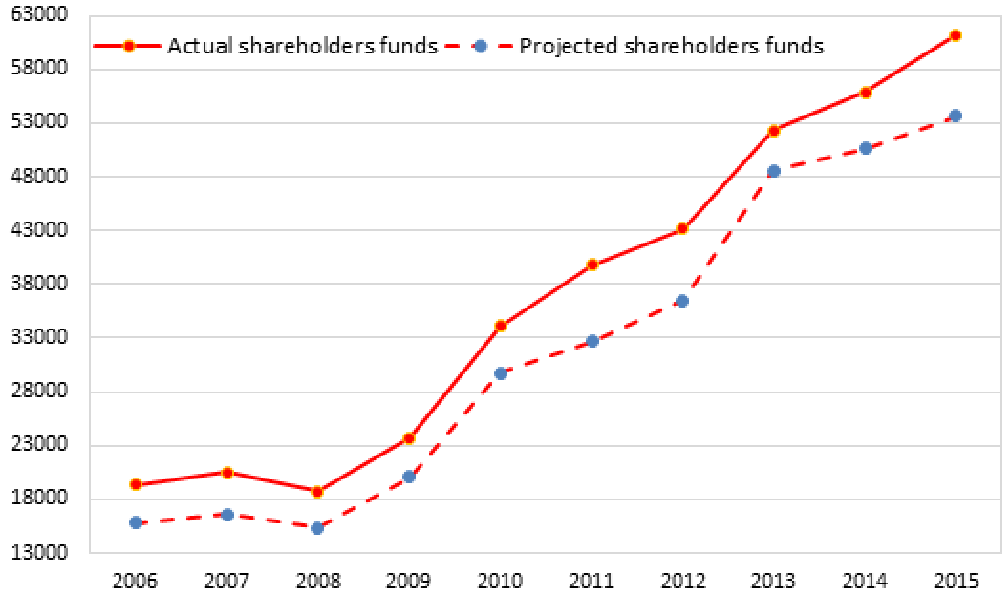


Figure 26. Norwegian salmon firms. Comparison of actual and projected usage of shareholders' funds.

4.1.2 Total Factor Productivity (TFP)

As explained in Section 3.2, total factor productivity (TFP) changes can both be brought about by changes in efficiency (TE) and technology (TC). A productivity score of unity indicates that no change in productivity has occurred, while a value less than unity implies that productivity has decreased and a score above unity that productivity has increased. As shown in Table 8, TFP declined on average by 0.2% during the period 2007-2015. This slowdown can be attributed to both decreasing technical efficiency and technical regress. The average TE change measured -0.1, and the average TC score was likewise -0.1, indicating that the lower efficiency performance of Norwegian salmon firms can be traced in equal parts to decreasing efficiency and technical regress.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 635761

Table 8. Norwegian salmon firms. Annual mean changes in productivity (TFP) decomposed into changes in pure technical efficiency (PE), scale efficiency (SE), technical efficiency (TE) and technology (TC).

Year	PE (1)	SE (2)	TE (3)=(1)*(2)	TC (4)	TFP (5)=(3)*(4)
2007	0.974	1.013	0.986	1.075	1.060
2008	1.022	0.976	0.998	1.095	1.093
2009	1.049	0.998	1.047	0.961	1.006
2010	1.001	1.007	1.008	0.848	0.855
2011	0.994	1.017	1.011	0.942	0.953
2012	1.010	1.021	1.031	1.036	1.068
2013	1.009	0.972	0.981	0.904	0.886
2014	0.957	1.004	0.961	1.039	0.998
2015	0.972	0.999	0.971	1.123	1.090
Mean	0.998	1.001	0.999	0.999	0.998

Note: All TFP averages are geometric means of the sample.

Figure 27 shows graphically changes in TFP and its components over years. The change in productivity (MI) is mainly caused by changes in technology (TC). For example, although TE decreased by 2.9% in year 2015 compared to 2014, productivity in 2015 increased by 9% due to mainly a rise of 12.3% in technology.

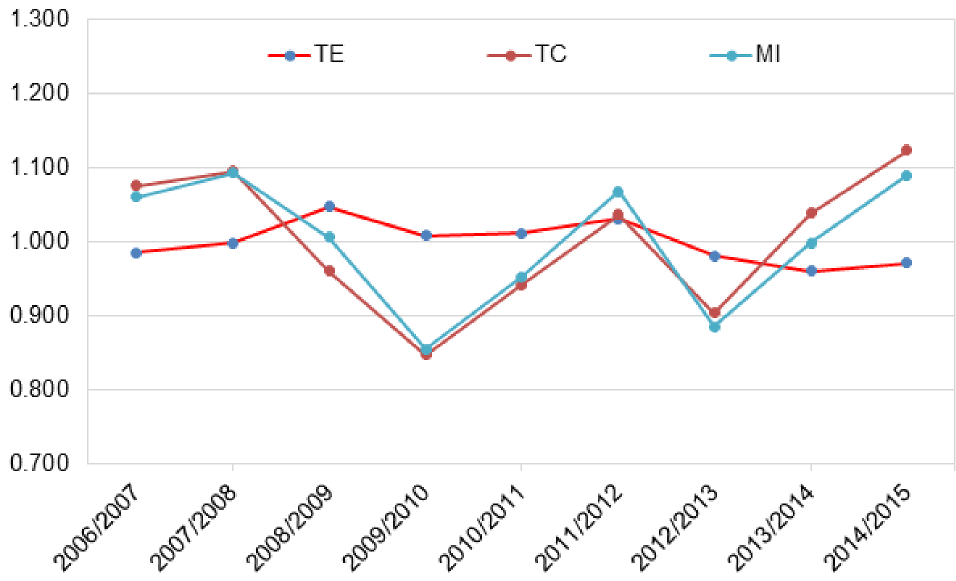


Figure 27. Norwegian salmon firms. Annual mean changes in productivity decomposed into changes in efficiency and technology.

Of the 30 firms included in the sample, 12 experienced increasing productivity, but productivity decreased for 15 firms (Table A1 in Appendix). Productivity did not change at all in three cases. Average productivity changes for all the firms in the sample are illustrated in Figure 28. Apart from firm number 20, the changes are relatively small. However, that particular firm experienced a productivity increase of almost 25%, which was almost entirely brought about by technology improvements.

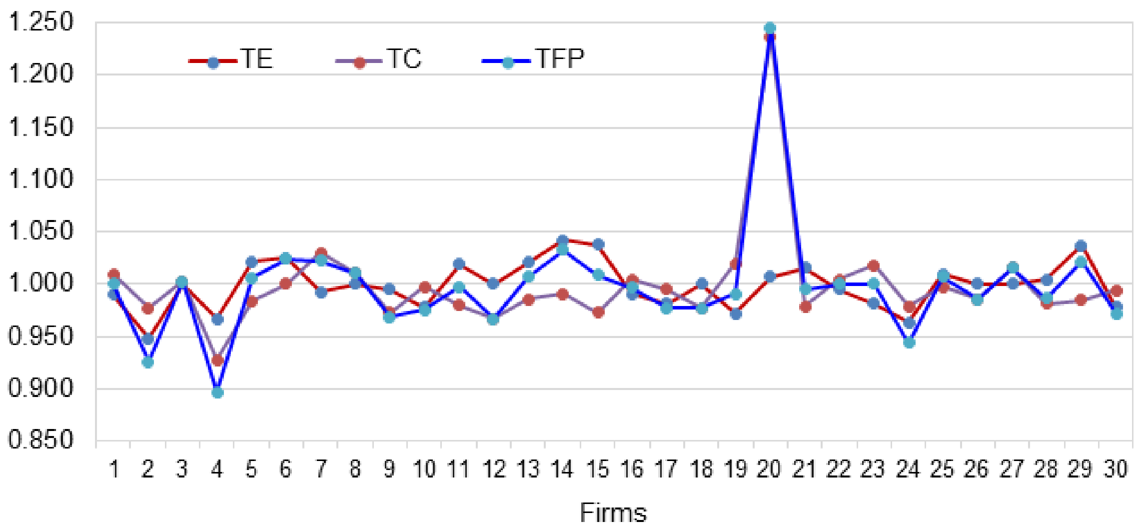


Figure 28. Norwegian salmon firms. Average productivity in period 2006-2015 by companies.

In summary, Norwegian salmon firms have achieved performance efficiently over last decades. At least a third of companies have been in the frontier line of the productivity. The significant increase in production efficiency stems from the improvement in technology and saving input costs (employee and raw material costs).

4.2 Vietnamese pangasius firms

Data for 20 pangasius producers during the period of 2009-2014 are available for efficiency analysis. Most these firms are medium to large scale (in term of capital and turnover) and their business activities include farming, processing and exporting. In this analysis, the development of output is discussed in terms of the utilisation of four inputs; current assets, fixed assets, current liabilities and non-current liabilities.

4.2.1 Technical and scale efficiency

Overall, pangasius firms have performed at low technical efficiency. Under the assumption of variable-return-to-scale (VRS), it was found that the average technical efficiency (TE) for pangasius amounted to only 0.677, implying that the Vietnamese pangasius firms included in this study could have reduced inputs by 32.3% while maintaining the same level of output (see Table 9). The calculated TE under the assumption of constant-return-to-scale (CRS) was 0.794 which is higher the average score of TE under VRS assumption. In general, Vietnamese pangasius firms operated far below the efficiency frontier.

The scale efficiency, calculated as the ratio of the TE under CRS and TE under VRS, was only 0.855. This indicates that the Vietnamese pangasius firms are operating at a far below level of optimal scale efficient level. That means firms could increase their efficiency by 14.5% on average by taking better advantage of the existing economies of scale.

As shown in Table 9, calculated TE is highest in 2011 under both CRS and VRS, but both measures of TE show considerable variation. The calculated SE is more stable. There is a slight increase in scale efficiency in 2009-2011, followed by a downward trend.

Table 9. Vietnamese pangasius firms. Average technical efficiency and scale efficiency.

Year	CRS-TE (1)	VRS-TE (2)	SE (3)=(1)/(2)
2009	0.515	0.646	0.836
2010	0.660	0.775	0.838
2011	0.823	0.883	0.928
2012	0.723	0.863	0.844
2013	0.662	0.782	0.864
2014	0.676	0.814	0.820
Mean	0.677	0.794	0.855

Note: CRSTE = technical efficiency from CRS DEA

VRSTE = technical efficiency from VRS DEA

SE = scale efficiency = CRSTE/VRSTE

Figure 29 graphically presents the TE scores obtained under the assumption of constant to scale and variable to scale during the period under consideration. Annual average scores of TE under the assumption of VRS and VRS in general have an increasing trend in years 2009–2011, a decrease in years 2011–2013, and a slight increase in 2014.

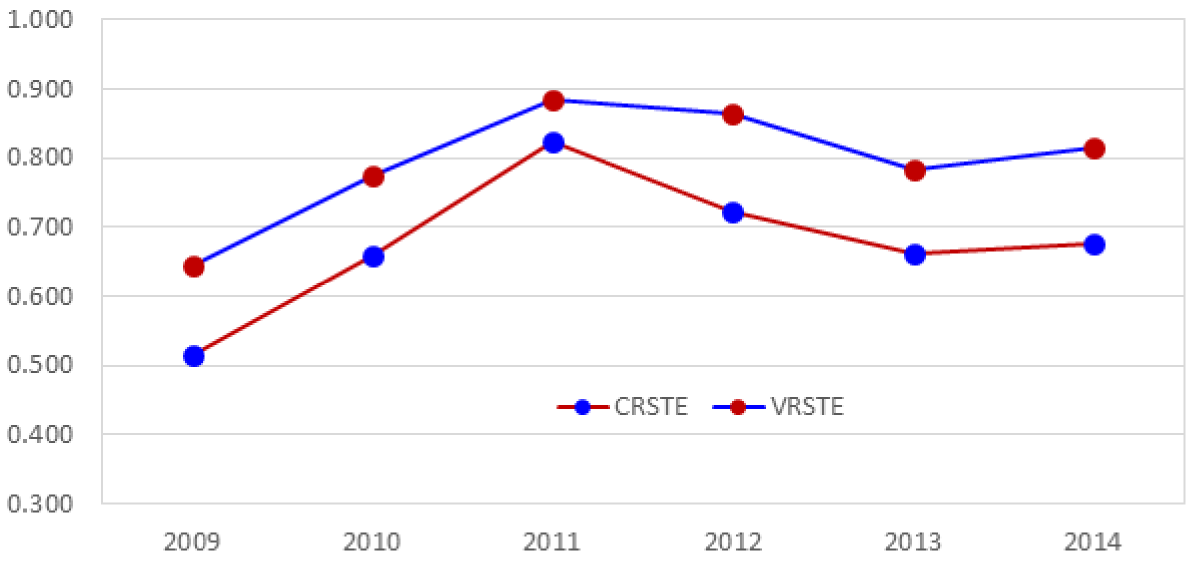


Figure 30. Vietnamese pangasius firms. Development of technical efficiency under VRS and CRS.

As shown in Table 10, pangasius firms have large saving potentials in their input usage. On the average, the companies could, by operating on the frontier, reducer their current assets by 25.2%, fixed assets by 26.3%, non-current liabilities by 45%, and current liabilities by 30.4%.

Table 10. Vietnamese pangasius firms. Comparison of actual and projected input usage (EUR 1000 per year).

	Current assets	Fixed assets	Non-current liabilities	Current liabilities
Actual value	26,513	11,946	2,305	24,142
Projected value on frontier	19,821	8,802	1,267	16,791
Difference (%)	-25.2	-26.3	-45.0	-30.4

Figure 31-34 compare the actual and projected (frontier) input usage over the period of study, and thus illustrates further the input savings presented in Table 10. In general, the largest gains could be achieved through reducing by nearly half the utilization of non-current liabilities.

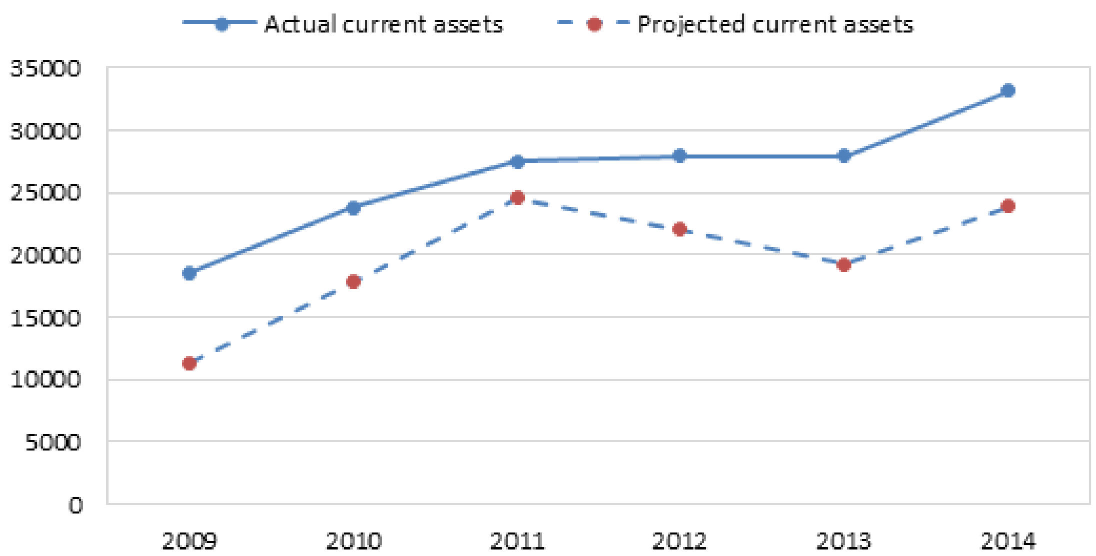


Figure 31. Vietnamese pangasius firms. Actual and projected (frontier) values of current assets.

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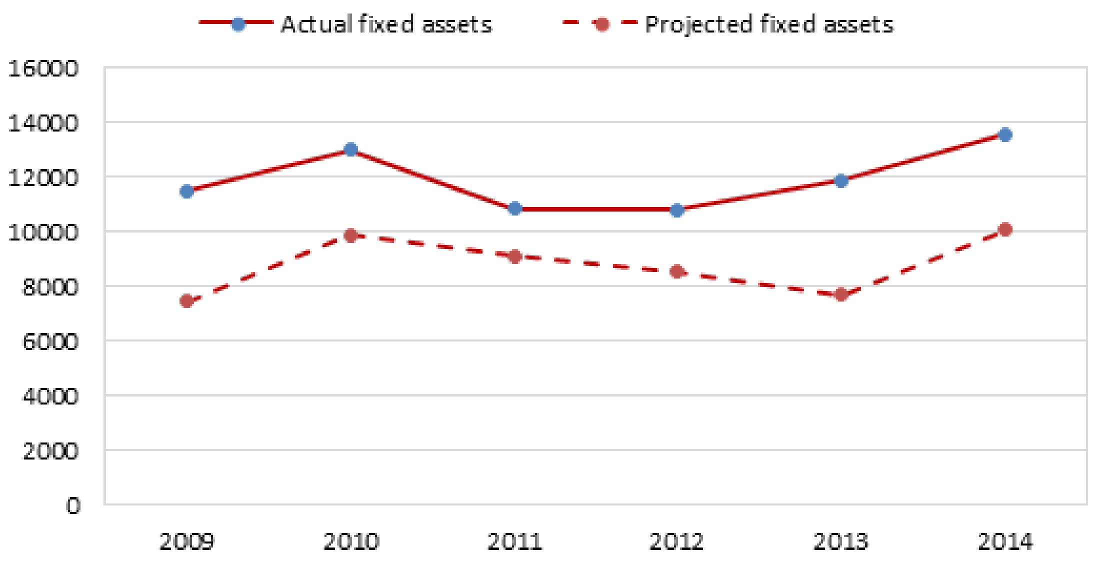

Figure 32. Vietnamese pangasius firms. Actual and projected (frontier) values of fixed assets.

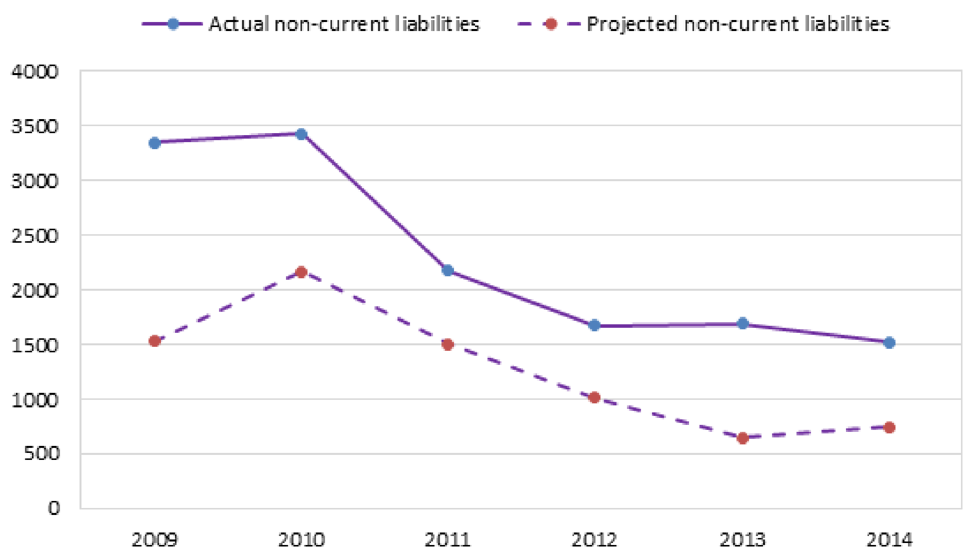

Figure 33. Vietnamese pangasius firms. Actual and projected (frontier) values of non-current liabilities.

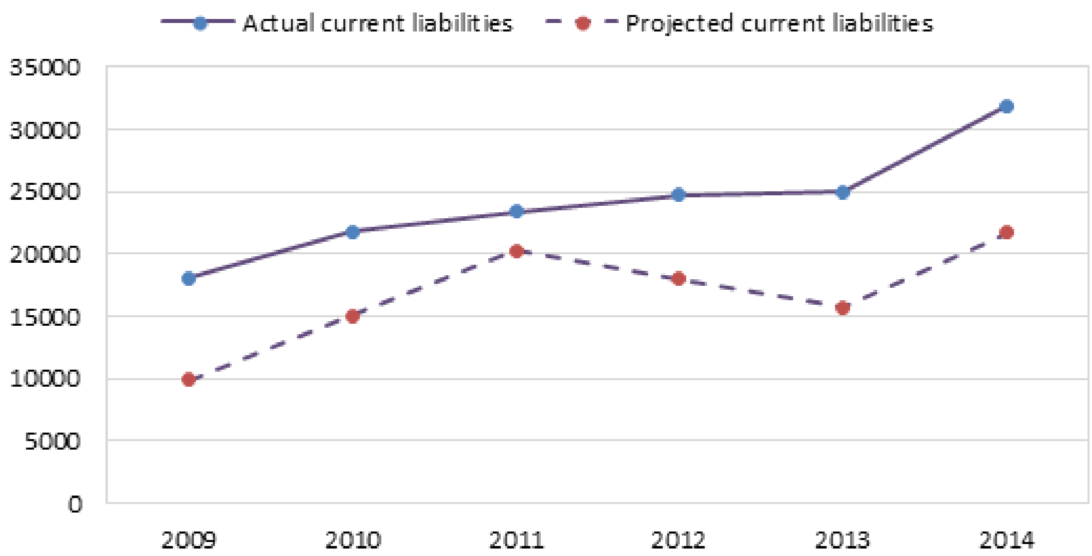

Figure 34. Vietnamese pangasius firms. Actual and projected (frontier) values of current liabilities.

4.2.2 Total Factor Productivity

As shown in Table 11, TFP increases on average by 16%. This increase can be attributed equally much to increases in technical efficiency (EC) and improvement in technology (TC). Incredible productivity increases of 41.7% and 39.6% are registered in 2011 and 2012, but productivity declined by 10.2% in 2010, and by 1.1% in 2014.

Table 11. Vietnamese pangasius firms. Annual mean changes in productivity (TFP) decomposed into changes in pure technical efficiency (PE), scale efficiency (SE), technical efficiency (TE) and technology (TC).

Year	PE (1)	SE (2)	TE (3)=(1)*(2)	TC (4)	TFP (5)=(3)*(4)
2010	1.274	1.181	1.504	0.597	0.898
2011	1.159	1.147	1.329	1.066	1.417
2012	0.969	0.898	0.870	1.603	1.396
2013	0.887	0.988	0.877	1.255	1.101
2014	1.035	0.935	0.968	1.022	0.989
Mean	1.065	1.030	1.110	1.109	1.160

Note that all TFP averages are geometric means of the sample

Figure 35 reveals these fluctuations in productivity (MI) further, but also shows quite clearly how the different components of productivity have behaved during the period under study. Most of the productivity growth in the last few years can be attributed to improvements in technology, i.e. Vietnamese pangasius firms have been updating the technology used.

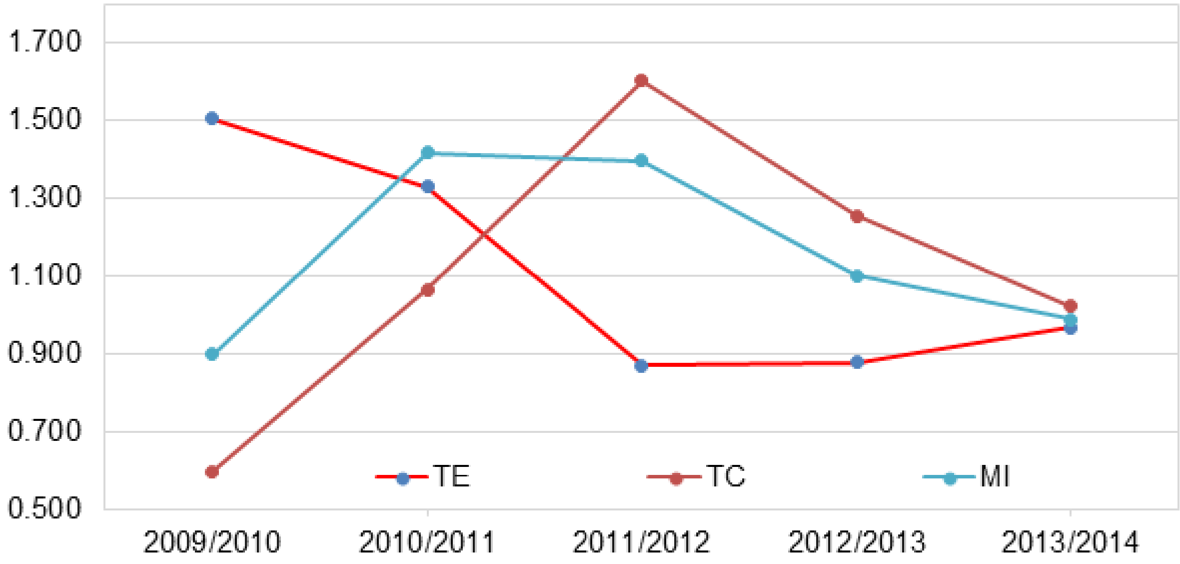

Figure 35. Vietnamese pangasius firms. Annual mean changes in productivity decomposed into changes in efficiency and technology.

The productivity development of each and every firm in the sample is traced in Table A2 in the Appendix, but average productivity changes for individual firms are shown in Figure 36. Productivity increased for 11 out of 20 firms included in the sample, but declined in the other nine cases. Most of the firms experiencing the largest performance improvements are small and medium size; these firms have outperformed their larger competitor in Vietnam.

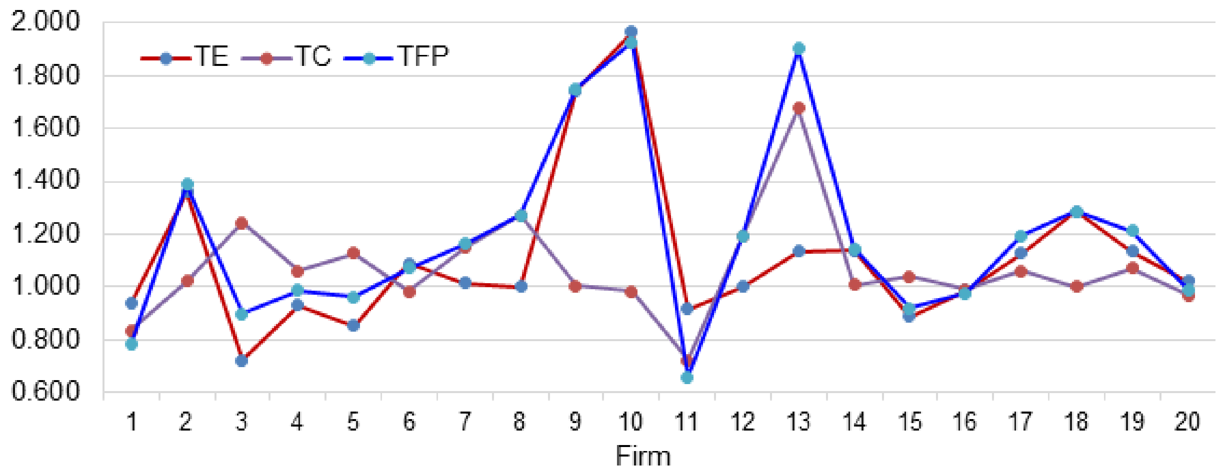

Figure 36 Vietnamese pangasius firms. Average productivity in period 2009-2014 by companies.

4.3 Mediterranean sea bass and bream firms

Dataset of seabass and seabream consist only 13 production companies from 2009 to 2014. The DEA was conducted using current assets, fixed assets, non-current liabilities, current liabilities and number of employees, as well as output.

4.3.1 Technical and scale efficiency

In general, technical and scale efficiency of seabass and bream firms are low and have not improved much in recent years. As shown in Table 12, technical efficiency scores under CRS averaged only 0.429, indicating that sea bass and bream firms could have reduced inputs by 57.1% while maintaining the same level of output. In another word, seabass and seabream have operated much far below the frontier. The average score of technical efficiency under VRS is considerably higher, or 0.72.

Calculated scale efficiency is 0.605, implying that firms could on average reduce input utilisation by almost 40% by taking better advantage of their scale opportunities. Interestingly, no firm in the sample was found to be operating at the scale optimal level.

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Table 12. Mediterranean sea-bass and bream firms. Average technical efficiency and scale efficiency.

Year	CRS-TE (1)	VRS-TE (2)	SE (3)=(1)/(2)
2009	0.365	0.836	0.428
2010	0.395	0.754	0.546
2011	0.414	0.681	0.610
2012	0.443	0.676	0.672
2013	0.477	0.690	0.658
2014	0.481	0.681	0.713
Mean	0.429	0.720	0.605

Note: CRSTE = technical efficiency from CRS DEA

VRSTE = technical efficiency from VRS DEA

SE = scale efficiency = CRSTE/VRSTE

As shown in Figure 37, technical efficiency under VRS has been decreasing but increasing under CRS.

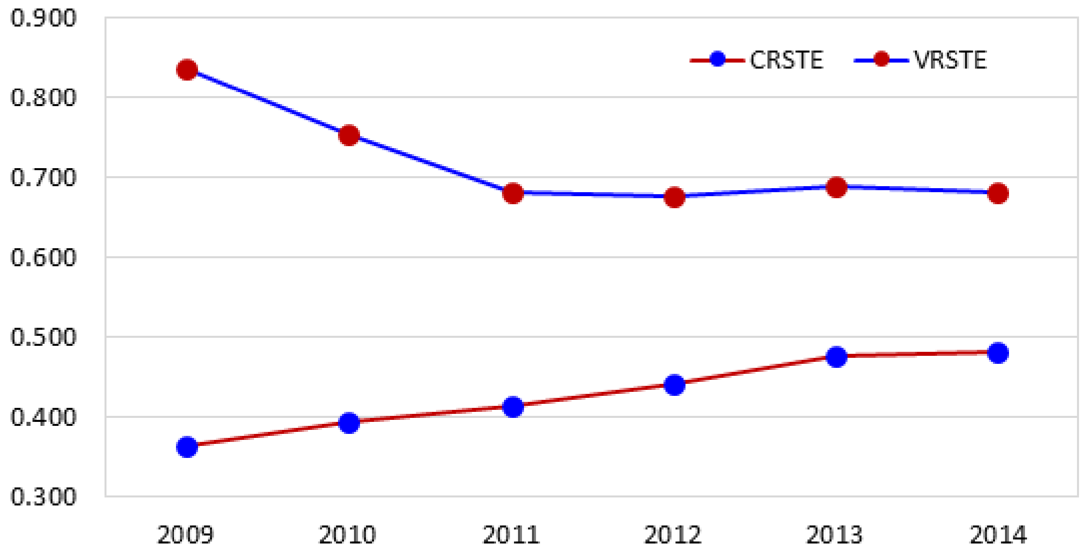

Figure 37. Mediterranean sea bass and bream firms. Development of technical efficiency under VRS and CRS.

The production efficiencies far below the frontier indicate that seabass and seabream firms could have reduced significantly input utilization to keep the same output level. Table 13 compares the mean level of actual and projected frontier inputs. The results show a very high possibility for seabass and seabream firm to reduce level of the inputs, ranging from 32.1% to 40.1%. Based on these results, the seabass and seabream companies could, on average, by operating on the frontier reduce their fixed assets by 33%, current asset by approximately 36.4%, number of employees by 36.6%, non-current liability by 40.1% and current liabilities by 32.1%.

Table 13. Mediterranean sea bass and bream firms. Comparison of actual and projected input usage (EUR 1000 per year).

	Current assets	Fixed assets	Non-current liabilities	Current liabilities	Number of employees
Actual value	56,387	37,036	26,859	46,647	284
Projected value on frontier	35,874	24,806	16,076	31,665	180
Difference (%)	-36.4	-33.0	-40.1	-32.1	-36.6

Figures 38-42 compare actual and projected (frontier) input usage over the period of study. In general, the largest gains could be achieved by reducing non-current liabilities, numbers of employment and current assets, especially in year 2011. As the figures reveal, Mediterranean sea bass and bream firms could realise huge savings by moving closer to the efficiency frontier.

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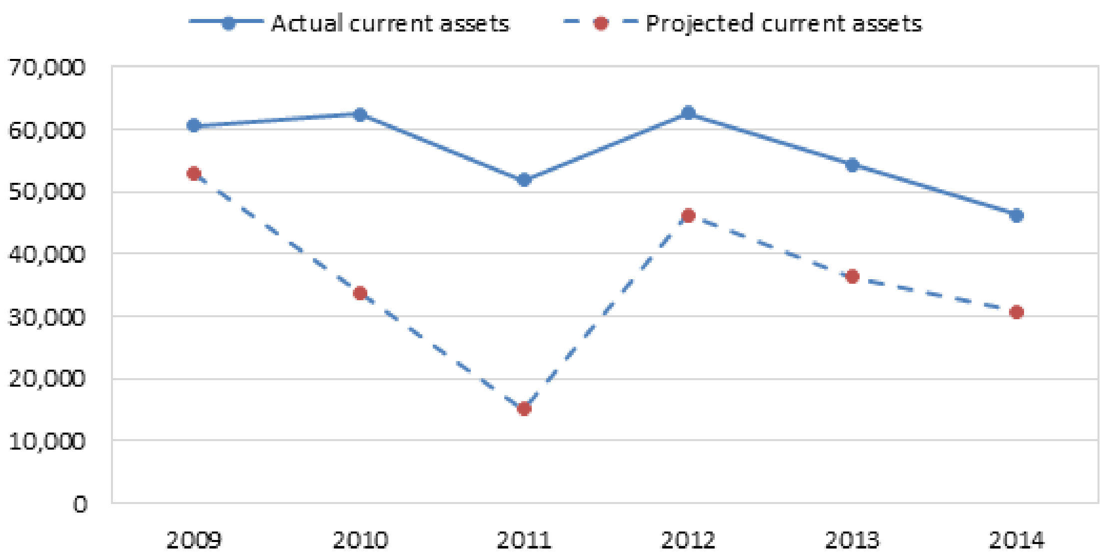

Figure 38. Mediterranean sea bass and bream firms. Actual and projected (frontier) values of current assets.

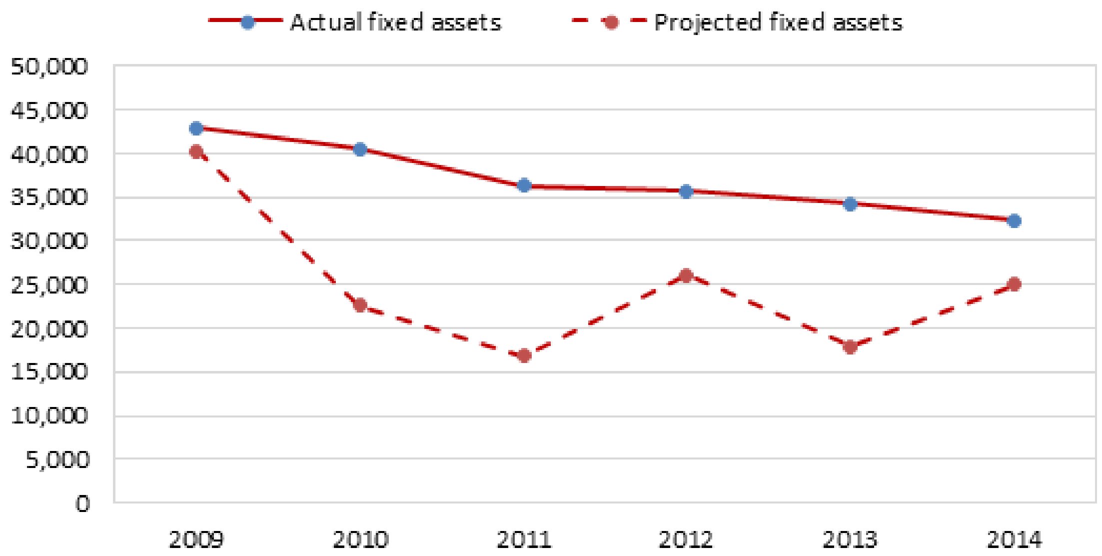

Figure 39. Mediterranean sea bass and bream firms. Actual and projected (frontier) values of fixed assets.

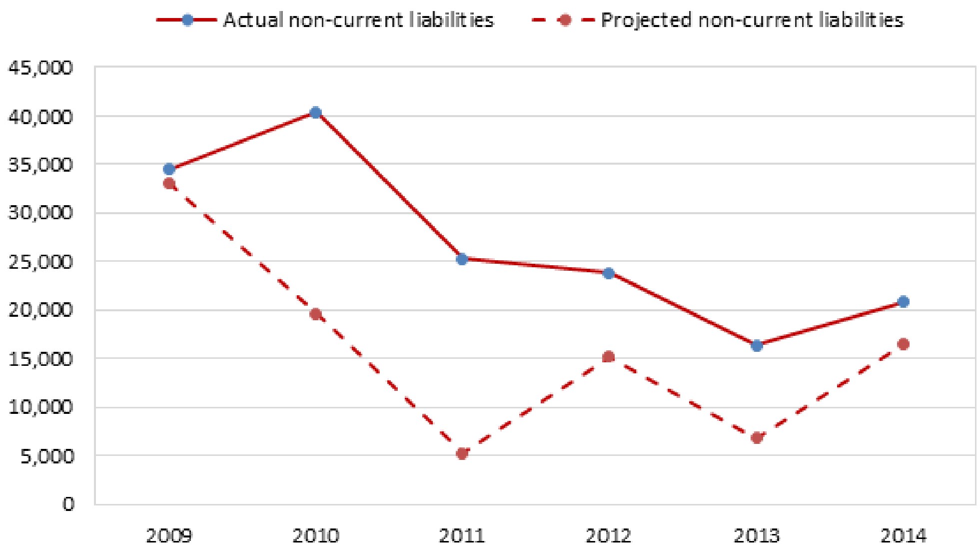

Figure 40. Mediterranean sea bass and bream firms. Actual and projected (frontier) values of non-current liabilities.

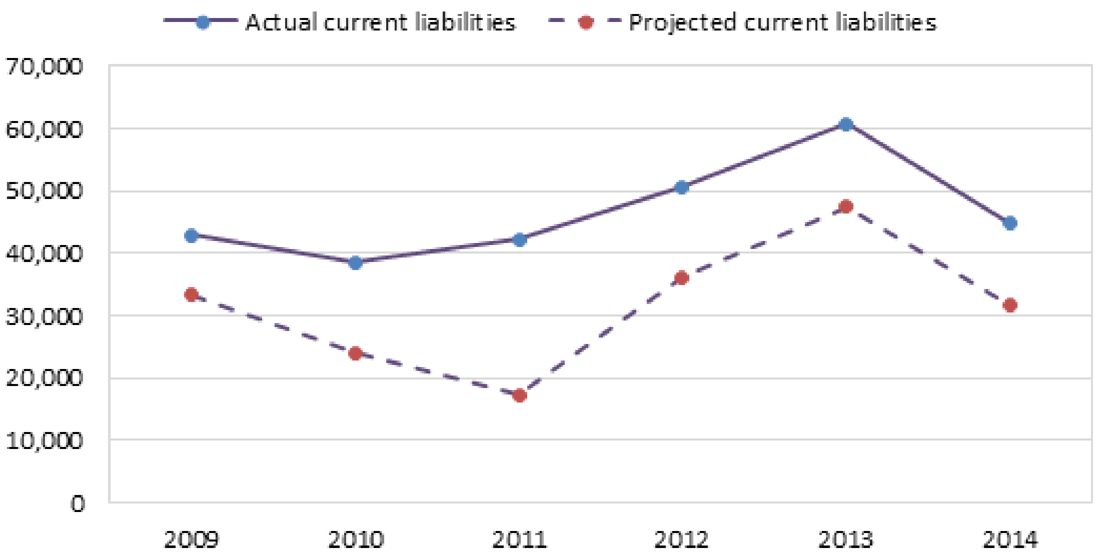

Figure 41. Mediterranean sea bass and bream firms. Actual and projected (frontier) values of current liabilities.

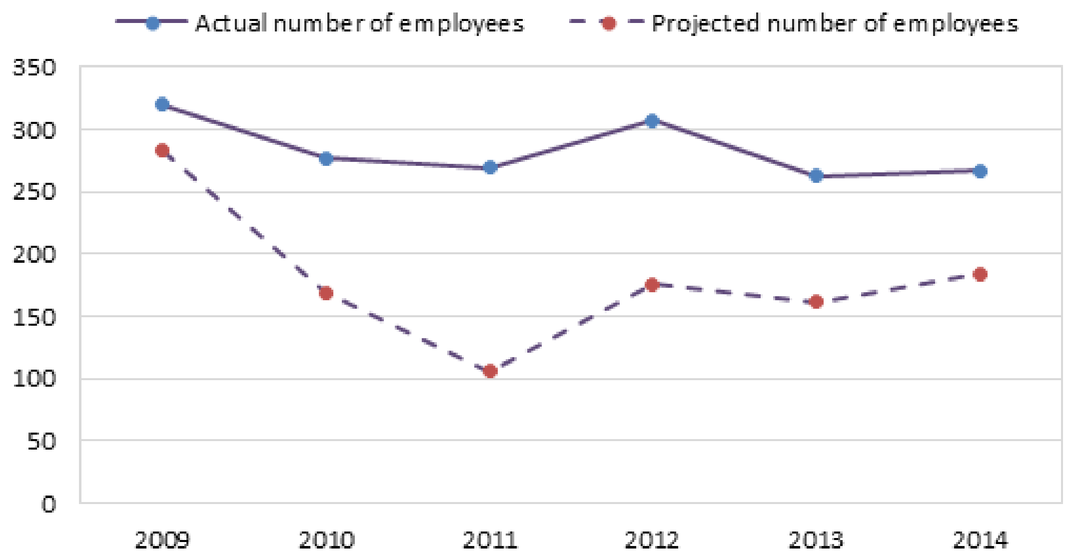

Figure 42. Mediterranean sea bass and bream firms. Actual and projected (frontier) values of number of employees.

4.3.2 Total factor productivity (TEP)

As shown in Table 14, the TFP increased on average by 9%, with productivity increases experienced in all the years except 2014 when productivity declined by 23.1%. Productivity growth was very rapid in 2012 and 2013, but more moderate in 2010 and 2011. The increase in productivity in this period a mostly attributed to increases in technical efficiency (TE) which increased productivity by 7.6%. Technological improvements increased productivity by 2%.

Table 14. Mediterranean sea bass and bream firms. Annual mean changes in productivity (TFP) decomposed into changes in pure technical efficiency (PE), scale efficiency (SE), technical efficiency (TE) and technology (TC).

Year	PE (1)	SE (2)	TE (3)=(1)*(2)	TC (4)	TFP (5)=(3)*(4)
2010	0.861	1.357	1.169	0.903	1.055
2011	0.857	1.105	0.947	1.139	1.078
2012	1.019	1.122	1.143	1.096	1.252
2013	1.019	1.020	1.040	1.248	1.298
2014	0.944	1.144	1.080	0.712	0.769
Mean	0.940	1.150	1.076	1.020	1.090

Note that all TFP averages are geometric means of the sample.

As shown more clearly in Figure 43, the TFP decrease in 2014 is entirely due to technical regress which hampered productivity growth by 28.8%.

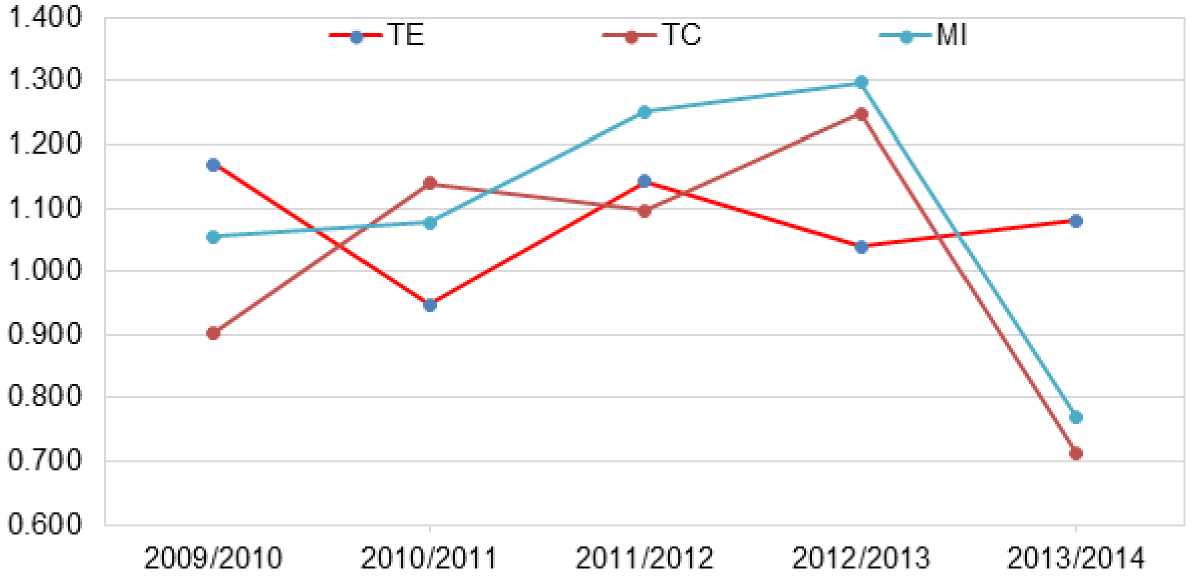

Figure 43. Mediterranean sea bass and bream firms. Annual mean changes in productivity decomposed into changes in efficiency and technology.

The performance of individual firms in the sample are scrutinised in more detail in Figure 44 and Table A3 in the Appendix. Productivity improvements were observed for eight out of the 13 firms, with the remaining five firms experiencing deteriorating performance.

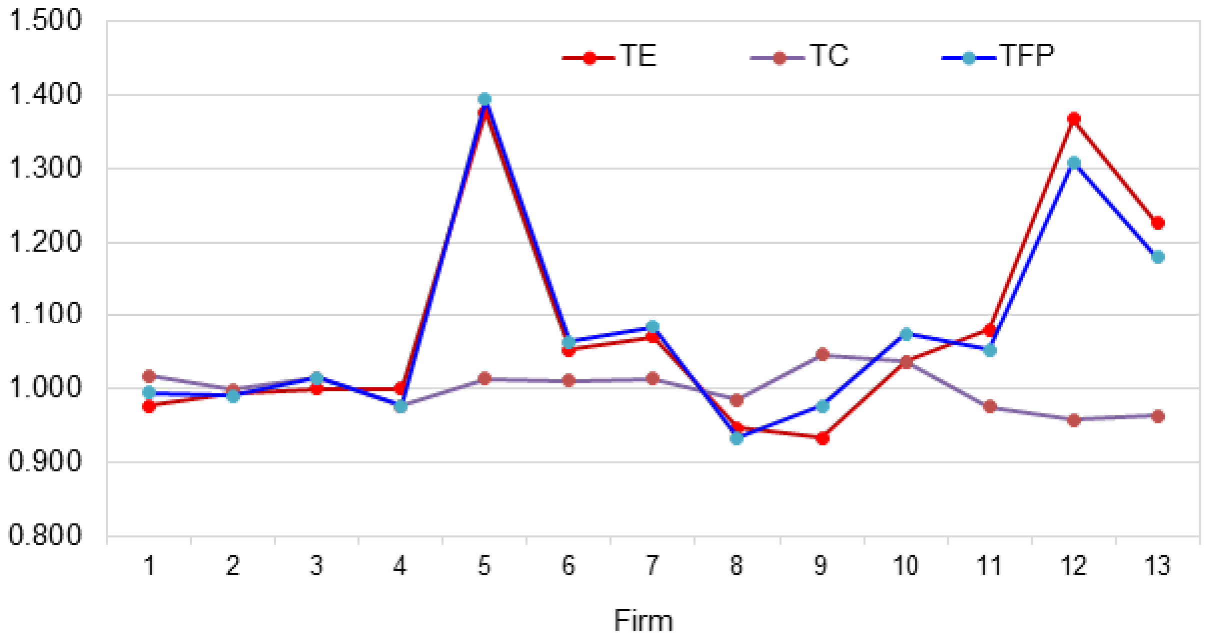

Figure 44. Mediterranean sea bass and bream firms. Average productivity changes of individual firms.

The performance of small and medium sized firms, as measured by current assets, improved the most, with two quite small firms experiencing the largest improvements.

4.4 UK salmon firms

Data from eight UK salmon producers in the period of 2008-2015 are used for DEA. The analysis is based using four inputs (current assets, fixed assets, current liabilities and number of employee, as well as output.

4.4.1 Technical and scale efficiency

The UK salmon firms are found to be quite efficient. The average technical efficiency score under VRS is 0.962, implying that the UK salmon firms included in the study could have reduced inputs by 3.28% while maintaining the same level of output. The TE calculated under assumption of constant-return-to-scale (CRS) is 0.896, which is slightly lower than TE calculated under VRS.

The scale efficiency measured on average 0.933, indicating that by operating at a more efficient scale, input usage could on average be reduced by 6.7%.

Table 15 UK salmon firms. Average technical efficiency and scale efficiency.

Year	CRS-TE (1)	VRS-TE (2)	SE (3)=(1)/(2)
2008	0.904	0.975	0.927
2009	0.948	0.972	0.975
2010	0.908	0.974	0.934
2011	0.880	0.912	0.966
2012	0.849	0.937	0.908
2013	0.823	0.934	0.889
2014	0.921	1.000	0.921
2015	0.933	0.988	0.944
Mean	0.896	0.962	0.933

Note: CRSTE = technical efficiency from CRS DEA

VRSTE = technical efficiency from VRS DEA

SE = scale efficiency = CRSTE/VRSTE

As revealed in Figure 45, estimated technical efficiency under VRS of UK salmon firms is close to the frontier, indeed the efficiecny score in 2013 was 1.0 indicating that firms were on average operating on the fronter.

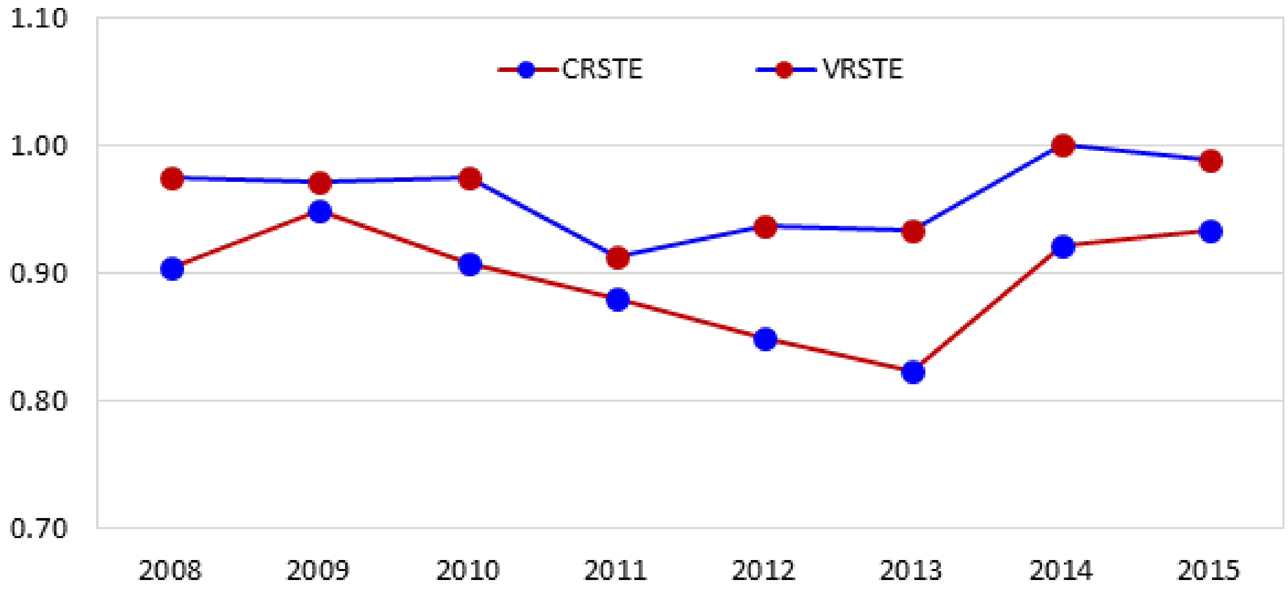

Figure 45. UK salmon firms. Development of technical efficiency under VRS and CRS

Table 16 compares the mean levels of actual and (projected) frontier inputs. Based on these results, UK salmon firms could on average by operating on the frontier reduce their current assets by 5.2%, fixed assets by 11.7%, their current liabilities by 14% and number of employees by 8%.

Table 16. UK salmon firms. Comparison of actual and projected input usage (EUR 1000 per year).

	Current assets	Fixed assets	Current liabilities	Number of employees
Actual value	46,494	22,457	29,785	192
Projected value on frontier	44,079	19,825	25,617	177
Difference (%)	-5.2	-11.7	-14.0	-8.0

Figures 46-49 show in more detail the input saving potential of the UK salmon firms.

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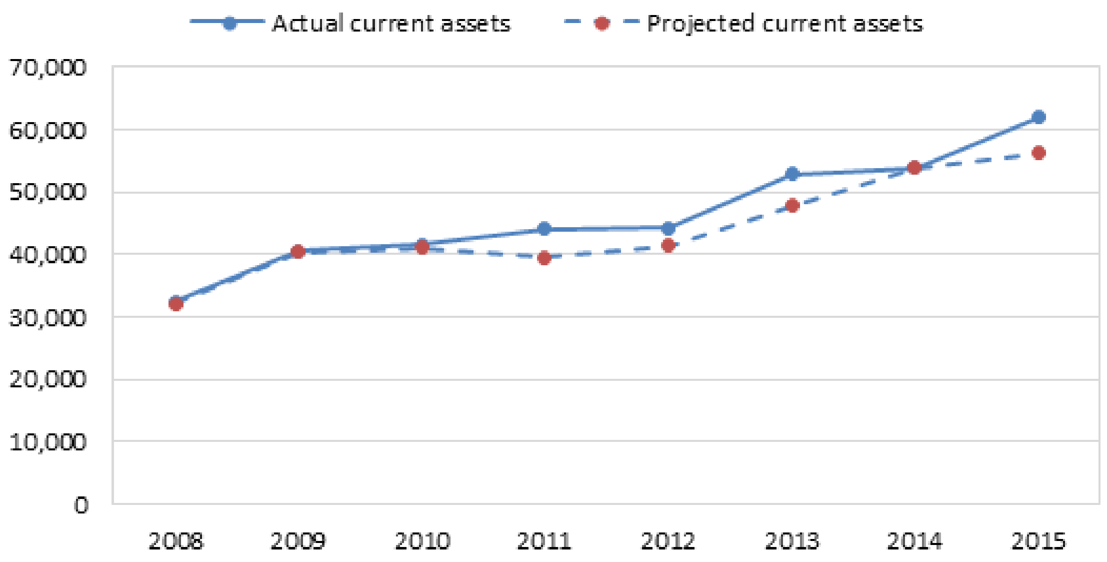

Figure 46. UK salmon firms. Actual and projected (frontier) values of number of current assets.

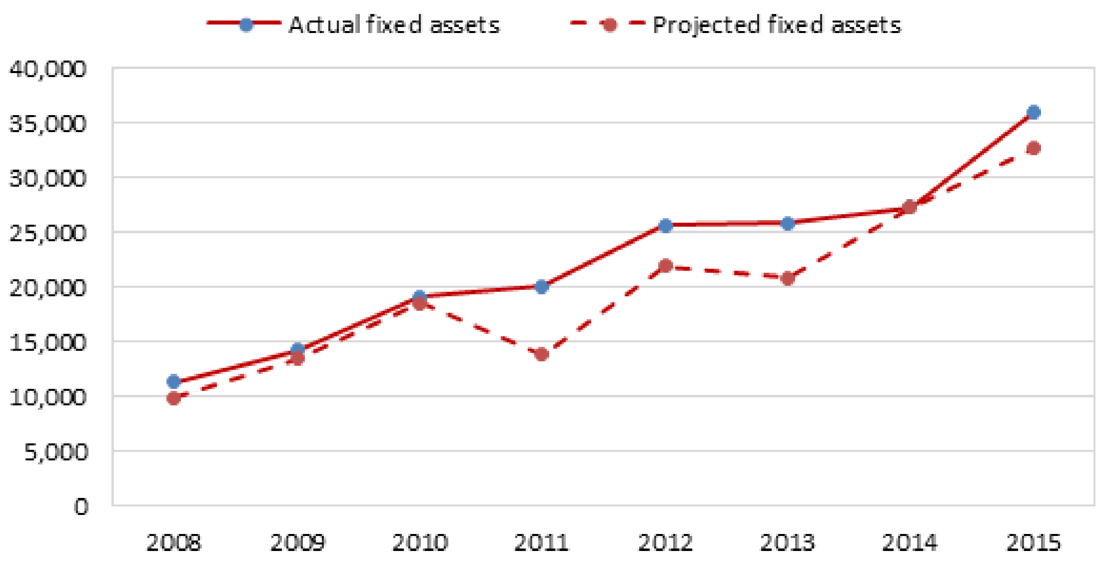

Figure 47. UK salmon firms. Actual and projected (frontier) values of number of fixed assets.

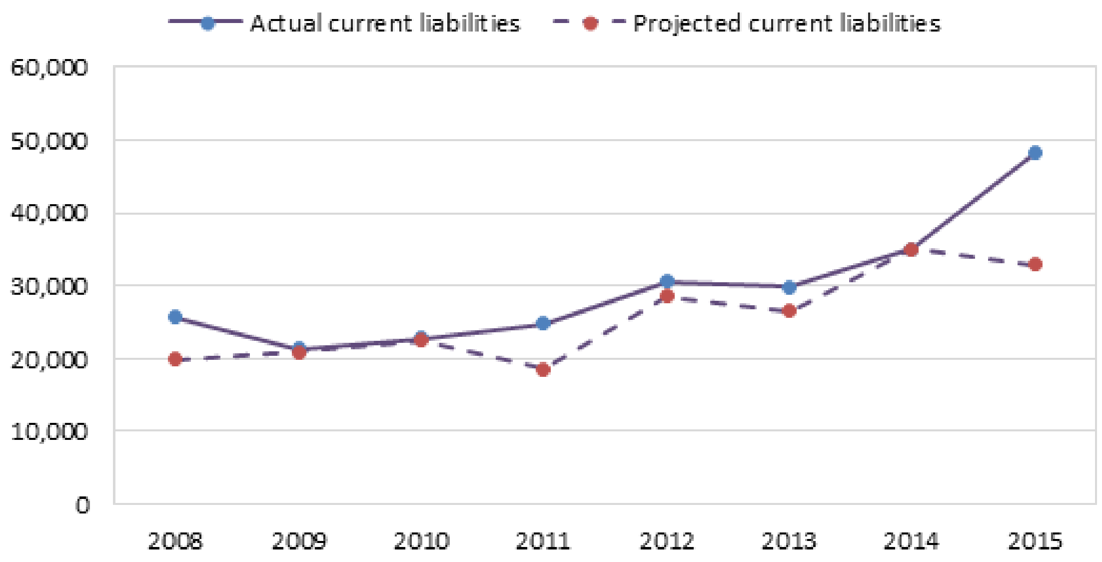

Figure 48. UK salmon firms. Actual and projected (frontier) values of number of current liabilities.

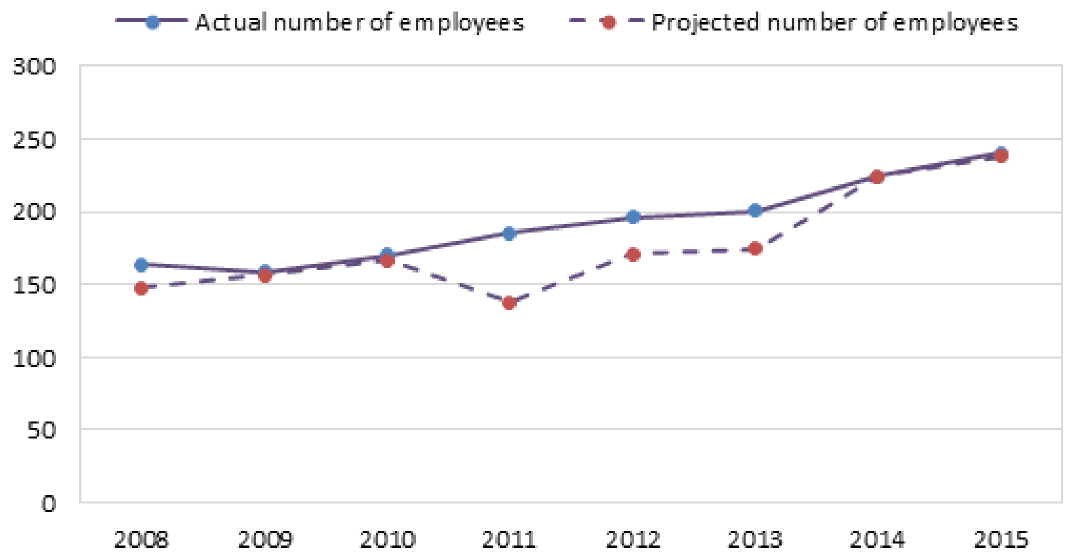

Figure 49. UK salmon firms. Actual and projected (frontier) values of number of employees.

Figure 30 presents graphically the difference between actual and projected (frontier) input usage of each input variables. In general, there is a considerable possibility in period 2010-2014 that UK salmon firms could reduce the usage of all types of inputs.

4.4.2 Total factor productivity (TFP)

TFP calculated for UK salmon firms in the period of 2008-2015 are presented in Table 17. TFP had decreased slightly the period of 2008-2015, indicated by the fact that the average TFP score is below unity. The decreased averaged 1.4% per year, but as shown in the last column of Table 17, productivity growth was positive in four out of seven years. The decomposition of productivity growth reveals that while technical efficiency increased on average by 0.8% per year, the UK salmon firms experienced technical regress which on average reduced productivity growth by 1.8%.

Table 17. UK salmon firms. Annual mean changes in productivity (TFP) decomposed into changes in pure technical efficiency (PE), scale efficiency (SE), technical efficiency (TE) and technology (TC).

Year	PE (1)	SE (2)	TE (3)=(1)*(2)	TC (4)	TFP (5)=(3)*(4)
2009	0.996	1.061	1.057	0.950	1.004
2010	1.001	0.935	0.936	1.097	1.027
2011	0.932	1.059	0.986	0.936	0.924
2012	1.027	0.909	0.933	0.906	0.846
2013	0.989	0.958	0.947	1.217	1.152
2014	1.089	1.078	1.174	0.911	1.070
2015	0.988	1.037	1.024	0.857	0.878
Mean	1.003	1.005	1.008	0.982	0.986

Note that all TFP averages are geometric means of the sample

The development of productivity is examined in more detail in Figure 50 which clearly shows that the changes in technical efficiency and technology have not always usually been in the same direction, i.e. improvements in efficiency have not gone hand in hand with technical progress, and vice versa.

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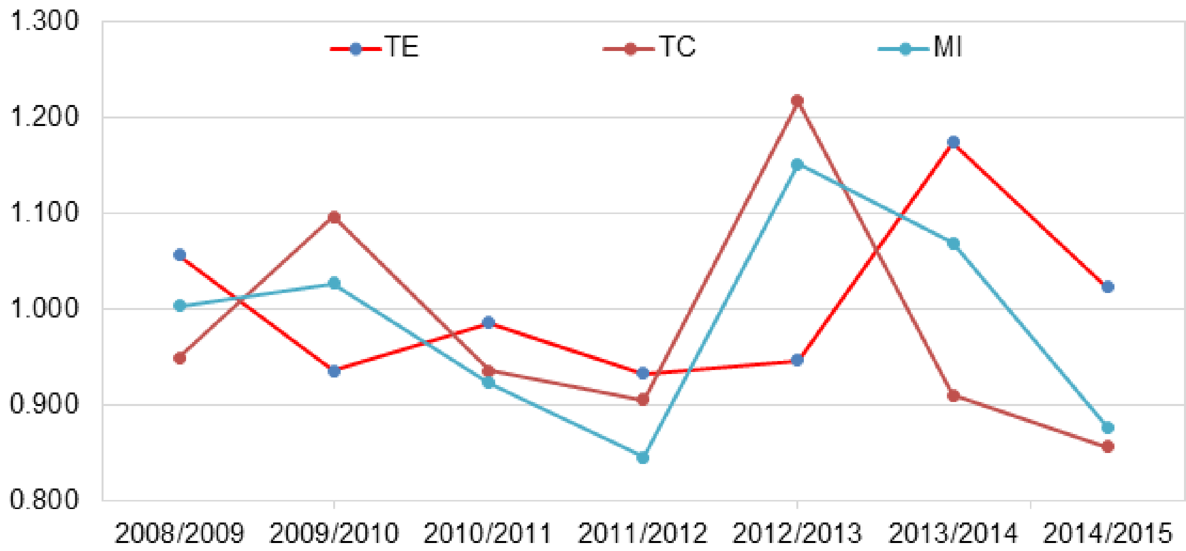

Figure 50. UK salmon firms. Annual mean changes in productivity decomposed into changes in efficiency and technology.

The performance of individual firms is shown in Figure 51 and Table A4 in Appendix. Half of the UK salmon firms in the sample improved their performance during the period under study, as indicated that their respective MI score exceeds unity. Firm number 2 appears to be having difficulties as it has been experiencing retarded productivity. The performance of firms umber 3 and 8 is also poor.

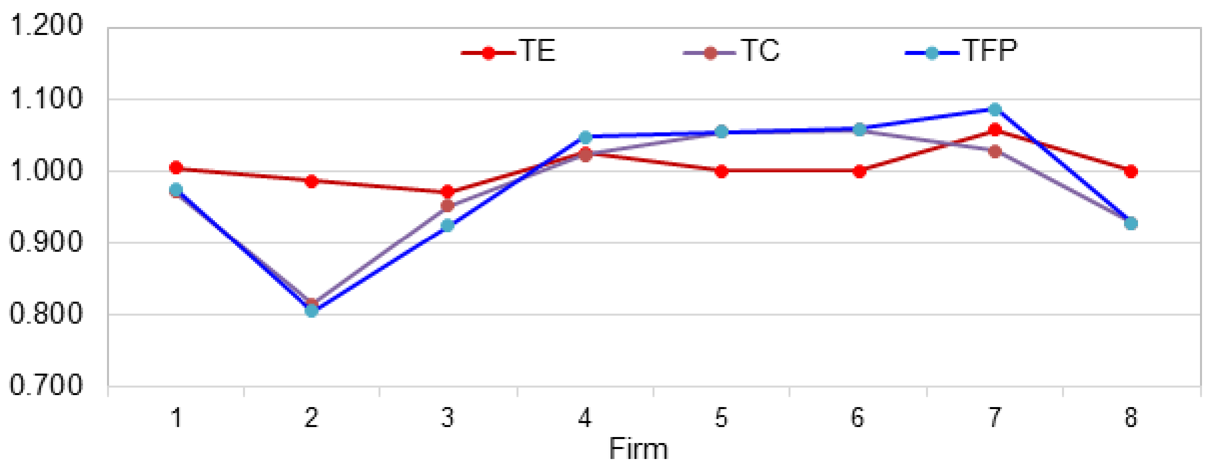

Figure 51. UK salmon firms. Average productivity changes of individual firms.

4.5 Comparison

The development of technical efficiency, technological change and productivity reveals some interesting differences between the four industries included in the study, salmon farming in Norway and the Uk (Scotland), Mediterranean sea bass and bream firms and pangasius firms in Vietnam. Turning first to efficiency, the salmon firms in Norway and Scotland were on average more efficient than the other aquaculture firms, both as regards technical efficiency and the ability to take advantage of the scale efficiency at hand. Figure 52 illustrates this point well. Technical efficiency under the assumption of variable-returns-to-scale averaged 0.962 for Scottish salmon firms and 0.947 for their Norwegian counterparts, but was only 0.794 for Vietnamese pangasius firms and 0.72 for sea bass and bream firms in the EU. Salmon firms in Norway and Scotland enjoyed scale efficiencies of 0.949 and 0.933, while the estimated scale efficiency of Vietnamese firms was 0.855 and only 0.605 for EU sea bass and bream firms.

However, comparison of productivity performance yields a completely different picture. Here, Vietnamese pangasius firms show a remarkable performance, with average productivity of 16% per year, with the EU sea bass and bream firms also showing strong productivity growth of 9% per year. Both Norway and the UK experienced a productivity decline during this period. The productivity growth of the Vietnamese firms can both be attributed to improvements in technical efficiency and improved technology, while better efficiency explains most of the growth of the EU firms. The UK salmon firms have also become more technically efficient, but technical regress has a negative impact on their productivity growth. Norwegian firms have seen their technical efficiency decline slightly and have also experienced a slight technical regress.

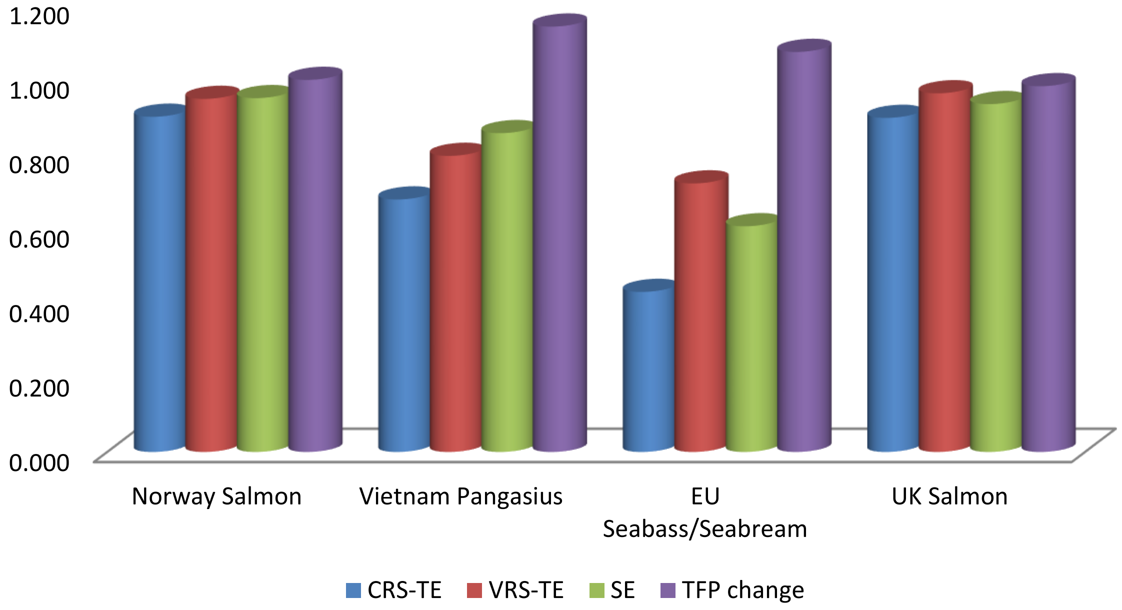

Figure 52. Comparison of calculated efficiency score and productivity change

The analysis provides mixed results for European competitiveness. The technical efficiency of the EU sea bass and bream industry appears rather weak, but despite this the sector has been experiencing rapid productivity growth in recent years. By contrast, the Scottish salmon industry is very efficient, but productivity has been stagnant at best. The Norwegian salmon farms are technical efficient, but have also been suffering from low productivity growth. The study also clearly shows how competitive the Vietnamese pangasius firms have become, as their recent extraordinary productivity growth underlines.

Two caveats are though, in order. First, the variables used in all four studies are not always the same. Although the output variable – revenue – is the same in all cases, the inputs differ from case to case. The Norwegian study uses costs of employment and materials, current and fixed assets and shareholders' funds, while the Scottish data includes observations on current and fixed assets, current liabilities and the number of employees. The Vietnamese data includes current and fixed assets as well as current and non-current liabilities, and the data on the EU sea bass and bream industry has information on these same four variables as well as the number of employees. Second, the study period differs between countries. For Norway, the data covers the period 2006-2015, for Scotland/UK 2008-2015, and for the EU sea bass and bream and Vietnamese pangasius firms the study covers the years 2009-2014. Because of these discrepancies it was not possible to compile all the data together and estimate a joint frontier for all four sectors. Such an exercise would have revealed which of the firms are on the frontier and which below. Despite this, there is good reason to believe that the results of this study are meaningful and show that there exists substantially differences between the salmon fish farms in Scotland and Norway on the one hand, and the EU sea bass and bream and Vietnamese pangasius firms on the other hand. The study also indicates that the Vietnamese firms have in recent years, enjoyed considerable productivity improvements, and that these improvements can both be traced to efficiency gains and better technology.

5 Conclusion

Global production of the main farmed species consumed in the EU has increased drastically in recent years. Production of Atlantic salmon is estimated to have grown by 157% during 2000-2016 and exports of pangasius from Vietnam increased from 700 tonnes in 2000 to 660 thousand tonnes a decade later, with a quarter of those exports finding its way to EU markets. Production of sea bass and bream increased by 259% between 2003 and 2016. But not only has the volume increased, prices of salmon and sea bass and bream have become higher, up approx. 100 and 10%, respectively, while pangasius prices have fallen

Fish farmers within the EU face competition from many directions. They must compete with wild capture fisheries within and outside the EU, aquaculture firms from outside Europe, as well as other food products.

The aim of this deliverable is to use firm level data to analyse and compare the economic performance of aquaculture firms within and outside the EU. For this purpose, it was decided to base the analysis on two key fish farming activities within the EU - Scottish salmon firms and Mediterranean sea bass and sea bream firms – and two important international competitors – Norwegian salmon firms and Vietnamese pangasius firms.

The economic performance of firms is here gauged in terms of changes in efficiency and productivity. Using Data Enveopment Analysis (DEA), an efficiency frontier, which is made up of the most efficient firms, is constructed for each of the four case studies. The position of each firm relative to the frontier is then used to calculate efficiency scores, which are then decomposed into pure technical efficiency and scale efficiency. Technical efficiency indicates how well firms update existing production technology and improve production management, whereas scale efficiency is an indication of how well firms have managed to take advantage of the existing economies of scale. DEA also makes it possible to estimate shifts in the efficiency frontier which are taken to represent changes in technology. An outward shift will then signify technical progress and an inward shift technical regress. Productivity growth is then analysed in terms of these two factors, changes in technical efficiency and technology.

The data at hand differs slightly between case studies, both as regards the input variables available and time dimension. The output variable is the same for all cases, output revenue. The Norwegian study uses costs of employment and materials, current and fixed assets and shareholders' funds as inputs, while the Scottish data includes observations on current and fixed assets, current liabilities and the number of employees. The Vietnamese data includes current and fixed assets as well as current and non-current liabilities, and the data on the EU sea bass and bream industry has information on these same four variables as well as the number of employees. For Norway, the data covers the period 2006-2015, for Scotland 2008-2015, and for the EU sea bass and bream and Vietnamese pangasius firms the study covers the years 2009-2014. Despite these differences, there is both sufficient overlap in time period and in information available, to compare the four different sectors.

The salmon firms in Norway and Scotland were on average more efficient than the other aquaculture firms, as regards both technical efficiency and the ability to take advantage of the scale efficiency at hand. Technical efficiency under the assumption of variable-returns-to-scale averaged 0.962 for Scottish salmon firms and 0.947 for their Norwegian counterparts, but was only 0.794 for Vietnamese pangasius firms and 0.72 for sea bass and bream firm in the EU. Firms on the efficiency frontier are assigned a score of 1.0. The results thus show that Scottish salmon firms could on average reduce their input utilization by 3.8% (1-0.962) without reducing their level of output, and Norway could produce the same amount of salmon while using 5.3% less inputs. By contrast, Vietnamese firms could reduce their input utilization by 20.6% and Mediterranean firms by 28%.

Salmon firms in Norway and Scotland enjoyed scale efficiencies of 0.949 and 0.933, while the estimated scale efficiency of Vietnamese firms was 0.855 and only 0.605 for EU sea bass and bream firms.

However, comparison of productivity performance yields a completely different picture. Here, Vietnamese pangasius firms show a remarkable performance, with average productivity of 16% per year, with the EU sea bass and bream firms also showing strong productivity growth of 9% per year. Both Norway and the UK experienced a productivity decline during this period. The productivity growth of the Vietnamese firms can both be attributed to improvements in technical efficiency and improved technology, while better efficiency explains most of the growth of the EU firms. The UK salmon firms have also become more technically efficient, but technical regress has a negative impact on their productivity growth. Norwegian firms have seen their technical efficiency decline slightly and have also experienced a slight technical regress.

Using data at firm level has advantages for understanding the competitiveness of EU aquaculture, as it provides valuable insight into the industry structure; that enables us to understand better the overall trends in productivity and efficiency of the entire sector as well as also for individual firms, and to compare the performance between sectors as regards of utilisation of specific inputs at firm level. The results of this deliverable therefore are useful for discussion with industries regarding areas for improvement, and of course for the development of the simulation model and DSS tool within the project, i.e. in WP5 and WP6, respectively. However, the analysis provided in this deliverable is based on limited data, and the number of firms, period of data, and input variables used in analysis for four case sectors are not indentical. In addition, the results are based on the application of a single method, DEA, and may not be robust to the use of different methodological approach. The interpretation and implications of the results should acknowledge those limitations.

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This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 635761

Appendix

Table A1. Malmquist Index Summary of Norwegian Salmon Firms

Firm ID	EC	TC	PEC	SEC	TFP (MI)
1	0.990	1.010	0.988	1.002	1.000
2	0.948	0.977	0.950	0.999	0.926
3	1.000	1.003	1.000	1.000	1.003
4	0.967	0.928	0.990	0.977	0.897
5	1.022	0.984	1.021	1.002	1.006
6	1.025	1.000	1.010	1.015	1.024
7	0.993	1.030	1.009	0.985	1.023
8	1.000	1.011	1.000	1.000	1.011
9	0.995	0.973	0.996	0.999	0.969
10	0.978	0.998	0.974	1.004	0.976
11	1.019	0.980	1.017	1.002	0.998
12	1.000	0.967	1.000	1.000	0.967
13	1.021	0.986	1.016	1.005	1.007
14	1.042	0.991	1.000	1.042	1.033
15	1.038	0.973	1.038	1.000	1.009
16	0.991	1.005	0.971	1.021	0.997
17	0.982	0.995	0.990	0.992	0.977
18	1.000	0.977	1.000	1.000	0.977
19	0.972	1.020	0.974	0.998	0.991
20	1.007	1.237	1.001	1.005	1.246
21	1.016	0.979	1.009	1.007	0.995
22	0.995	1.005	0.999	0.997	1.000
23	0.982	1.018	0.986	0.996	1.000
24	0.964	0.979	1.000	0.964	0.944
25	1.010	0.998	1.010	1.000	1.007
26	1.000	0.986	1.000	1.000	0.986
27	1.000	1.016	1.000	1.000	1.016
28	1.005	0.982	0.989	1.016	0.987
29	1.037	0.985	1.032	1.005	1.022
30	0.978	0.994	0.987	0.992	0.972
Mean	0.999	0.999	0.998	1.001	0.998

Note that all MI averages are geometric means of the sample

Table A2. Malmquist Index Summary of Individual Pangasius Firms

Firm ID	EC	TC	PEC	SEC	TFP (MI)
1	0.938	0.833	1.000	0.938	0.782
2	1.358	1.021	1.347	1.009	1.387
3	0.720	1.245	0.916	0.786	0.897
4	0.931	1.059	0.947	0.983	0.986
5	0.851	1.127	0.858	0.992	0.960
6	1.089	0.983	1.167	0.933	1.070
7	1.014	1.147	1.032	0.983	1.163
8	1.000	1.272	1.000	1.000	1.272
9	1.743	1.005	1.000	1.743	1.751
10	1.965	0.982	1.000	1.965	1.929
11	0.915	0.721	0.933	0.981	0.659
12	1.000	1.190	1.110	0.901	1.191
13	1.135	1.677	1.106	1.026	1.904
14	1.136	1.008	1.148	0.989	1.145
15	0.887	1.038	1.198	0.740	0.920
16	0.986	0.991	0.989	0.997	0.977
17	1.126	1.061	1.107	1.017	1.194
18	1.286	1.001	1.272	1.011	1.287
19	1.133	1.069	1.127	1.005	1.211
20	1.022	0.969	1.000	1.022	0.991
Mean	1.081	1.055	1.056	1.023	1.141

Note that all MI averages are geometric means of the sample

Table A3. Malmquist Index of Individual Seabass and Seabream Firms

Firm ID	EC	TC	PEC	SEC	TFP (MI)
1	0.977	1.017	0.997	0.981	0.994
2	0.993	0.998	1.066	0.931	0.990
3	1.000	1.014	1.000	1.000	1.014
4	1.000	0.977	1.000	1.000	0.977
5	1.376	1.013	1.077	1.278	1.394
6	1.053	1.010	1.000	1.053	1.064
7	1.070	1.013	0.857	1.249	1.084
8	0.947	0.985	0.766	1.235	0.933
9	0.933	1.046	0.597	1.563	0.976
10	1.036	1.037	0.923	1.123	1.075
11	1.080	0.975	1.000	1.080	1.053
12	1.367	0.958	1.041	1.313	1.309
13	1.225	0.963	1.000	1.225	1.180
Mean	1.073	1.000	0.937	1.144	1.073

Note that all MI averages are geometric means of the sample

Table A4. Malmquist Index Summary of UK salmon firms

Firm ID	EC	TC	PEC	SEC	TFP (MI)
1	1.004	0.971	1.000	1.004	0.975
2	0.987	0.815	1.000	0.987	0.805
3	0.972	0.952	0.986	0.986	0.925
4	1.025	1.022	1.024	1.000	1.047
5	1.000	1.054	1.000	1.000	1.054
6	1.001	1.057	1.000	1.001	1.058
7	1.057	1.028	1.007	1.050	1.086
8	1.000	0.928	1.000	1.000	0.928
Mean	1.005	0.975	1.002	1.003	0.981

Note that all MI averages are geometric means of the sample

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 635761