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CLIMATE CHANGE AND FUTURE EXPANSION PATHS FOR THE NORWEGIAN SALMON AND TROUT INDUSTRY

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Abstract

Global warming is expected to affect the ecosystem in the Northeast Atlantic, and sufficient changes will also affect the aquaculture industry. Farming of salmon and trout is the biggest aquaculture industry in Norway. The first hand value was about 10 billion Norwegian kroner (about 2 billion US dollar) in 2004. The Norwegian salmon industry is the world’s largest producer of Atlantic salmon – and the production potential has still not been fully utilized. About 2500 persons are directly employed in the industry.

The analysis shows that the extensive allocation of licenses for aquacultural production has reduced the number of suitable, vacant areas for farming in especially coastal areas off Agder, Rogaland, Hordaland and Nord-Trøndelag. The future expansion will mainly take place in the areas north of Stadt.

We anticipate that the salmon aquaculture industry will be relocated from the south to further north along the coast, partly because vacant areas are in the north and partly because higher sea temperature in the future could make the southernmost coast (Vest Agder, Rogaland and Hordaland) unsuited for farming of salmon.

In the short run (5 yeas or so) the production will increase in the already established firms located along the coast, from today’s 600,000 tons to 800,000-900,000 tons. An econometric model shows that an expansion in existing plants will increase the gross revenue by about 2 billion Norwegian kroner per year. Expansion beyond 900,000 tons must therefore be produced in new plants. We have estimated the production potential from *new* plants to about 1.2 million tons. We calculate that the aggregated, future production potential is about 2.1 million tons (0.9 + 1.2) of salmon and trout per year, given *no* “extraordinary” climate changes. On the other hand, if the sea temperature continues to increase, it could in the worst case make it too risky to farm salmon in open cages in the sea off Vest Agder, Rogaland and Hordaland. The said areas will then lose a yearly aggregated production of about 240,000 tons. An overall future increase in the sea temperature will increase the productivity in the industry located north of Stadt. The combination of full utilization of vacant areas north of Stadt and increased productivity there, but radical reduction in the three southernmost counties, would result in a future aggregated supply of about 2 million tons of Norwegian salmon per year.

The econometric analysis shows that there is a long run negative relationship between export prices and quantity supplied of Norwegian salmon. The negative relationship between price and quantity (elastic demand) indicates a potential of realizing extra profit in the export market by restricting the supply. The partial model does not take into account that increased supply from competing salmon producing countries can undermine the quantity restriction strategy.

1. INTRODUCTION

In general, 'aquaculture industry' can be defined in the following way (Hishamunda and Percy 2001):

> *The farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.*

The analysis in this paper is limited to commercial aquaculture, i.e., rearing of aquatic organisms for selling in a market. This is an activity undertaken by the private sector and without direct financial assistance from government sources. The definition emphasises the commercial objective of these operations.

There are indications that the climate is changing and will continue to do so for some time (IPCC 2001). One of the predicted changes is an increase in the average temperature. Aquaculture is one of the industries most likely to be affected by this, as it is under today's technology dependent on natural conditions. How the industry will change depends on what kind of climate change we will experience and how fast. It also depends on what kind of species are cultivated. In this report we focus on production of Atlantic salmon and trout.

Sustainable aquaculture requires legislation which secures private ownership and production on defined sites. Environmental sustainability implies legislation that limits ecological damages and external costs imposed on the remainder of society and future generations. Commercial sustainability implies competitive profits and a stable level of returns over the long term. An environmental breakdown on a particular site because of feed loss, self inflicted pollution and too high density of fish will make the goal of environmental and commercial sustainability unattainable. But even though the farmers follow prudent procedures and feed optimally, sea farming can fail because of climate changes. This, needless to say, they would try to avoid; they would try to accommodate to structural changes in climate, cultivate alternative species that are more suitable for the "new" climate, apply a new production technology which controls more of the environment, continue cultivating the same species as before but a genetic type more suitable to the new climate, or move the cages to colder sea areas.

In the following we will analyse two scenarios, one where the climate does not change but the industry expands, and a second scenario where the sea temperature increases. What can we expect will happen to the salmon and trout industry, and where along the coast will the industry be located in the future? It is also relevant to ask the question what species will be farmed in the future.

The paper is structured as follows. In the next section we describe the Norwegian aquaculture industry and its development, to provide background. In Section Three we examine the areas suitable for aquaculture production, as given by nature and other restrictions. This discussion is based on the so-called LENKA project, which examined the suitability of areas along the coast of Norway for aquaculture production. This is followed up in Section Four by estimating the production potential for aquaculture. In Section Five the relation between price and quantity produced of Norwegian salmon is estimated, and in Section Six this function is used to evaluate how the revenue will increase as a result of increased production. Due to the negative relationship between price and quantity supplied, revenues will not increase in proportion to supply. Finally there is a concluding section.

2. THE NORWEGIAN AQUACULTURE INDUSTRY

Industrial farming of salmon and trout is a relatively new activity world wide. Farming of salmon and trout started in Norway in the early 1970s. Since then the technology has spread to other areas around the world which are climatically suited for farming of Atlantic salmon or similar species. Wild Atlantic salmon was traditionally a highly priced fish, but salmon farming has changed that picture. Salmon is still valued as a tasty product and an important protein source, but the high productivity and huge supply at low cost has made it possible to sell salmon at a relatively low price, and it is now a common food item.

Figure 1 shows the production of salmon and trout in Norway during the period from 1980 to 2003. The plot indicates an exponential growth in production. The figure also shows the aggregated first hand value of the production of salmon and trout. The average growth rate of the quantity produced is estimated at 0.18.

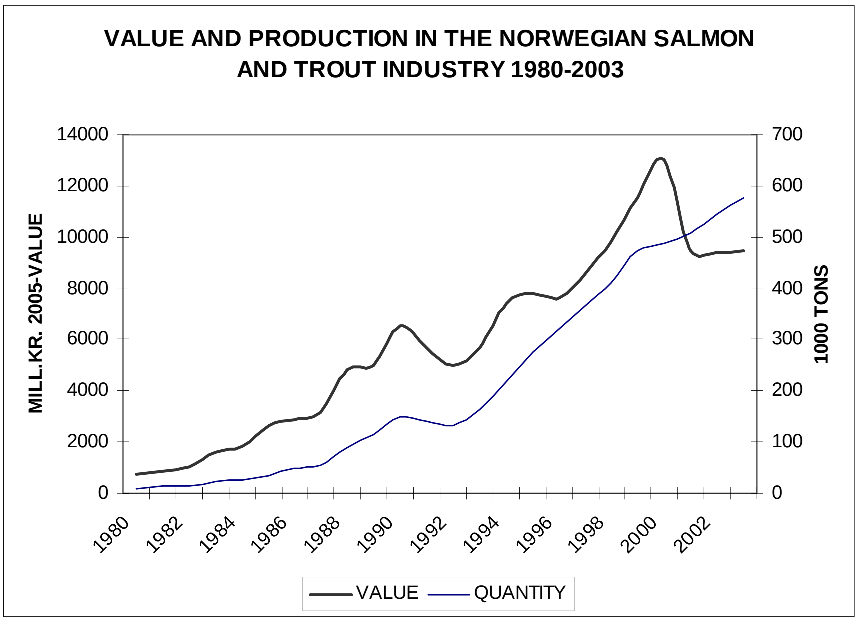


Figure 1: Production and value in the Norwegian salmon and trout industry
Source: Statistics Norway

The aggregated production in 2000 was 489,000 tons, and in 2003 the production had increased to 577,000 tons. The first hand value of production was 13 and 9.5 billion Norwegian kroner (2005-value of money) respectively. So, despite the increase in production, its value actually fell from 2000 to 2003.

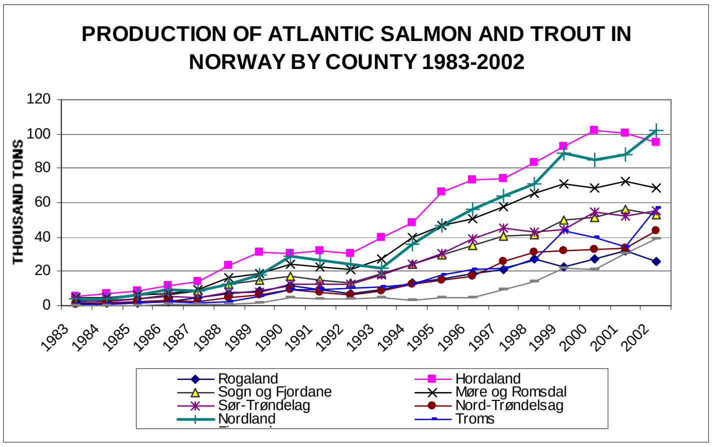


Figure 2: Production of salmon and trout by county
Source: Statistics Norway

The salmon- and trout farming industry is located inside the coastal archipelago and close to the mainland. Figure 2 shows the production by county. The industry has expanded in all counties, but the growth rate has flattened out for most of them during the last three or four years. The farming industry is important for the economic activity in coastal communities. Figure 3 shows the employment in the industry. The employment in the hatcheries and in the production of smolt has been constant during the said time span while employment in farming has fluctuated during the period. The figure also shows an increase in productivity. Production per person has increased about tenfold during a period of eighteen years, from about 19 tons per employee in 1986 to over 200 tons in 2003.

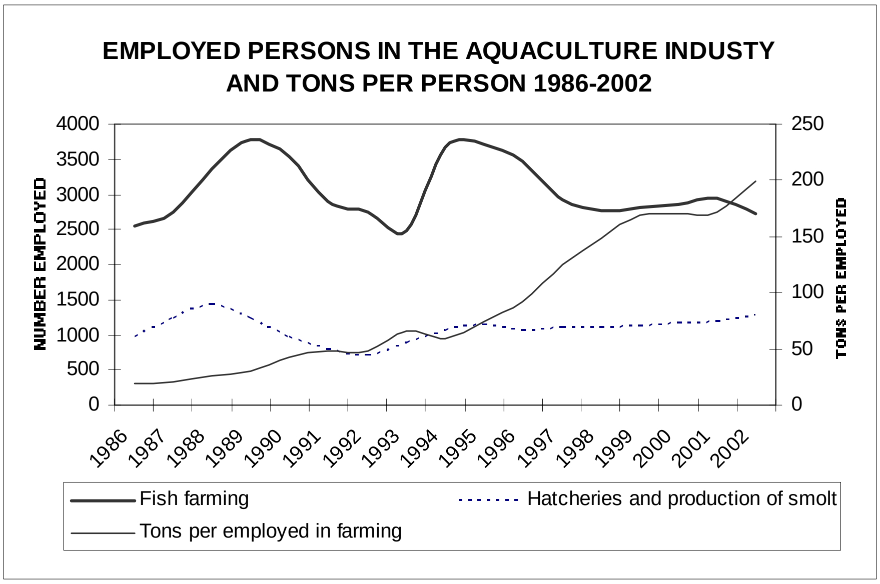


Figure 3: Employment and productivity in the salmon and trout industry
Source: Statistics Norway

About 90% of the produced quantity of salmon is exported, the EU being the most important market. Norway supplies fresh and frozen salmon directly both to the consumer market and to the processing industry, for example the smoking industry in France, Germany and Denmark. Figure 4 shows the composition of the total export of farmed salmon. Fresh, whole salmon dominates in the exports of salmon products. Figure 5 shows the aggregated export of salmon from Norway.

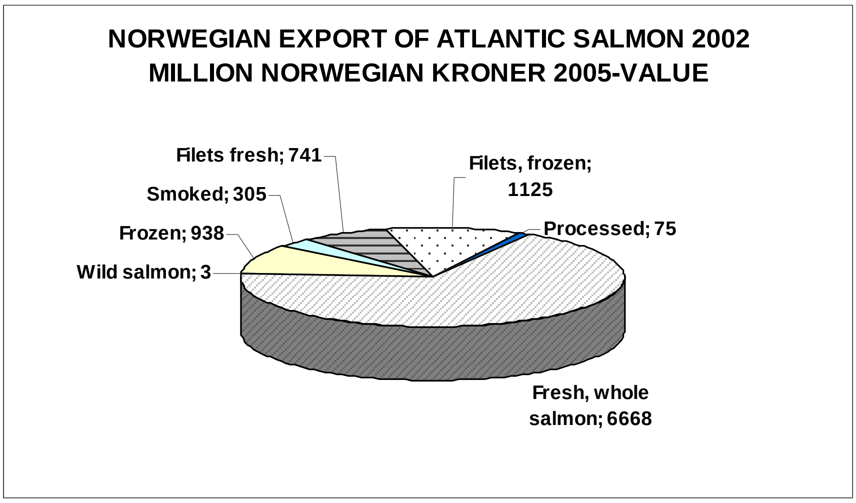


Figure 4: Export of salmon and trout by product
Source: Statistics Norway

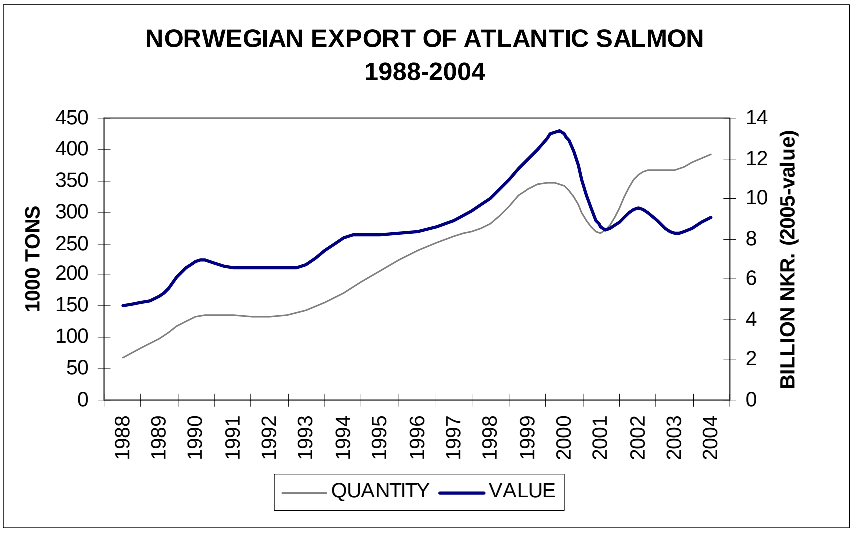


Figure 5: Aggregated export of salmon from Norway
Source: Statistics Norway

The real export value increased fairly steadily from 5 billion Norwegian kroner in 1988 to 13 billion in 2000. The growth was succeeded by a decline in 2001, which flattened out in 2002-2003. The decline was in part caused by an appreciation of the Norwegian currency and by EU regulations of the Norwegian access to the EU-market. The most important export markets are shown in Figure 6. Denmark, France and Japan are the three most important countries, but about 60% goes to the EU.

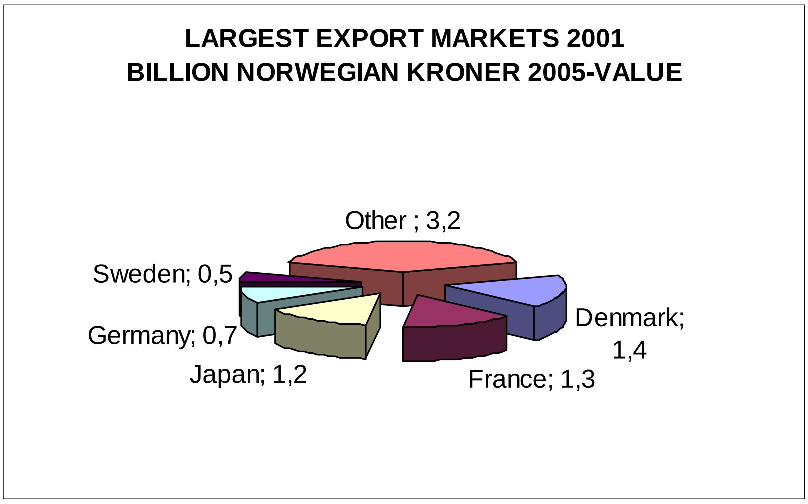


Figure 6: Export of salmon by most important markets
Source: Statistics Norway

The production of farmed salmon is growing fast in Chile, which can be explained by stable biological production conditions and few governmental restrictions. The growth in production has been about 20% per year during the last years. Chile exports mainly to the US and Japanese market, but also a minor share to Europe. Because of long distance and high costs of transportation to Europe, Chile exports frozen commodities, especially frozen fillets. The increased supply of frozen fillets is expected to put pressure on the fresh products of salmon in the future. Chile is capable of producing fillets for about 30 Norwegian kroner per kilo while the Norwegian cost for the same commodity is more than 50 Norwegian kroner per kilo (Norsk Fiskeoppdrett 2005). It is difficult, however, to predict how the real price on salmon will develop. This depends among other things on the future development of productivity and growth in the farmed salmon industry, as well as the productivity and supply of substitute products from agriculture and from the capture fisheries.

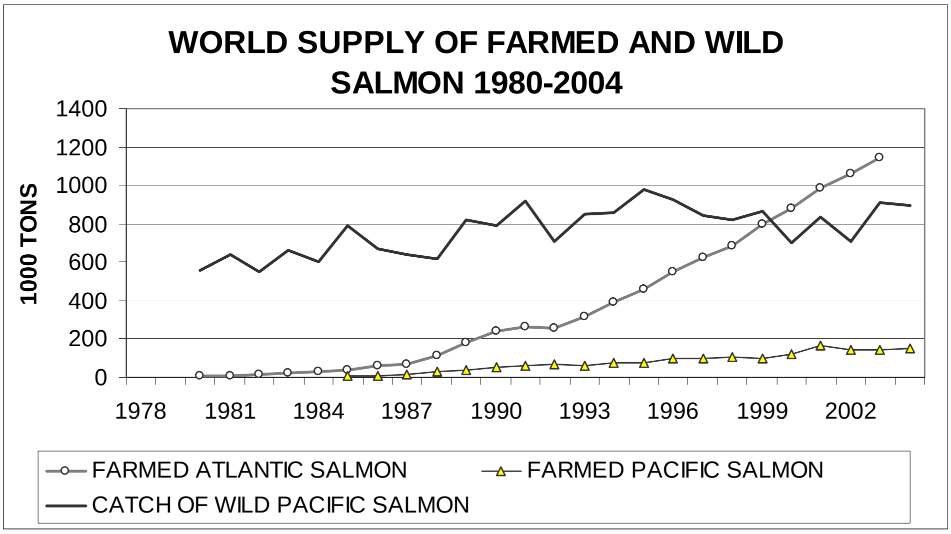


Figure 7: The world supply of wild and farmed salmon
Source: Norwegian Export Council for Fish (EFF)

The total production of salmon in the world is substantial. Figure 7 shows the world supply of farmed and wild salmon from 1980 to 2004. About 1.3 million tons of farmed salmon (Atlantic and Pacific salmon) was produced in 2003, and about 900,000 tons of wild salmon, mostly Pacific salmon, was landed in 2003. The figure shows that the catch of wild salmon fluctuates around 800,000 tons. The production of farmed, Pacific salmon seems to have stabilized around 150 thousand tons. The Pacific Pink salmon amounts to the biggest share of the catch of wild salmon and is mainly used for canning. It is farmed Atlantic salmon which represents the growth industry.

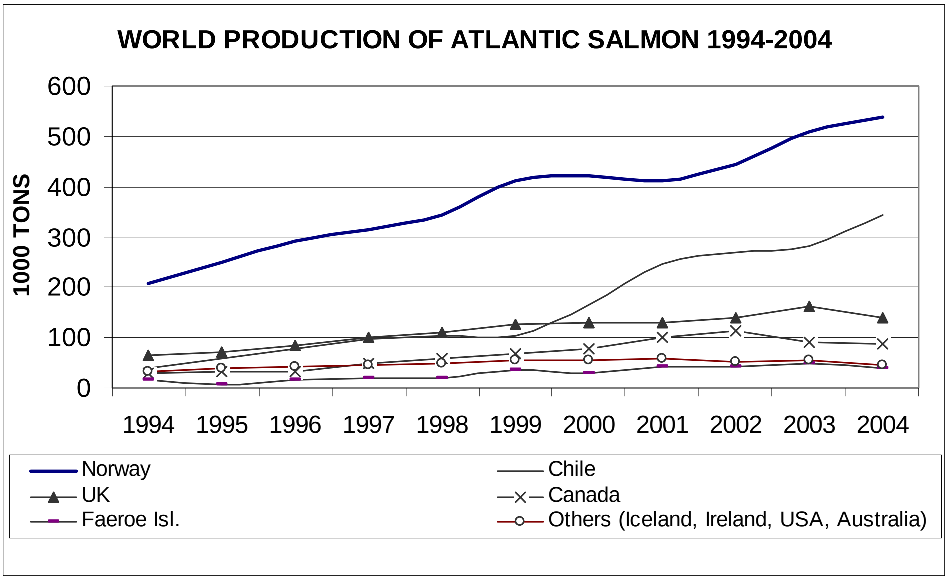


Figure 8: World supply of Atlantic salmon
Source: Norwegian Export Council for Fish (EFF)

Figure 8 shows the main world producers of farmed Atlantic salmon. The largest producers of farmed Atlantic salmon are Norway and Chile. Chile's production is estimated to about 340,000 tons Atlantic salmon in 2004. In 2003 the production was 281,000 tons, and in addition Chile produces over 100,000 tons of trout, and about 50,000 tons of Pacific salmon (Coho and Chinook). Next in line we find the UK and Canada. The growth of production in these countries is much less than in Norway and Chile.

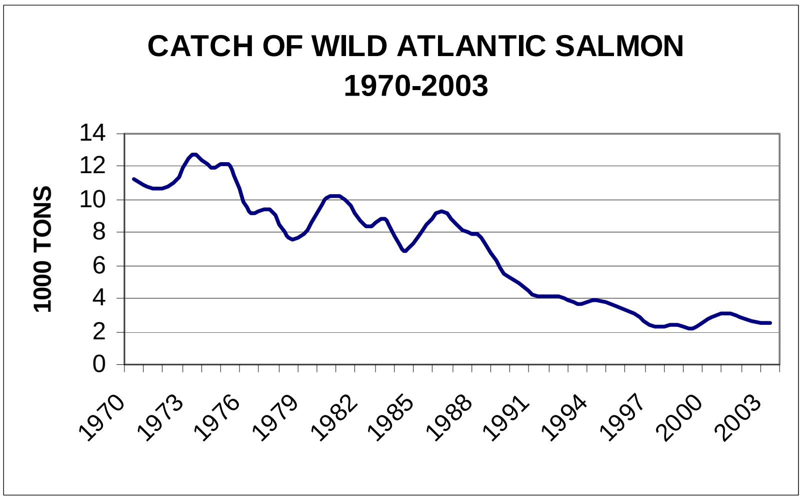
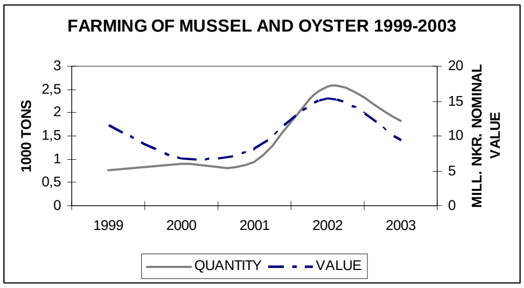


Figure 9: World supply of wild Atlantic salmon
Source: ICES 2004

The catches of wild salmon fluctuate on a slightly rising trend (Figure 7), while the catches of wild Atlantic salmon have declined (Figure 9) from about 12,000 tons in the early 1970s to slightly above 2,000 tons in 2003. One of the suggested reasons is that a temperature increase has a negative effect on wild salmon (ICES 2004).

Farming of other species

During the last 10 years, a number of licenses for shellfish and other species (haddock, halibut, hake, turbot, char, catfish, cod, eel, etc.) have been issued. The relatively large number of licenses and sites amounts to claims on relatively large coastal areas, even though the production is small. It is expected that the production of farmed cod, shellfish, halibut, etc. will increase in the future. Figures 10-12 show the production of farmed and partially farmed (caught wild and farmed) fish and shellfish in Norway 1999-2003.



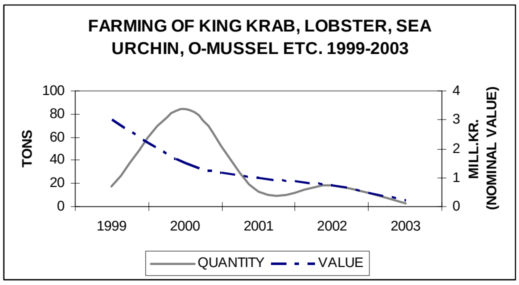


Figure 10 and 11: Farming of alternative species in Norway
Source: Norwegian Directorate of Fisheries

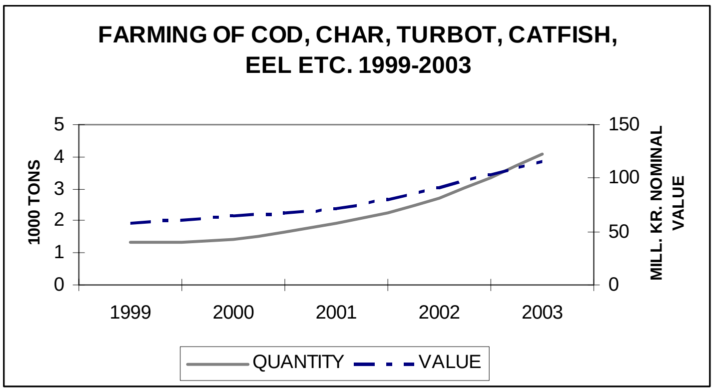


Figure 12: Farming of cod, char, catfish etc.
Source: Directorate of Fisheries in Norway

Table 1 shows the number of licenses for production of other species than salmon and trout by county. According to regulations, each license is 7477 cubic meters, and the license holder can maximally produce about 480 tons per license per year. The table also shows the maximum future production potential for each county. The table shows that the production potential is about 360,000 tons.

Table 1: Licenses and technical production capacity of marine fish

COUNTY	LICENSES	PRODUCTION POTENTIAL 1000 TONS
Finnmark	63	31
Troms	39	19
Nordland	241	117
Nord-Trøndelag	23	11
Sør-Trøndelag	24	12
Møre og Romsdal	84	41
Sogn og Fjordane	57	28
Hordaland	139	68
Rogaland	64	31
Vest-Agder	6	3
Aust-Agder	4	2
Other counties	5	2
TOTALT	749	364

3. AREAS SUITABLE FOR AQUACULTURE PRODUCTION IN NORWAY

The LENKA-project from 1990, Nationwide Assessment of the Suitability of the Norwegian Coastal Zone and Rivers for Aquaculture (Norwegian Public Report NOU 1990: 22), estimated the sea areas along the coast which are suitable for farming. The following is based on the results from that project.

The length of the mainland coastline is 21,347 km. If we do not include fiords and bays, the mainland coastline is 2,650 km. The length of the islands' coastline is 35,662 km. The total Norwegian coastal area is about 90 thousand square kilometres. This includes the areas off east Finnmark county and the Oslo fiord. The said areas (including east Finnmark and the Oslo fiord), plus the areas off Telemark, Buskerud, Østfold and Vestfold counties, are not of current interest for fish farming, especially for salmon and trout. The North Sea agreement from 1985 prohibits aquaculture in sea areas from the Swedish border to Lindesnes in Aust-Agder county. In the further analysis we exclude the coastal areas off the said counties. Hence the coastal area of commercial interest for aquaculture production is from Vest-Agder county in the south to Finnmark county in the north. Figure 13 shows the gross coastal area (sea area from the base line to the mainland) by county (data from LENKA, NOU 1990 p. 43). The figure shows that Nordland county has the biggest coastal sea area. The second largest is Finnmark, and Vest-Agder the smallest. The total coastal sea area is about 67,000 square kilometres. The sizes shown in Figure 13 only indicate the gross coastal area potentially suitable for aquacultural production. It needs to be taken into consideration that a substantial part of the area is already occupied or regulated for other purposes.

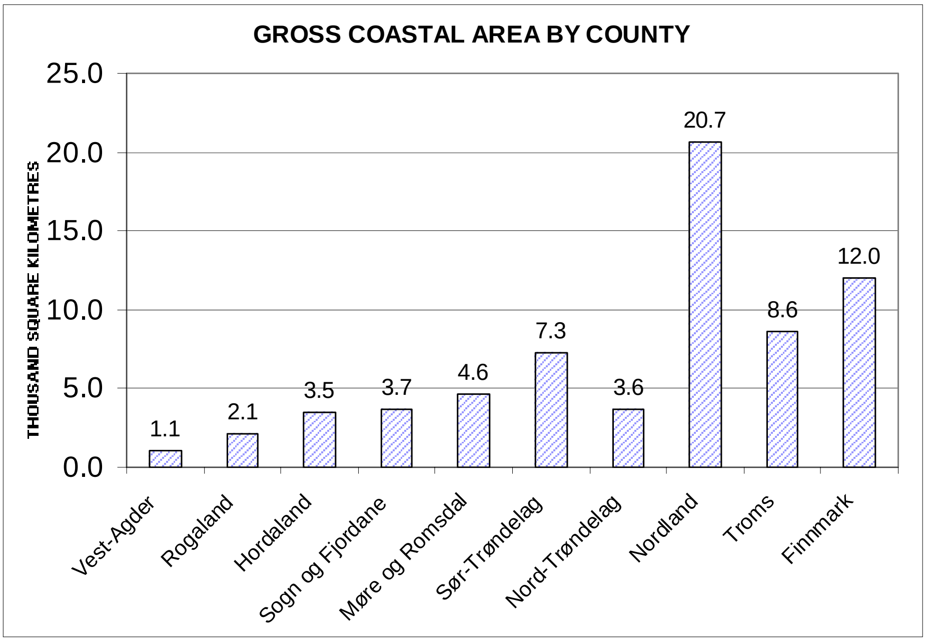


Figure 13: Gross coastal area in Norway

The coastal zone is vulnerable to pollution, and it is biologically important for many species. It is economically important, for example, for traditional coastal fisheries, recreation, fiords and rivers set aside for wild salmon, sea transport, and the established aquaculture industry. The first question to be answered is: which areas along the coast could potentially be suitable for additional aquaculture production? To answer this, it is necessary to subtract the unsuitable areas. The areas subtracted belong to either of two main groups; areas unsuitable due to natural conditions, and areas already used or reserved for other purposes. Characteristics that make aquaculture (of salmon and trout) impossible or very risky include the following (NOU: 1990):

- Critical exposure, i.e., sea areas with wave heights over 2 m,
- Shallow areas, i.e., depths less than 20 m (except in sounds/straits with strong currents),
- Critical temperatures, i.e., areas with sea temperature below 0 ^{o}C for long periods (more than six weeks), at least once every five years,
- Freezing, i.e., areas that are iced over at least once every fifth winter,
- Critical salinity, i.e., areas whose salinity occasionally falls below 10 ppt,
- Pollution, i.e., areas that are so heavily polluted that they are unfavourable for aquaculture.

In addition there are other sea areas set aside because of existing use in the following categories; existing fish farms, temporary protection zones for salmonids, nature conservation areas, defence areas, and areas earmarked by local planning authorities.

Most of the area that emerges after subtracting all unsuitable and areas used for other purposes has biological /ecological qualities which potentially can be used for commercial purposes. Whether the area will be applied for aquaculture production is largely a question of technology.

Over 80% of the population in Norway lives less than 10 km from the coast. The coastal area can be used for different purposes. This may easily lead to a conflict of interest. It is a challenge to find a set of criteria which can take care of all interests. In many cases the interests or objectives are mutually exclusive, which implies that in some cases commercial interests have to yield to environmental interests, and in other cases the opposite.

Factors limiting the area suitable for aquaculture

The gross coastal area, defined as A, of about 70,000 square kilometres potentially available for aquaculture production is further bounded by the following factors: (i) environment, (ii) current utilization, (iii) infrastructure, (iv) special areas, and (v) technology. All of these can change over time.

'*Environment*' refers to conditions of importance for aquaculture, i.e. requirements with respect to environmental conditions and area. The conditions include characteristics such as wave exposure, shallow areas, areas with critical temperature, number of hours with daylight, which is dependant on latitude, problem with icing, sea current, salinity, pollution, etc.

'*Current utilization*' includes uses which preclude aquaculture, such as housing, outdoor recreational activities, and traditional fishing.

'*Infrastructure*' includes roads, electricity, and services directly aimed at the aquaculture industry, such as feed manufacture, slaughtering facilities, and hazardous waste disposal facilities, all of which are important for existing fish farms and future establishments.

'*Special areas*' are marine areas to which particular attention must be paid when new fish farms are being established. These include existing fish farms, protection zones for salmonids, and nature conservation areas.

'*Technology*' refers primarily to cage technology and what kind of weather conditions (waves and wind) the cages and other floating facilities can tolerate. In general, the better the production technology can withstand tough weather, the greater sea area can potentially be used for aquaculture production. The technological level is not static, and it is under development.

*Current utilization, infrastructure, and special areas a*re policy variables, and to some extent *technology* as well via investment in research and development. Hence the area *A* is bounded by policy decisions and technology. In this part of the analysis we do not take into consideration that the total production of the industry is also bounded by the market. *Environment* reflects first of all the characteristics which are given by nature. It is a pure ecological variable reflecting the climate status at any given time.

Different organic holding capacity

The following section defines more precisely the environmental variable. It should be emphasized that the different sea areas suited for aquaculture production are not identical environmentally or ecologically. The sites and areas differ with respect to many factors; the annual water exchange rate, the topography, the seasonal temperature, the variance and maximum/minimum temperature, content of natural organic nutrients, extent of pollution and natural run-off, and time exposure of daylight.

Many of the fiords that indent much of the Norwegian coastline are threshold fiords with little water exchange with the open sea and thus particularly susceptible to problems of environmental degradation. Furthermore, different sea areas have different holding capacity of organic loading and nutrients. The production potential will therefore vary between sea areas, and so will productivity, for any given amount of inputs. The difference in natural production conditions is the source of differential economic rent between sites along the coast.

Every coastal area or site can be classified according to its organic holding capacity at time *t*. We define the *natural holding capacity* at site *j* as h_{cj} The annual loading (sum of all organic material) of an average standard fish farm of 12,000 cubic meters (with production of 25 kg/m^3 or 300 tons of fish produced on average per year) and with an inversion ratio of 1.5, was (NOU: 1990) in 1990 three tons of phosphorus (tot-P), 27 tons of nitrogen (tot-N), and approximately 150 tons of organic matter (BOD_7). Some of the sites and areas can tolerate the said substances from an average 12,000 m^3 plant, but some cannot, while others can tolerate more loadings still. The natural holding capacity represents a capacity restriction. The farmer can be viewed as maximizing an objective function, most likely profit, with respect to the site's natural holding capacity with respect to phosphorus, nitrogen and organic matter.

Example: Suppose the fish farming firm produces Atlantic salmon and trout, respectively q_S and q_T. The prices of the fish, p_S and p_T, are fixed. Suppose that a ton of salmon and trout "produces" respectively; a_{SN} and a_{TN} nitrogen, a_{SP} and a_{TP} of phosphorus, and a_{SO} and a_{TO} of organic matter. Biologists have estimated that the holding capacity for nitrogen, phosphorus and organic matter is, respectively; $\overline{N}$, $\overline{P}$ and $\overline{O}$. The maximization problem for the firm can be approximated by using linear programming in the following way:

$$Max \quad \pi = p_S q_S + p_T q_T$$

with respect to q_S, q_T and the holding restriction

$$\begin{bmatrix} a_{SN} & a_{TN} \\ a_{SP} & a_{SP} \\ a_{SO} & a_{SO} \end{bmatrix} \begin{bmatrix} q_S \\ q_T \end{bmatrix} \leq \begin{bmatrix} \overline{N} \\ \overline{P} \\ \overline{O} \end{bmatrix}$$

More generally the production function for a farmer, who produces for example salmon, can be expressed as a function of inputs (*v*) and ecological qualities (*e*) in a particular area (*a*) where the cages and production are located, i.e.

$$y = f(v : e, a)$$

If the farmer cannot influence the market prices, the profit will be maximized if he chooses inputs levels which minimize the production costs, i.e.

$$C = f(y : p_v, e, a)$$

where p_v is the vector of input prices. The point is to visualize that the production level, costs and profit realized by the farmer depend on a set of ecological factors, which in turn depend on climate. Climate changes will presumably influence the ecological qualities on the site. If that happens, it will in all probability also affect the farmers realized profit.

The *available organic capacity* for site *j* is h_{cj}^{A} and can be defined as the difference between the natural capacity h_{cj} and the existing organic inputs h_{Ej}. The available capacity for production of, for example, Atlantic salmon and trout at site *j* at time period *t* can be expressed in the following way (the time index is not included):

$$h_{cj}^{A} = h_{cj} - h_{Ej}$$

Total available production capacity for coastal area at time period *t* is defined as:

$$H_{C}^{A} = \sum_{j=1}^{n} h_{cj}^{A}$$

Each particular area or site can be ranked with respect to how suitable it is for aquaculture production, for example production of Atlantic salmon and trout. It follows from the previous discussion that H_{C}^{A} is a function of environmental and ecological variables. Hence, changes in climate potentially change the production capacity H_{C}^{A}.

In the following we will give a rough estimate of the technical production capacity by applying the area concept A. First we present the conclusions from the LENKA project (NOU 1990) with respect to production capacity for Atlantic salmon and trout in 1990.

Empirical findings

The LENKA-project estimated that the marine area from Rogaland county to the Russian border has a natural capacity for organic loading equivalent to a production capacity of 4.8 million tons of fish. Nordland county has about 35% of the total natural capacity, the county of Finnmark 21 and Troms county 14%. Altogether, the three northernmost counties have some 70% of the total natural capacity to tolerate organic loading, while western Norway has about 10% of the capacity (Ibrekk et al. 1993). The LENKA-project concluded that organic loading due to sewage, agriculture, industry and background runoff (natural runoff) corresponds to 632,000 tons of fish production between Rogaland and the Russian border. In 1990 the actual input of organic material from existing fish farming permits for salmon and trout corresponded to a production of about 177,000 tons of fish.

The production of salmon and trout was about 600,000 tons in 2004. If we include all forms of aquaculture production in 2004 it represents about 0.7 million tons. The LENKA estimate of organic loading from sewage, agriculture, industry and background runoff is equivalent to about 0.7 million tons of fish, rounded off upwards. Hence, a rough estimate of the potential, future production H_p of salmon and trout is:

$$H_p = 4.8 - 0.7 - 0.7 = 3.4 \text{ million tons of fish}$$

This estimate represents a global, theoretical upper limit. In practice it is definitely not attainable because of limitations due to critical wave exposure, lack of infrastructure, limiting environmental factors (temperature, icing), shallow areas, aquaculture-free fiords for protecting the wild salmon and its rivers, use of parts of the coastal zone for recreation, housing, coastal fisheries, and areas allocated to other form of aquaculture production than salmon and trout. A large share of the area is out of bounds for aquaculture due to ocean going traffic. Furthermore, a certain safety distance is required between sites for avoiding pollution, infection and collision between vessels and plant. We will return to this issue later in the report.

The LENKA project took into consideration the pre-empted and unsuitable areas, for example critical wave exposure areas, and estimated the available area for establishing aquaculture activities to 6,056 square kilometres. The estimated available area is about 9% of the coastal zone. According to the LENKA project, the area available for fish production is equivalent to an annual production of 900,000 tons of salmon and trout (Ibrekk et al. p. 64, 1993). The area estimated is divided among the counties in roughly the following way: Finnmark 20%, Troms 15%, Nordland 35% and Rogaland, Hordaland, Sogn and Fjordane, and Trøndelag about 30%. In thousand square kilometres it is as follows: Finnmark 180, Troms 90, Nordland 315, Rogaland, Hordaland, Sogn og Fjordane, Møre og Romsdal and Trøndelag 270. If we apply this result and subtract today's aquaculture production, which is about 600,000 tons, the available additional capacity is equivalent to 900-600 $\approx$300 thousand tons of fish.

According to the LENKA project, the production potential lies between 900,000 and 3.4 million tons of fish, given the *ecology*, *technology* and *climate* in 1990s. In the meantime, the production technology has become more efficient, among other things through development of antibiotics, vaccine, and feed. The infrastructure has also improved. This suggests that the lower bound of 900,000 tons is too low. On the other hand new licenses for aquaculture of other species than Atlantic salmon and trout have been granted. In the late 1990s it was also decided to establish aquaculture free fiords to protect the wild salmon. These factors pull in the opposite direction.

4. ESTIMATION OF PRODUCTION POTENTIAL

The new regulatory regime for aquaculture production in Norway is based on the biomass carrying capacity related to each site. Figure 13 above shows the coastal areas found by the LENKA project to be suitable for aquaculture production. According to LENKA, about 90% of the gross sea area off each coastal county is exposed to critical sea waves, i.e. maximum sea waves about 2m. The LENKA project operated with maximum waves about 2m. This implies that the so called significant wave height is about 1m. The significant wave is defined as 1/3 of the upper part of the distribution of waves during a year. Today the plants and cages can withstand about 2m significant waves, i.e. about 4-5m maximum waves. It implies that the suitable area is not restricted to only about 10% of the coastal sea area (Figure 13) as LENKA concluded, but perhaps 30-40 or even 50%.

Table 2 shows the suitable area after subtracting areas exposed to high waves. We present three scenarios. In the first scenario we operate with the same assumption as in LENKA, which assumed that 90% of the sea area is not suitable for plants due to critical sea waves. In the second scenario 60% is exposed to critical waves. In the third scenario 50%, and in the last 40% is exposed to critical waves. The 60-50-40 scenarios reflect the new, stronger cage-technology introduced in the late 1990s.

Table 2: Available area for aquaculture purposes adjusted for different shares of critical waves (1000 square kilometers)

		CRITICAL WAVES (CRITICAL EXPOSURE)			
		90 %	60 %	50 %	40 %
COUNTY	GROSS AREA 1000 SQUARE KM	GROSS DISPOSABLE AREA 1000 SQUARE KM			
Vest-Agder	1.058	0.11	0.42	0.53	0.63
Rogaland	2.14	0.214	0.86	1.07	1.28
Hordaland	3.52	0.35	1.41	1.76	2.11
Sogn og Fjordane	3.724	0.37	1.49	1.86	2.23
Møre og Romsdal	4.646	0.46	1.86	2.32	2.79
Sør-Trøndelag	7.259	0.73	2.90	3.63	4.36
Nord-Trøndelag	3.645	0.36	1.46	1.82	2.19
Nordland	20.683	2.07	8.27	10.34	12.41
Troms	8.585	0.86	3.43	4.29	5.15
Finnmark	12.037	1.20	4.81	6.02	7.22
SUM	67.297	6.73	26.92	33.65	40.38

The table shows that the northernmost counties have the biggest share of the available area. If we look at the sum, about 6,700 square kilometers are available if 90% of the area is exposed to critical waves. On the other hand technological progress has made it possible to utilize a bigger area compared to the technological level in 1980s and 1990s. Therefore, the last columns in the table are probably closer to reality.

Model for area-calculation

We have made a simple model for calculating the suitable area for aquaculture production. Table 3 shows number of sites for aquacultural production by county. Existing and planned sites for salmon, trout, other marine fish and shellfish will occupy or preempt a large area, which we have estimated. The calculations are based on the assumption that each site needs a security zone between plants. We assume that each shellfish site and plants need a security zone of about 1 to 2 km, and farming of fish (required by law) between 1.5 and 3 km. The category ‘other species’ includes haddock, halibut, hake, turbot, char, catfish, cod, eel, etc. Figure 14 shows the occupied area by county.

Table 3: Sites for aquacultural production by county

	ACTUAL SITES 2004		
COUNTY	*Salmon and trout*	*Other fish species*	*Shellfish*
Vest-Agder	19	6	65
Rogaland	79	28	78
Hordaland	287	78	135
Sogn og Fjordane	146	42	77
Møre og Romsdal	149	51	25
Sør-Trøndelag	178	13	64
Nord-Trøndelag	132	13	60
Nordland	310	191	315
Troms	149	38	61
Finnmark	102	34	37
SUM	1551	494	917

Source: Norwegian Directorate for Fisheries

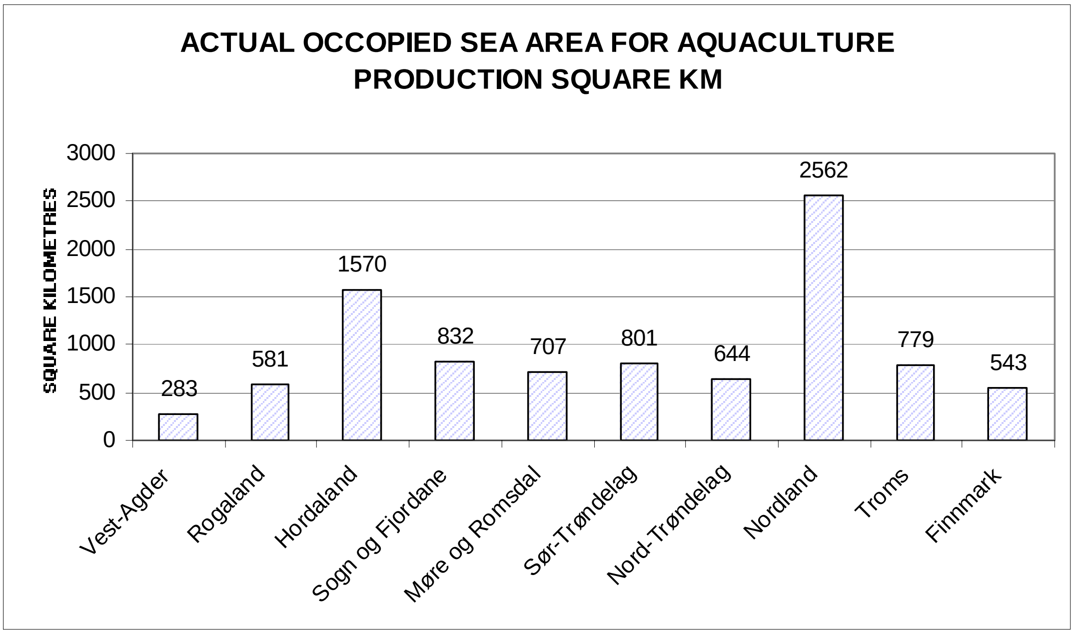


Figure 14: Occupied area for aquaculture production

The estimation of occupied area is based on the following model:

$$A_O = (S_{ST} + S_{MF})\pi d_1^2 + S_{SH}\pi d_2^2$$

where:

A_O : Occupied area (square kilometers)

S_{ST} : Number of sites for salmon and trout

S_{MF} : Number of sites for marine species

π : Constant equal to 3.14

d_1: Security distance between neighboring sites. If there is a provision that it should be 2 km mutual distance between each site, then $d_1 = 1$. If the distance is 3 km, then $d_1 = 1.5$.

S_{SH}: Number of sites for shellfish

d_2: Security distance between neighboring sites

We have not indexed the variables with time, but it should be obvious that all variables are time dependent. Notice that the occupied area is sensitive to changes in the security distance *d*, because the area is related to distance squared. If we, as an example, look at the total preempted coastal area, and *d* = 1 km, then *A* = 7,300 square km. If *d* = 1.5, *A* = 15,400. An increase in *d* by 50% increases the occupied area by about 110%.

Critical areas and climate change

The LENKA-project (NOU 1990) estimated the following as being critical or not suited for aquaculture production of especially salmon and trout with respect to the following six factors:

F_1: Critical temperature, about 1229 square km. High temperature and/or low winter temperature in the inner part of fjords and shallow areas.

F_2: Critical areas due to ice, about 2721 square km.

F_3: Critical areas due to high salinity, about 1000 square km.

F_4: Critical areas due to pollution, about 400 square km.

F_5: Excluded areas due to sea ranching, about 30 square km [Aarset, B. (2005)].

F_6: Critical areas due to shallow areas equal to or less than 20m depth, about 4.7 thousand square kilometers.

F_7: Critical areas due to high sea waves. On average LENKA calculated that about 90% of the gross coastal area is exposed to critical waves.

Table 4 shows the critical areas estimated by applying figures from the LENKA project (NOU 1990:22). If we subtract the critical areas in table 4 from the gross area in table 2, we get a rough estimate of the available area for aquaculture production.

Table 4: Critical areas by county

CRITICAL AREAS - ASSEMENTS BASED ON THE LENKA-PROJECT (SQUARE KM)						
	Critical temperature areas	*Critical ice-exposed areas*	*Areas with critical salinity*	*Polluted areas*	*Critical shallow areas*	*Sum critical areas*
Vest-Agder	37.8	87.9	27.3	25.8	123.3	302.0
Rogaland	43.5	97.8	35.2	34.2	175.0	385.6
Hordaland	85.0	193.0	65.8	63.3	309.1	716.1
Sogn og Fjordane	74.4	165.4	60.0	57.9	63.5	421.2
Møre og Romsdal	97.7	218.6	77.9	75.2	590.7	1060.1
Sør-Trøndelag	121.8	264.5	102.4	99.5	476.1	1064.2
Nord-Trøndelag	85.1	192.1	66.2	63.6	710.6	1117.6
Nordland	356.4	788.7	300.6		1514.6	2960.3
Troms	164.2	365.6	134.3		651.4	1315.5
Finnmark	163.1	348.3	147.3		80.5	739.2
SUM	1228.9	2721.9	1017.0	419.5	4694.6	10081.8

Source: Based on figures from NOU 1990: 22.

It is expected that a climate change will affect critical areas associated with high or low temperature, i.e., F_1 and F_2. It is likely that a climate change will change both the extreme temperatures and the average temperature during the year. In general the extremes can change without affecting the average, and the average can change without the extreme values changing. We expect that a climate change will increase the average and increase the extreme value(s). It is of course difficult to quantify these effects.

It is well known that the coast from Hordaland to Trøndelag is today the most efficient and suitable area for farming of Atlantic salmon. This area is suitable partly because it has the highest sea temperature during the winter, and partly because the temperature is close to optimal during the summer months, especially along the coast of Møre. Along the southern coast, south of Rogaland, the temperature is too low during the winter months and too high during the summer. In northern Norway conditions for farming salmon are not optimal, but nevertheless some farms are located along that part of the coast.

Predictions based on expected climate change (Sundby and Stenevik 2004) show that if the sea temperature in the uppermost 10m layer increases on average by 2-3 degrees in summer and winter, the coastal areas south of Stadt will be optimal for salmon production in the winter months but too warm for farming of salmon and trout during the warmest summer months. Especially the Skagerack coast will become too warm. This area also has a relatively high frequency of algae blooms, a problem that will most likely become more frequent as a result of climate change (Lorentzen and Pettersson 2005). In the future the coast of Rogaland and Hordaland will probably no longer be suitable locations for farming of Atlantic salmon. Hence the climate change will push the salmon aquaculture industry further north; the most suitable areas will be from the coast of Møre to the coast of the southern part of Troms county. The sea temperature north of Lofoten and off Finnmark will still be low during the winter months, and it is uncertain how significant the positive shift for the industry located in that area will be. In any case, if the average temperature during the year increases, the possibility of increased production of salmon in Finnmark should not be excluded.

We thus anticipate that the salmon aquaculture industry will be relocated from south to further north along the coast. Nevertheless, the predicted climate change will not significantly affect the potential production capacity in the salmon aquaculture industry in Norway. The sites which are lost in the southern part of the coast will be replaced by new sites further north. The production of salmon is not limited by sites or locations.

Institutional limitations

The salmon farming industry is potentially limited by the demand side of the market. If the aggregated demand does not grow but the aggregated supply expands, the market will set a limit for the industry. Furthermore the aquaculture industry is strictly regulated by the government. Assuming that the concession or licensing policy does not change, the government will continue to be rather restrictive with respect to issuing new licences. It is expected that the total production will not change, apart from the relocation generated by the climate change. But the fact that a change in climate also changes the production conditions makes it necessary that the future concession policy reflect the need for geographical relocation of the fish farms.

Given the total production, we expect that the industry will shrink in the southern part of the west coast of Norway by about the same number as the increase in employed persons in the northern part of the coast. We expect that the change will be so gradual that it will induce only marginal moving or adaptation costs. On the other hand, the distance to the markets in central Europe will increase, and the implication is a slight increase in the transport costs.

Specie-specific ecological criteria for farming

Above it has been argued that ecological factors or climate factors have significant influence on the production of salmon and trout. Here we shall look closer at how ecological factors can influence the economic outcome of fish farming.

Each species must have particular water quality and farming conditions to survive and attain high product quality. Table 5 shows some of the ecological criteria for each species; depth, current, salinity, and temperature. The numbers reported for each factor are the optimal conditions, and the numbers in brackets are boundary values.

Table 5: Ecological condition for different species

SPECIE	**OPTIMAL DEPTH**	**OPTIMAL CURRENT**	**SALINITY PER THOUSAND**	**OPTIMAL TEMPERATURE**
Atlantic salmon and trout	>50m	10-20cm/sec (5-20)	>30 (>20)	Atl.salmon: 12-14 ^{0}C (>2 ^{0}C) Trout: 15-17 ^{0}C (>2 ^{0}C)
Cod	>30m	10-20 cm/sec (5-50 cm/sec)	>30 (>5)	12-14 ^{0}C (>2 ^{0}C)
Halibut	>15m		25-30	6-14 ^{0}C (0-18 ^{0}C)
Mussel	10-30m (30-50m)	25-75cm/sec (>75cm/sec)	17-32 (>5)	10-20 ^{0}C (>0 ^{0}C)
Öyster	1-6m	25-75cm/sec (>75cm/sec)	>24-33 (>16)	16-20 ^{0}C (>3 ^{0}C)
Scalopp Drooping-culture Bottom-culture	 10-20m 5-40m	<15 cm/sec (10-20cm/sec)	>31	15-18 ^{0}C >4 ^{0}C
Turbot				> 16 ^{0}C

Source: Norconsult (2002): Havbruksanalyse for Sunnhordland (Aquaculture analysis for Sunnhordland).

The production potential

There are three sources for increasing the production of salmon and trout; vacant areas can be used for farming of fish, full utilization of capacity in existing plants, and increased production because of higher growth rate, for example due to climate change or technical progress (better feed and genetic manipulation).

To estimate the production potential of vacant, suitable areas A_D we convert square km to number of licences, each of 12000 cubic meters. We assume that each licence has three sites which occupy sea area, i.e.

$$A_S = 3\pi d_1^2$$

where d_1 is half the required security distance between sites. A 'site' means the geographical, physical area the company can use for production. 'Licence' is the formal concession required to produce the fish. Number of new licences N_L can be estimated in the following way

$$N_L = \frac{A_D}{A_S} = \frac{A_D}{3\pi d_1^2}$$

According to the cost and earnings studies of the aquaculture industry in Norway carried out by the Norwegian Directorate of Fisheries, the production of a 12,000 cubic meters licence is between 700 and 1000 tons per year on the average. The production potential of the vacant areas then is, given today productivity:

$$Q_{VP} = N_L q = \left[\frac{A_D}{3\pi d_1^2}\right] q \text{ and } q \in [700, \quad 1000]$$

The actual production of salmon and trout was about 600,000 tons in 2004. We define the actual production as

$Q_A \approx 600$ thousand tons.

The production potential by the existing plants Q_{AP} is as follows:

$Q_{AP} = N_{AL} q$, $q \in [700, \quad 1000]$ and $N_{AL} = 863$ licences.

With $N_{AL} = 863$ and q = 700 or 1000 tons, the unused production potential of actual licences for the total industry is marginal. Existing plants can potentially produce between 600 and 863 thousand tons if they fully utilize their capacity. It should also be mentioned that new licenses were issued during the last three years, and some of them have not started production. Figure 15 shows the actual and potential production from already established firms by county.

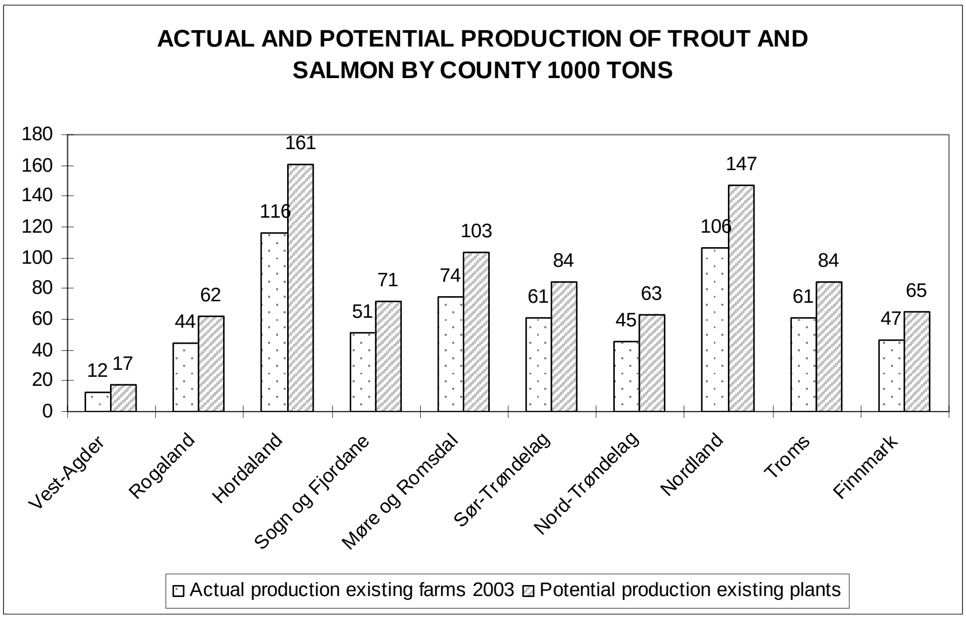


Figure 15: Observed and potential production of salmon and trout

The existing plants could technically *increase* the production by about 260 thousand tons, i.e.

$$\Delta Q_{AP} = Q_{AP} - Q_A \approx 260 \text{ thousand tons}$$

Hence an increase in the Norwegian aquaculture production must mainly come from establishing new plants in new areas. According to the previous calculations the increase would be about:

$$Q_{NP} = N_L q = \left[\frac{A_D}{3\pi d_1^2}\right] q$$

where A_D, net disposable area for aquaculture production can be more precisely defined as:

$$A_D = A_G - A_O = A_G - (S_{ST} + S_{MF})\pi d_F^2 - S_{SH}\pi d_S^2 - \sum_{i=1}^{7} F_i$$

with A_G being the gross available coastal area (67,000 square kilometre), and the other variables and parameters are defined in the following way

A_O:	Occupied area (square kilometre)
S_{ST}:	Number of sites for salmon and trout
S_{MF}:	Number of sites for marine species
π:	Constant equal 3.14
d_F:	Security distance between neighbor sites in the salmon and trout industry. If there is a provision that it should be 2 km mutual distance between each site, then $d_F = 1$. If the distance is 3 km, then $d_F = 1.5$.
S_{SH}:	Number of sites for shellfish
d_S:	Security distance between neighboring sites in the shellfish industry
F_i:	Critical factor *i* which makes it impossible or difficult for aquaculture production

The total production potential for the Norwegian salmon and trout farming industry thus is as follows:

$$Q_P = Q_{NP} + Q_A + \Delta Q_{AP} = Q_{NP} + Q_{AP}$$

As already argued, the production of Atlantic salmon and trout from existing farms could potentially be increased by about 260,000 tons per year. The calculations assume no changes in climate or environment conditions. Figure 16 shows the vacant sea areas, i.e. sea areas potentially disposable for future aquacultural production by county.

The vacant area depends critically on the height of the sea waves and how high waves the plants can stand, and the required distance between plants along the coast. Table 6 shows the share of the sea area in each county which is supposed to be exposed to critical sea waves. We do not have the exact numbers, but we assume that this guess is not unrealistic, among other factors because today's plants can withstand higher waves than assumed in the LENKA-scenario.

Table 6: Critical sea waves

SHARE OF THE SEA AREA EXPOSED TO CRITICAL WAVES	
Vest-Agder	0.5
Rogaland	0.5
Hordaland	0.5
Sogn og Fjordane	0.5
Møre og Romsdal	0.5
Sør-Trøndelag	0.5
Nord-Trøndelag	0.5
Nordland	0.5
Troms	0.6
Finnmark	0.7

Based on the assumptions of critical waves (Table 6) and other factors (occupied areas by established plants, critical temperature, areas exposed to icing, pollution, shallow areas) which reduce the suitable area, and given that the required distance between the existing sites are 2 kilometres, we have estimated the vacant areas suitable for future aquaculture production (Figure 16).

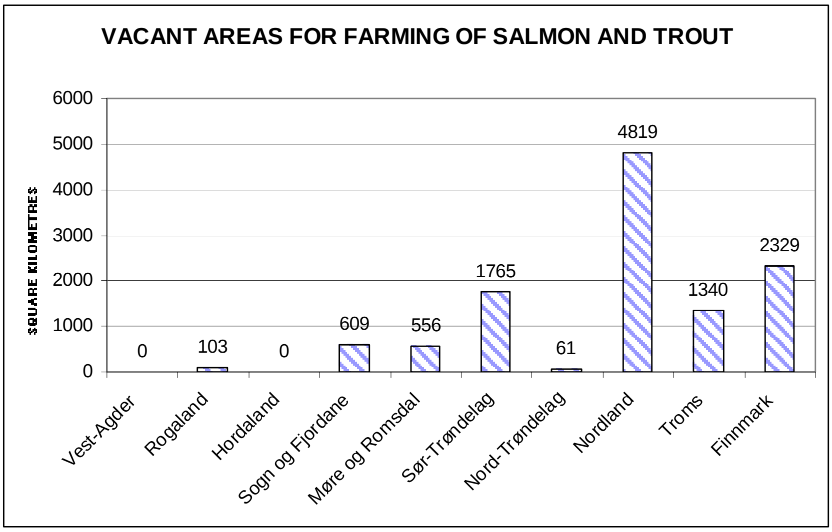


Figure 16: Vacant areas for production of salmon and trout

Figure 16 shows that Vest-Agder and Hordaland do not have vacant, suitable areas for aquaculture, given that the distance between sites is 2 kilometres and the assumption of critical sea waves given in table 6. Rogaland and Nord-Trøndelag have a few vacant areas. It should be mentioned that the estimation of suitable areas does not take into consideration whether there exists the necessary infrastructure for expansion in the "new" sea areas. We expect that there is a lack of infrastructure, and that this represents a limiting factor for the industry. We have estimated the potential production of salmon and trout generated from the vacant areas, given the already mentioned set of assumptions. Figure 17 shows the potential increase in production by county.

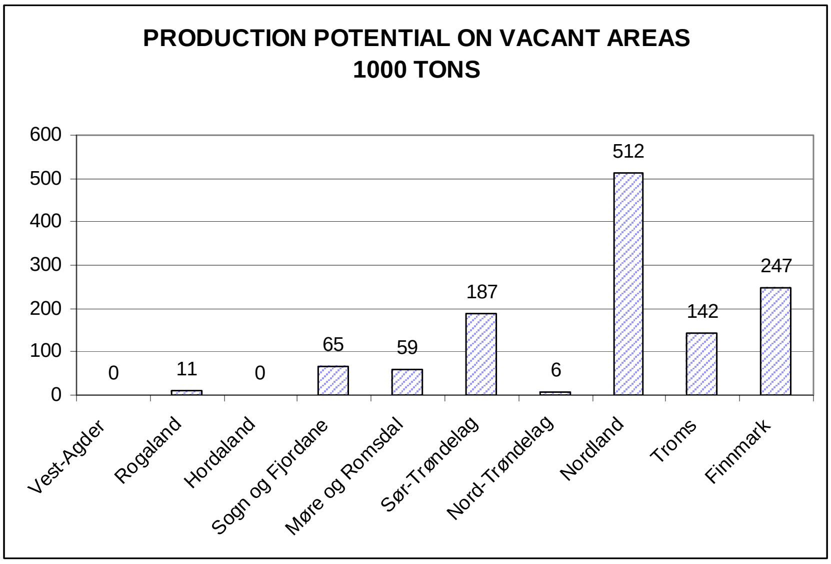


Figure 17: Production potential for salmon and trout

Given our assumptions, the total production of salmon and trout from *vacant* areas is about 1.2 million tons. The area model indicates that the growth in the industry will take place mainly off the northernmost counties, but also in the mid-region, i.e. Sogn og Fjordane, Møre og Romsdal and Sør-Trøndelag. Nordland and Finnmark county have the biggest production potential. Whether the technical production level will be realized or not depends among other factors on the infrastructure. The salmon and trout industry can, technically, almost triple the production level in the coming years, compared to the production level in 2004. The production in 2005 is well over 600,000 tons, and existing plants can increase the production to about 900,000 tons in the short run. The expansion beyond 900,000 tons must then be produced in new plants, and as mentioned; we have estimated the production potential from new plants to about 1.2 million tons. We calculate that the aggregated, future production potential is about: 0.9 + 1.2 = 2.1 million tons of salmon and trout per year, given no "extraordinary" climate changes.

Discussion

Even though the aquaculture industry is very similar to industrial production where every phase in the production process is controlled by man, the industry is still critically dependent on natural conditions. The production is located in the archipelago, close to the mainland. Natural or ecological factors such as temperature, waves, salinity, icing, water depth (less than 20m is undesirable), natural runoff, brackish water, current, etc. influence and limit production.

The combination of a large number of established plants for aquaculture production and the required security zones between sites means that there are very few or no vacant areas for fish farming along the coast of Agder, Rogaland and Hordaland county. In these counties, growth will have to come from unutilized production capacity in already established firms. We have estimated that the total production of today's operating plants can potentially increase from about 600,000 tons in 2004 to 850,000-900,000 tons during a period of minimum 2 years ($t^* = \dfrac{\ln 850 - \ln 600}{0.18}$) if the industry follows the same, average growth rate of $\delta \approx 0.18$ as it did during the period 1980-2003. If we extrapolate the production, it will take 2-3 years to fully utilize existing capacity in established plants. Geographically the growth in the industry will take place in the sea areas off the northernmost counties, mainly in the area off Nordland county. The salmon and trout industry can at least triple its production to over 2 million tons.

Higher temperature will probably have a negative effect on the production in the Agder area, Rogaland and Hordaland. Higher temperature will make the production of salmon and trout more risky in the southernmost counties than it is today. Too high temperature will increase the mortality rate, reduce the growth rate, and increase the occurrence of parasites, for example salmon lice. Higher temperature will increase the costs of production and, ceteris paribus, make the industry located in the south less profitable. On the other hand we expect that the industry will try to compensate for the disadvantages of higher temperature by (a) genetic selection of fish which can tolerate relatively higher temperature and (b) implementation of technology which can reduce the temperature locally in the cages (by pumping colder water into the cages) or apply equipment which increases the density of oxygen in the cages. On the other hand we expect that higher temperature in the initially colder areas in the northernmost counties will make it easier to expand production and increase productivity.

Temperature has a significant effect on fish metabolism, i.e. too low and too high temperature kills the fish. When the sea temperature reaches 17-20 degrees Celsius serious metabolic dysfunctions come into force. The anomaly is indicated in Figure 17 where the efficiency in the growth process is reduced. The problem is not the temperature as such, but rather that the density of oxygen in the water masses decreases with higher temperature. Figure 17 shows the combination between different temperature regimes and how long it takes for a salmon to grow from about 100 to 3500 gram.

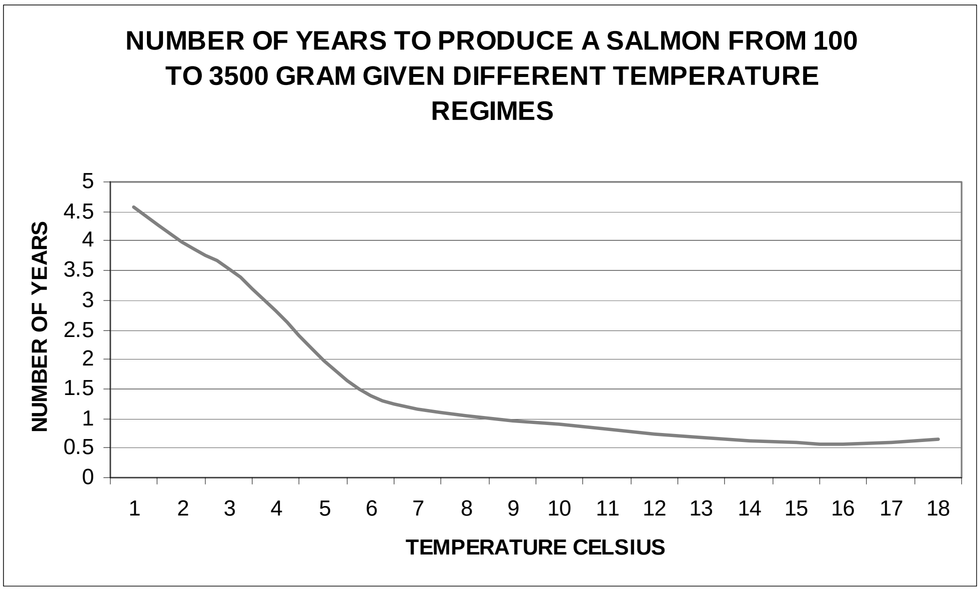


Figure 17: Temperature regimes and growth rates

The estimated numbers are based on input data from laboratory experiments done by Skretting and Ewos (Skretting and Ewos 2004), two of the biggest producers of feed for the aquaculture industry. The figure shows that higher temperature has a positive, but decreasing, effect on the growth rate (Figure 17). The biggest effect of an increase in temperature is the range from 1 to 7 degrees Celsius. We have estimated the growth function for different temperature regimes. The estimates indicate clearly that temperature has an effect on the growth path. Figure 18 shows the weight increase for a salmon growing from 100 to 4000 grams for three different temperature regimes, respectively 7, 8 and 9 degrees Celsius.

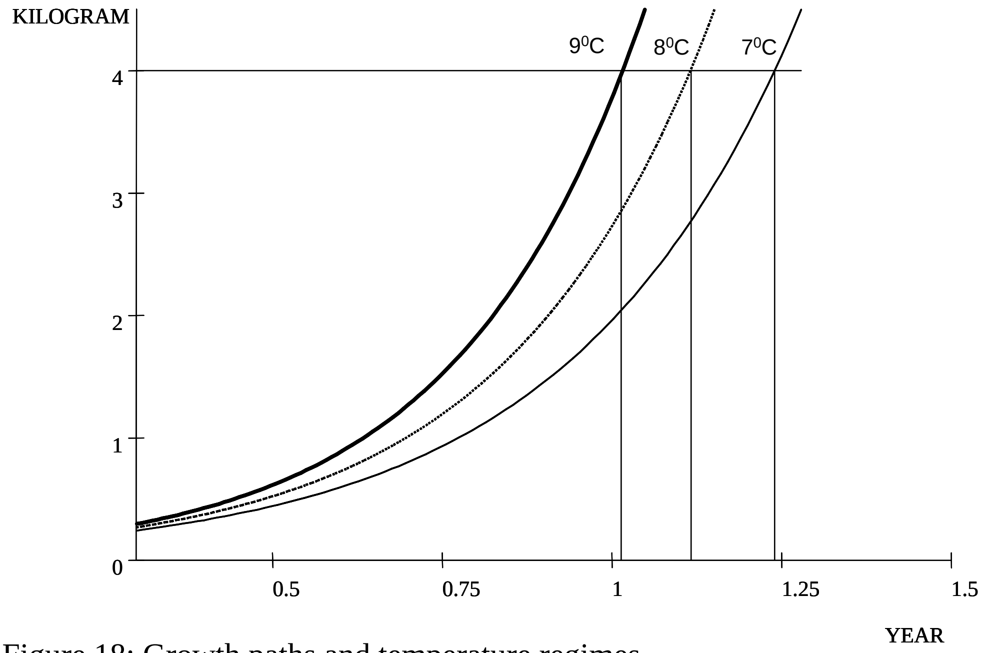


Figure 18: Growth paths and temperature regimes

The uppermost curve is the growth path for 9 degrees centigrade (constant temperature during the growth period), the curve in the middle shows the growth path for 8 degrees centigrade and the lowest 7 degrees. The figure shows also how long time it takes for the fish to reach 4000 grams for each temperature regime. Table 7 summarizes the numbers from the functions in figure 18.

Table 7: Differences between temperature regimes

Temperature regime	Growth rate	Number of months growing from 100 to 4000 grams.	Time difference (months) compared to 9^0C regime
7 ^{0}C	2.976	14.9	2.5
8 ^{0}C	3.307	13.9	1.5
9 ^{0}C	3.634	12.4	Reference point

Table 7 shows that it takes 12.4 months for the salmon reaching 4000 grams when the temperature is constant 9^0C. If the temperature is 2 degrees centigrade lower, it takes about 15 months to reach the same weight. A difference of two degrees makes the production process about 2.5 months or one fifth of a year longer in the low-temperature sea water compared to the 9^0C-regime. Note that the difference between the paths reaching 4000 grams is a monotonically increasing, non-linear function.

In Lorentzen and Hannesson (2005) we show that the difference in yearly temperature in the 1-50m water column off Lista in Vest-Agder and Skrova in Troms county is between 1 and 2 degrees centigrade. The average yearly temperature at Lista is about 9 degrees and Skrova is between 7 and 8. If we use the figures in the table, the production cycle in the said locations will be different. The estimations in the two figures and tables are founded on laboratory experiments, however. In practice the temperature is not constant over the year but cyclical. The growth rate is also influenced by hours of daylight. To explain differences in growth only by water temperature is therefore incomplete. It has been shown that seasonal variations in hours of daylight apart from temperature have an important influence on the growth of fish (Ewos 2005). A simple example of this is when we compare growth of Atlantic salmon in northern vs. southern Norway. Temperatures are higher in the south compared to the north at any given date in the year, and yet farmers in the north report *faster* growth during the summer and early autumn than their counterparts in the south (Ewos 2005). There are two important ecological factors, namely temperature and the seasonality in hours of daylight, which separate the geographical areas in north and south. The Norwegian coast lies in the north-south direction, so the average temperature is decreasing with northern latitude. In the summer period the geographical area north of the polar circle (Nordland, Troms and Finnmark County) is exposed to about 24 hours of daylight. On the other, the said counties have only couple of hours of daylight in the winter period. In the southernmost counties the number of hours of daylight is also seasonal, but the fluctuation is not as high as in the north.

A climate change will gradually “push” the different geographical regions into new temperature zones. If we look at Figure 17, a climate change which on average increases the average temperature in the coastal water masses can be described as a path of motion along the curve to the right. As mentioned the temperature is seasonal and in the southernmost parts of the coast the temperature in the future summer months will probably be too high for production of salmon. On the other hand, in the north the temperature increase will increase the productivity in the salmon and trout industry. The effect of climate change is therefore not unambiguous. The economic effect of differences in temperature is analyzed in Lorentzen and Hannesson (2005).

5. ESTIMATION OF THE LONG RUN RELATIONSHIP BETWEEN PRICE AND QUANTITY

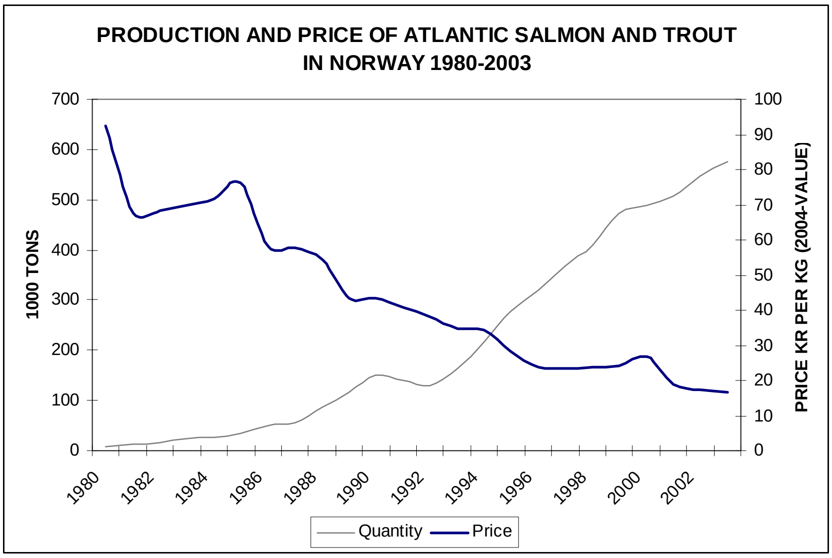


Figure 19: Price and quantity supplied of salmon and trout
Source: Statistics Norway

Figure 19 shows quantity and price (2004-value of money) of Norwegian-produced Atlantic salmon and trout during the period 1980 to 2003. The figure shows an overall negative trend in price and a positive trend in quantity. This indicates that the aggregated Norwegian supply has some influence on the market price. The overall trend in both variables indicates that price and quantity are not stationary processes, which could violate the conditions for using ordinary least squares as an estimator and make the ordinary statistical *t* and *F*-tests misleading. The figure shows some intermezzos which merit a comment. The increase in real price and quantity in the early eighties indicates that the demand for salmon and trout increased relatively faster than the growth in supply. In the period 1990 to 1992 the quantity supplied was reduced while the price fell. It could indicate negative shifts in demand or increased supply of substitutes. In the late 1990s the real price was almost constant while production increased rapidly. This indicates either growth in demand in the main market or supply to other, new markets, or both.

We should also be aware that the Norwegian salmon industry has been affected by a number of trade disputes with EU during the last 15 years. These conflicts have probably had some influence on the market (dis)equilibrium.

We will emphasize that the following analysis is partial because we focuses only on the interrelation between the Norwegian salmon production and price. The objective is to analyse whether there exists a long run relationship between price and quantity of salmon and trout. The model does not integrate other variables, for example supply of salmon from other countries, and shift parameters due to institutional arrangements, for example the said trade dispute, which could influence the market equilibrium. Generally speaking, economic theory predicts that the demand (Marshallian) for a commodity (y) is a function of its own price (p_y), price on substitutes and complements ($\mathbf{p}_{sc}$) and income level (I), i.e. $y = f(p_y, \mathbf{p}_{sc}, I)$. Even if we estimated this single equation model, we could run into the simultaneity problem because we have a two-way effect, i.e. price p_y effects quantity and quantity supplied y affects the price level p_y. The estimated coefficients could be biased and inconsistent because the explanatory variable p_y could be correlated with the residuals (*u*), i.e. $E(p_y u) \neq 0$. The closest set of substitutes for the Norwegian salmon is supply of Atlantic salmon from Chile, Scotland and Ireland. Statistical analyses show that many of the wild fish species, and even red and white meat, are substitutes for Atlantic salmon (Asche et al. 2005, Salvanes and DeVoretz 1997). The model we apply is this respect (see below) not complete, and it does only explain a portion of the variation in the price level. Because the Norwegian salmon industry is a dominant producer and supplier of salmon in Europe, we expect that the supply from Norway has some effect on the realized price. If the objective is to explain the world market dynamics for salmon it is necessary to estimate a complete interrelated Walrasian demand and supply system.

Granger causality

Price is treated as the endogenous variable in the estimated model. It is also assumed that fish farming companies make their decisions on the basis of expectations of future prices. The planning horizon in the production of salmon and trout is between one and two years, from investment in juveniles to selling the fish on the market. We expect that the aggregated supply has some influence on the market price and that yesterday's prices have some influence on production decisions. But there exists no clear cut argument for treating price or quantity as the dependent or independent variable. We shall therefore not exclude the possibility that there exist feedback mechanisms in the system: We applied a *F*-test for instantaneous causality (and feedback) $q(t) \Leftrightarrow p(t)$ and for Granger causality $q(t-i) \rightarrow p(t)$ and $p(t-i) \rightarrow q(t)$ for i = 1,2 in the restricted and unrestricted regression. In both cases we could not reject the null hypothesis of no Granger and instantaneous causality. The validity of the tests seems to be weak because the coefficients in the regressions were insignificant in most of the cases. The validity of the Granger causality test could also break down if we difference cointegrated variables (see the following paragraph for further discussion of the topic).

Non-stationarity and cointegration

Price and quantity are non-stationary variables (mean, variance and covariance is not autonomous). The risk of spurious regression is high by applying ordinary least square regression (OLS) without knowing whether the variables (in levels) are integrated of order one, i.e. I(1), and are cointegrated or not. It is therefore necessary to test the data generating process (DGP) for each variable.

An Augmented Dickey-Fuller (ADF) unit root tests shows that untransformed price and quantity have at least one unit root and are both non-stationary. The results from the test are presented in Appendix A. A first differencing of the quantity variable did not succeed (10% significant level) in rejecting the null-hypothesis of unit root, indicating exponential growth and more than one root. On the other hand the autocorrelation plot indicates that the first differenced quantity variable is stationary. We applied an Augmented Dickey-Fuller test to evaluate whether a linear combination of the logarithmically transformed price and quantity is stationary and cointegrating. If these variables are cointegrated, there is evidence that there exists a long run relationship between the non-stationary variables.

The first model to be estimated is as follows:

$$p_t = \alpha + \beta q_t + u_t$$

where

p_t : Natural logarithm of price for year *t*

q_t : Natural logarithm of quantity for year *t*

α : Constant term

u_t : The residual term for year *t*

The statistical results show that the variables are not cointegrated (see Appendix C), i.e. $u_t \sim I(1)$. Price and quantity are probably difference stationary variables (DS). Price and quantity as the relation was formulated are not cointegrated, and there exists no long run relationship. We tested the relationship between price and quantity after differencing the variables. First differencing made the price stationary I(0). The analysis was also tricky because the ADF-test indicates that quantity is still an I(1) variable after first differencing (Appendix B), and regression models with the sufficiently transformed, stationary variables could not explain any variance in the real price. The odd result of the regression with properly differentiated variables can be explained by the fact that the variables are cointegrated. If we differentiate cointegrated variables, the risk of running a misspecified regression is high. But the level regression above did estimate the cointegrating β. Blough (1992) and Hamilton (1994) suggest two possible strategies for solving the problem with spurious regression. Firstly we can include lagged dependent and independent variables in the model and the problem with spurious regression is potentially solved. The second method of solving the spurious regression problem is to transform the variables by applying a Cochrane-Orcutt adjustment for first-order serial correlation. Bloug (1992) has shown that the Cochrane-Orcutt GLS regression is asymptotically equivalent to the differenced regression of the regression model (above). In the following we present the result by including lagged independent and dependent variables. We estimated the following model:

$$p_t = \delta + \theta p_{t-1} + \phi_0 q_t + \phi_1 q_{t-1} + \varepsilon_t$$

where

p_t:	Natural logarithm of price for year *t*
q_t:	Natural logarithm of quantity for year *t*
p_{t-1}, q_{t-1}:	Lagged variables (one period)
ε_t:	The residual term for year *t*
$\delta, \theta, \phi_0, \phi_1$:	Parameters to be estimated

The spurious regression problem is not solved if there exist parameter values that take the following values: $\theta = 1$, and $\phi_0 = \phi_1 = 0$, and still that ε_t is stationary I(0). See tests and discussion below. The result from the estimation is presented in table 8. Ordinary least squares regression (OLS) is used as estimator. Table 8 summarizes the results from the regression.

Table 8: Coefficients

Variable Name	Estimated Coefficient	Standard Error	T-Ratio	p-Value 19 DF	Partial Correlation	Standardised Coefficient	Elasticity at Means
p_{t-1}	0.71209	0.1769	4.026	0.001	0.678	0.7134	0.7121
q_t	-0.23969	0.2085	-1.149	0.265	-0.255	-0.5931	-0.2397
q_{t-1}	0.12145	0.2068	0.5873	0.564	0.134	0.3220	0.1215
δ	1.5880	0.9610	1.652	0.115	0.354	0.0000	1.5880

The model explains about 95% of the variation in the price ($\overline{R}^2 \approx 0.95$). It is only the coefficient for the lagged price which is significantly different from zero. Because the model has a lagged dependent variable as an explanatory variable, the DW-test for autocorrelation must be modified. The following test operator is applied:

$$h = \left[1 - \frac{DW}{2}\right]\sqrt{\frac{T}{1 - T[\mathrm{var}(\theta)]}}$$

The formula gives the value $h = -0.50$, and the hypothesis of autocorrelation is rejected. The value of the Durbin-Watson statistic DW=1.88. Hansen's test indicates no unstable parameters at the 10% level. Different tests for heteroscedasticity (Glejser, Harvey, White tests and Harvey-Philips test) are rejected. Harvey-Collier test for non-random residuals was rejected. On the other hand the Chow test for equal parameters for different subsets indicates a structural shift in the parameters in the period 1999-2003. The Goldfeld-Quandt test for equal error variance for different subsets indicates that the variance in the subset of observations in the period 1999-2003 is different from the subset of preceding observations.

We tested also whether the variables in the model are cointegrated, and whether we could find any long run relationship between the non-stationary variables. The test shows that we can not rejected the hypothesis of cointegration at the 5% level. But the result is only valid if the value of the coefficients are significant and do not have the mentioned critical values. The result of the test is presented in Appendix D. We tested the hypothesis $H_0 : \theta = 1$ against the alternative hypothesis $H_0 : \theta \neq 1$. The H_0 hypothesis could *not* be rejected, i.e. *t*-statistic equal -1.62 with 19 degrees of freedom and p-value equal 0.12005. The student *t*-values for the other coefficients, in addition that $\theta = 1$, shows that $\phi_0 = \phi_1 = 0$. Theoretically the model can be reduced to $\Delta p_t = \delta + \varepsilon_t$, where p_t is a random walk process with stochastic drift, i.e. $\varepsilon_t \sim I(0)$, but the model does not fulfil the convergence criteria because $p_t = p_0 + t\delta + \sum_{i=1}^{t} \varepsilon_i$, where p_0 is the starting value. The model is therefore rejected. We tested the solution suggested by Blough (1992). We estimated the original model, $p_t = \alpha + \beta q_t + u_t$, by using GLS as the estimator. The result from the regression is as follows:

Table 9: *Coefficients*

Variable Name	Estimated Coeff.	Standard Error	T-Ratio	p-Value 22 DF	Partial Correlation	Standardised Coeff.	Elastasticity at Means
q_t	-0.36734	0.04714	-7.792	0.000	-0.857	-0.9407	-0.3673
CONSTANT	5.3726	0.2329	23.07	0.000	0.980	0.0000	5.3726

The model explains 95% of the variation in price. DW=1.79 and $\rho = 0.08$, and the hypothesis of first order autocorrelation can be rejected. The coefficient for the first order autocorrelation in the original model is 0.7193 with t = 5.073. We tested whether the variables in the model are cointegrated, and whether we could find any long run, common stochastic trend between the non-stationary variables. The cointegration test shows that we can find β for which the residuals are I(0) and the problem of spurious regression is solved, and the variables are cointegrated C(1,1), with the cointegrating vector $(1,\ 0.3673)$. The long run relationship between price and quantity is as follows:

$$p_L = \underset{(SE=0.2329)}{5.3726} - \underset{(SE=0.0474)}{0.3673}\, q_L$$

The standard errors are in brackets. A more detailed description of the estimation is given in Appendix E. The long run price model indicates that the price on average will be reduced by about 0.36% if the quantity increases by 1%. If we assume (which is unrealistic) that salmon has no substitutes, we can calculate an approximated measure for the demand elasticity, i.e. by inverting (Houck 1965) the inverse demand function. i.e. -1/0.3673 = -2.72. Based on 13 demand analyses of salmon reported in Asche et al. 2005, the average demand elasticity is 2.16. The value of the standard error indicates that the coefficient estimate is accurate. Figures 20 and 21 show respectively the interrelationship between price and quantity, and the short and long run relation between price and quantity.

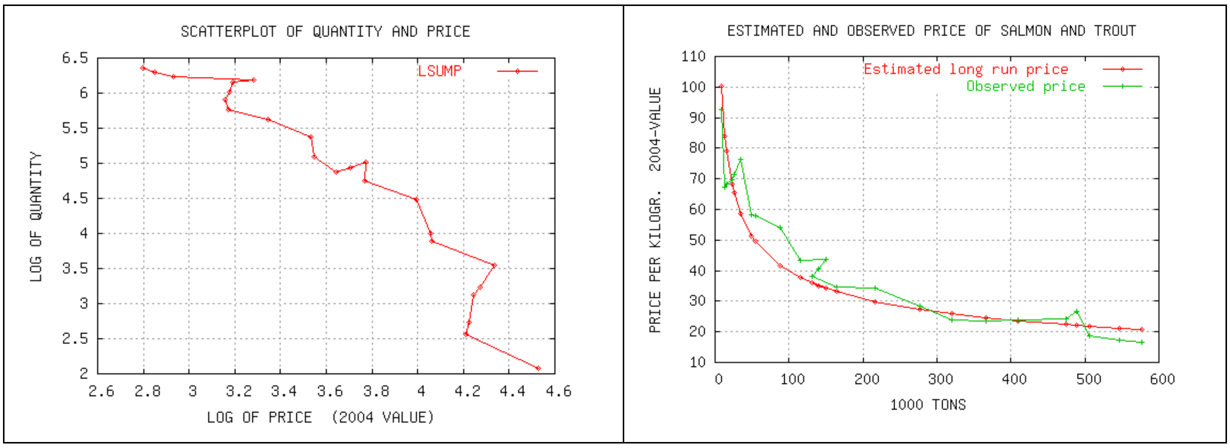


Figure 20 and 21: The observed relation between price and quantity and the estimated and observed price.

The scatterplot strongly suggests that the two series are related, and the statistical findings seem to confirm that. Figure 21 shows that the error term converges to the long run relationship. The figure shows that the estimated static long run price level fits the price quite well. According to the Granger causality tests and the fact that we have no precise argument which could qualify for an identification of what market relation we are actually estimating, we conclude that model we have estimated is the long-run equilibrium between price and quantity and *not* the demand curve. Because we have estimated the long run relationship, we can apply the result in the economic analysis.

Error correcting model (ECM)

According to Granger's 1997 representation theorem (Granger 1997) there exists an error correction mechanism in a dynamic system with cointegrated variables. We follow Granger and estimated the following short run error correcting model (ECM) related to the long run relationship between price and quantity:

$$\Delta p_t = \theta_1 \Delta q_t + \theta_2 \varepsilon_{t-1}$$

The estimation shows that DW=1.81, and there exist no first order serial correlation. The *t*-value for the error correcting coefficient θ_2 is not significantly different from zero, but the coefficient has the correct sign. θ_1 is significantly different from zero. The EC has the following structure:

$$\Delta p_t = -0.3022\Delta q_t - 0.1997\varepsilon_{t-1}$$

θ_2 is an indicator on how quickly the disequilibrium will be removed. The result shows that about 20% of the disequilibrium in period $t-1$ is removed in period t. The θ_1 term is significant at 2.5% level and indicates that the contemporaneous adjustment to equilibrium is strongest. In a cointegrating system all variables have the same status, so there exists also a second EC-model, where price is the independent variable. In this case we got the following estimated model with the use of GLS estimation due to indication of autocorrelated residuals:

$$\Delta q_t = -0.4482\Delta p_t - 0.1897\varepsilon_{t-1}$$

The θ_1 coefficient is significantly different from zero at the 10% significance level, but the error correcting coefficient is not. A comparison of the models shows that the speed of the error correcting process is quit similar. Note that the value of θ_1 is bigger than the cointegrating coefficient β in the long run model, and this indicates that there is an overadjustment in the quantity to a change in price. In the first model the θ_1 value is less than the cointegrating coefficient, and it indicates partial instantaneous adjustment to a unit change from the long run equilibrium. The error correcting dynamics term $-0.1997\varepsilon_{t-1}$ from the first EC-model is mapped in figure 22. The result from the regression is presented in Appendix F.

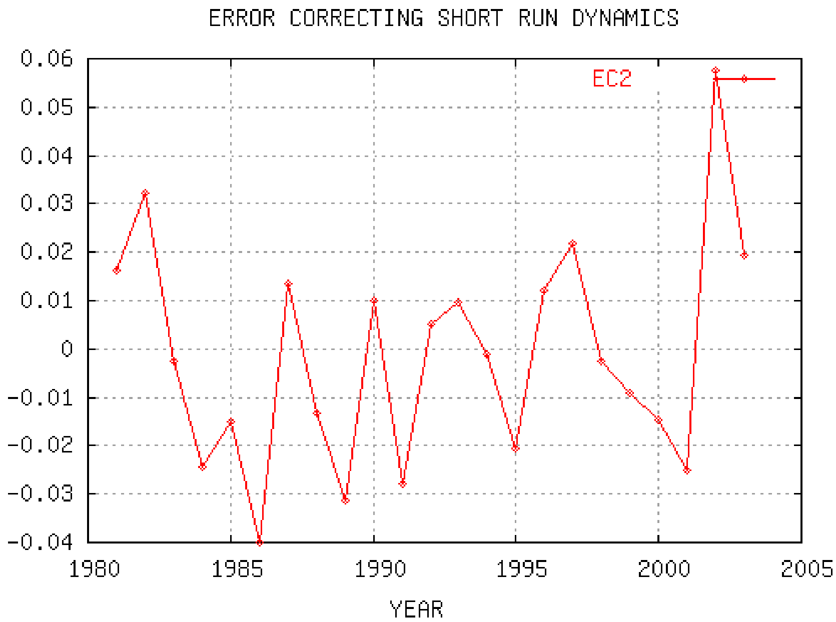


Figure 22: The error correcting dynamics toward equilibrium

The figure indicates that the error correcting mechanism takes on average about five to reach the long run equilibrium level.

6. REVENUE EFFECTS OF CHANGED PRODUCTION

Here we analyse the scenario where the aggregated supply of salmon and trout has an influence on the market price, as estimated in the above model. Above we concluded that total production of farmed salmon in Norway will not be reduced by climate change. The production is expected to move further north – first of all to Nordland county. In the long run we expect that a rise in sea temperature will redistribute the production from the southern counties, respectively the Agder area, Rogaland and Hordaland county to the northernmost counties. As the total production will probably increase, we will analyse how the revenue is expected to change due to a greater production of farmed salmon and trout.

In the immediate future (short run) the production of salmon and trout will probably increase in all counties, due to unused production capacity in existing plants. We have estimated that the production in existing farms could increase from today's 600,000 tons of salmon and trout to a maximum of 800,000-900,000 tons. The increase will be made possible by a complete utilisation of the available technical production capacity. During the period 1999 to 2004 the growth in the salmon farming industry was controlled by feed quotas. Today the feed-quota restriction has been abolished, and so it is expected that the production will increase.

The potential production capacity in the Norwegian aquaculture industry is high. Whether it will be utilized depends on market conditions. EU represents the main market for Norwegian produced salmon (about 60% of the total export is sold to the EU-market) but EU's recurrent sanctions against Norwegian salmon industry, because of alleged dumping and subsidies during a period of almost 15 years, has restrained the Norwegian salmon farming industry and its plans for further expansion. The above model shows that there is an inverse relationship between quantity produced and the realized market price. Because of high uncertainty with respect to market conditions and the predicted climate effect, it is difficult to specify a percentage change in farmed salmon due to climate change. To deal with the uncertainty in the future scenario, we have applied a long run static model to assumed changes in production and analysed the relationship between changes in total supply and changes in gross revenue. Prior to the climate change we assume that the initial production level is 600,000 tons, i.e. actual production in 2004 was $Q_0 = 600$. By applying the coefficients from the estimated long run relationship between price and quantity, the change in gross revenue can be expressed in the following way:

$$\begin{aligned}\Delta R &= p_1 \Delta Q + \Delta p Q_0 \\ &= Q_0 (e^{5.37})((Q_0(1+\beta))^{-0.37} - Q_0^{-0.37}) + (e^{5.37})(Q_0(1+\beta) - Q_0)(Q_0(1+\beta))^{-0.37} \\ &= e^{5.37} Q_0^{0.63}\left[(1+\beta)^{0.63} - 1\right]\end{aligned}$$

where $\beta = \dfrac{r}{100}$, *r*: percentage change in production of salmon and trout.

Figure 23 shows how the gross revenue changes for the salmon industry in Norway due to a change in production. The upper and lowermost curves show the changes in revenue given ± 2 standard deviation changes in the coefficients, the constant term and the coefficient for the long run quantity. The *y*-axis in the figure measures the change in gross revenue (ΔR) in million Norwegian kroner per year (2004 value) and the *x*-axis measures the percentage change in supply.

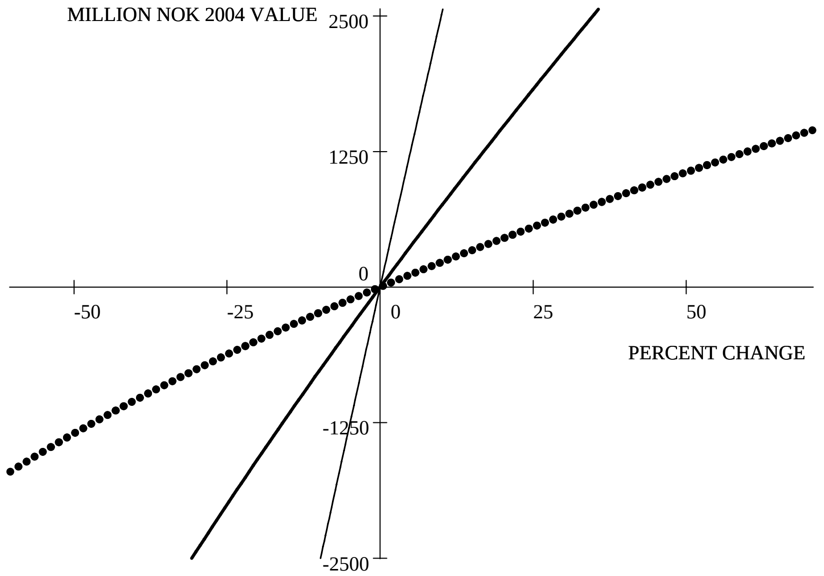


Figure 23: Change in gross revenue per year due to change in production
(delta revenue figure SWP-figure)

The figure shows that the 95% confidence interval is wide. It was mentioned that the percentage change is calculated from an initial production level $Q_0 = 600$. A 33% increase in production implies a total production about 800,000 tons salmon and trout, and a production of 1 million tons implies about a 67% increase. According to Figure 22, an increase of 33%, i.e. a 100% utilisation of the technical production capacity in *existing* plants in 2005, would increase the gross revenue between about 0.8 and 2.3 billion Norwegian kroner per year. The figure also maps a possible negative development in production, even if this is an unlikely scenario. Figure 24 shows the 95% confidence interval for the price level of salmon and trout (± 2 standard deviation changes in the coefficient estimate for the long run quantity variable) if the aggregated production increases to about 1 million tons.

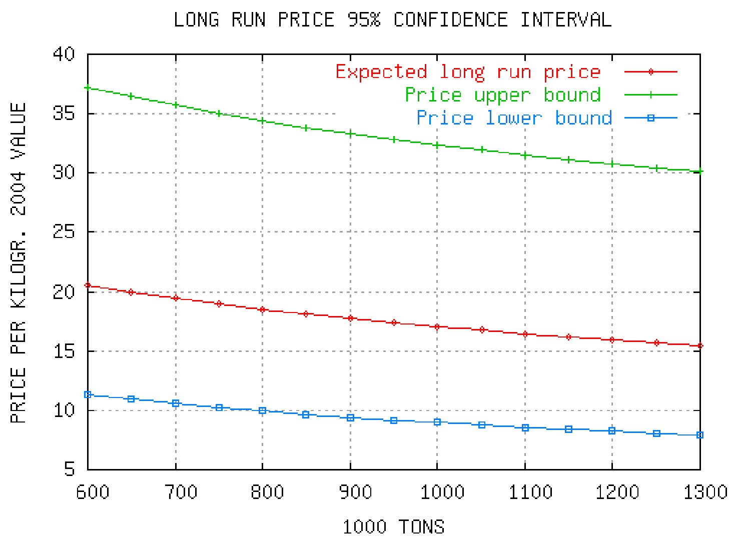


Figure 24: Price level and aggregated production of farmed salmon

The figure shows that the estimated expected future price interval is quite big. The lower predicted price is probably much too low compared to today's market situation and the production costs, while the expected price in the figure has a realistic level. The expected long run dependence between quantity and price gives the opportunity to set a production quota or apply other means to control the production in such a way that it maximizes the profit in the salmon aquaculture industry. The scenario is based on a partial analysis, and it does not take into account changes in the supply of important substitutes – first of all salmon from Chile. The opportunity to regulate the production level with a view to influence the profit is also discussed for the managing the wild species cod, herring and mackerel in Lorentzen and Hannesson (2005).

Figure 25 shows the profit-maximizing production level given the estimated long run relationship between price and quantity and for different levels of marginal cost, which at the industry level is assumed to be constant. The thick line, labelled $\text{Max } \pi$, shows the production level which maximizes the aggregated profit in the industry. The assumption of constant marginal cost can be criticized because less suitable sites will be used for production as the latter increases, but technological progress and utilization of vacant production capacity give the opposite effect. The line labelled $\pi = 0$ shows the relationship between production level and respectively marginal and average costs where the profit is zero. In practice and individually, each farmer and exporting company do not exercise any market power. The fact that actors individually have no market power implies that they expand production as long as the profit is positive. Without any collective coordinating mechanism, the industry will tend to expand until it reaches the uppermost curve when average cost is equal to the price in the figure, where the profit has been driven down to zero. Notice that the scope for expansion from the maximum profit level to the zero profit is over a million tons if the marginal and average costs are 14 kroner per kilogram. The curves and assessments are based on the long run static model.

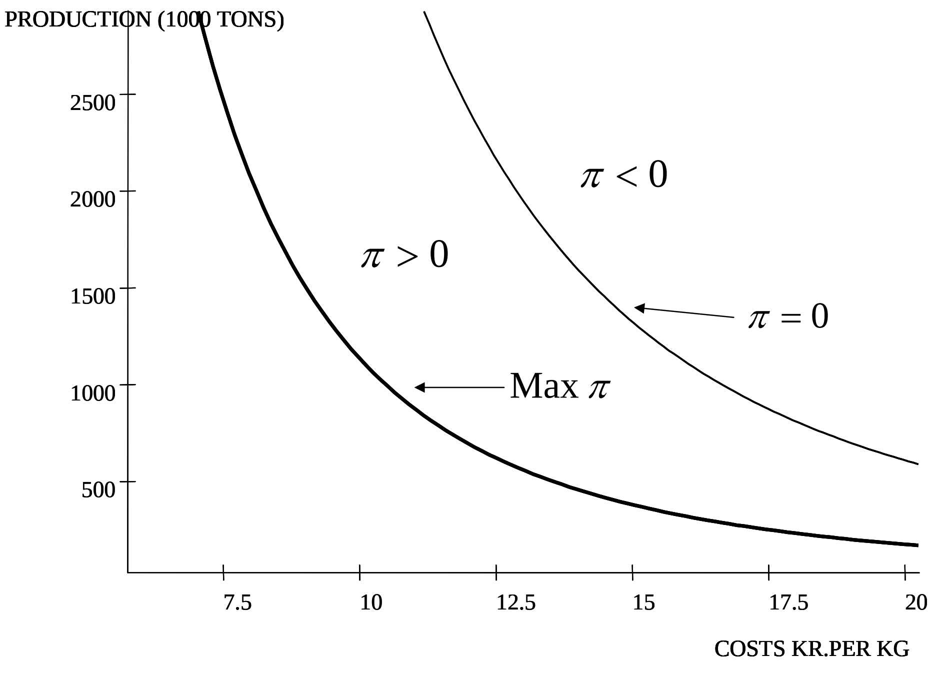


Figure 25: Production level, profit and costs in the salmon and trout industry

The figure shows that (the scales in the figure are unfortunately not correct) if the marginal cost of producing salmon is about 15 Norwegian kroner, the optimal production level would be 500,000 tons. If the marginal cost is 13, the profit maximizing level would be about 700,000 tons, and if the marginal cost is 9, the optimal production level would be about 2 million tons per year. The yearly cost and earnings study carried out by the Norwegian Directorate of Fisheries shows that technical progress in the industry has reduced the real average production costs (2004 value of money) from about 30 Norwegian kroner in 1993 to about 16 kroner in 2003. It implies a reduction of about 47% during a period of 10 years, i.e. on average a yearly reduction of about 5%. It is likely that technical progress will continue in the future. On the other hand, it is also likely that an expansion in the industry will make it necessary to use less suitable sites, which would increase marginal cost.

7. CONCLUSION

Irrespective of climate change, the production of Norwegian salmon and trout will most likely continue to increase. Technically, i.e. without regard to the market, the production from already established firms could increase from about 600,000 tons to 800,000-900,000 tons during a period of at least 2-3 years. The market model shows that an expansion of 30-40% from today’s level (2004) would increase the aggregated revenue by about 2 billion Norwegian kroner per year. Whether the industry would realize this potential depends on access to markets in other countries, and on the expansion in competing countries. As long as the producers can realize some profit, they will expand. In the long run the non-cooperative accommodation to the market will eliminate the profit. By applying some controls which would limit the production, the industry could realize a higher profit. The problem is that the government can only control the Norwegian supply and not the world supply of Atlantic salmon or its substitutes.

The econometric analysis shows that there is a long run negative relationship between export prices and quantity supplied of Norwegian salmon. The error correcting model indicates that about 20% of the disequilibrium is removed in the following period and 80% is adjusted instantaneously. The negative relationship between price and quantity (elastic demand) indicates the potential of realizing extra profit in the export market by restricting the supply. The partial model does not take into account that significant shifts in the supply from competing salmon producing countries can undermine the quantity restriction strategy.

If the sea temperature in the upper 10m layer increases on average by 2-3 degrees in summer and winter, the coastal areas south of Stadt will probably be optimal for salmon production in the winter months but too warm for farming of salmon and trout during the warmest summer months. Especially the Skagerrack coast will become too warm. This area also has a relatively high frequency of algae-blooms, and this problem will probably increase because of the climate change. In the future the coast of Rogaland and Hordaland will probably no longer be suitable locations for farming of Atlantic salmon. In the worst case the temperature increase can make it too risky to farm salmon in open cages in the sea off Vest Agder, Rogaland and Hordaland. The said areas will then loose a yearly aggregated production of about 240,000 tons. The climate change will “push” the salmon aquaculture industry further north: the most suitable areas will be from the coast of Møre to the coast of the southern part of Troms county. The sea temperature north of Lofoten and off Finnmark will still be low during the winter months and it is uncertain how significant the positive change for the industry located in that area will be. If the average temperature during the year increases, production of salmon in Finnmark may possibly increase. In sum, a climate change that would increase the sea temperatures along the coast would not change significantly the potential production capacity in the salmon aquaculture industry in Norway. The sites which would be lost in the southern part of the coast are likely to be replaced by new sites further north. Profitable production of salmon is not limited by sites or locations. The limiting factors are market access and a price fall in response to increased production, pushing marginal firms to or beyond the break-even point.

How early or fast we, or the coming generation, will experience the effects from the expected climate change depends on how rapidly the temperature changes. A statistical analysis indicates that the August temperature in the sea masses off Lista increases on average by about 0.08 ^{0}C per year, so that the temperature would increase from about 14.5 to 16 degrees during a 20 year period. This increase would at a critical point have a clearly negative effect of the growth rate of the fish. A statistical analysis of the Skrova region, Troms county, did not confirm any significant increase in the average temperature in August, March, or the annual average (Lorentzen and Hannesson, 2005). The indicated increase in the sea temperature seems so far to be a local phenomenon.

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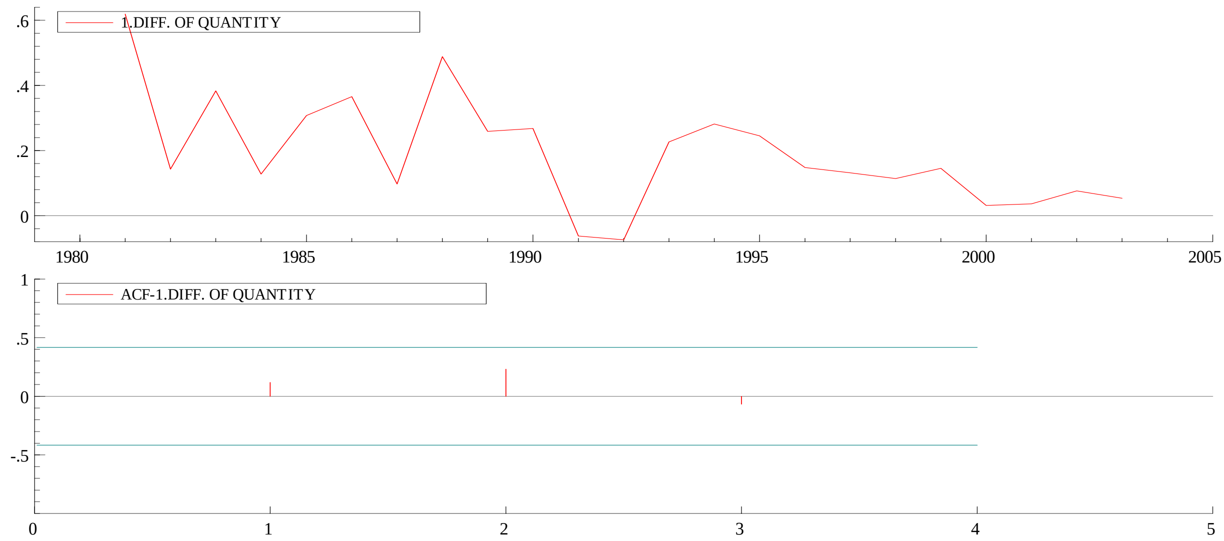
Appendix A: The ACF-plot of the 1.difference of quantity



The plot of the 1.difference of log quantity indicates that process is not stationary, but the ACF plot gives the opposite impression.

Appendix B

APPLICATION OF AUGMENTED DICKEY-FULLER TEST FOR IDENTIFYING DATAGENERATING PROCESS, UNIT ROOT, STATIONARITY

```
 VARIABLE: LOG-TRANSFORMED PRICE

 DICKEY-FULLER TESTS - NO.LAGS =   4   NO.OBS =   19

     NULL                 TEST       ASY. CRITICAL
  HYPOTHESIS            STATISTIC      VALUE 10%
---------------------------------------------------------------------------
 CONSTANT, NO TREND
 A(1)=0  T-TEST        -0.10781     -2.57
 A(0)=A(1)=0             7.9530      3.78
                                                 AIC =     -4.275
                                                  SC =     -3.977
---------------------------------------------------------------------------
 CONSTANT, TREND
 A(1)=0  T-TEST         -2.3302     -3.13
 A(0)=A(1)=A(2)=0        8.9096      4.03
 A(1)=A(2)=0             2.7166      5.34
                                                 AIC =     -4.542
                                                  SC =     -4.194
---------------------------------------------------------------------------
```

VARIABLE : LOG-TRANSFORMED QUANTITY

```
 DICKEY-FULLER TESTS - NO.LAGS =   0   NO.OBS =   23

     NULL              TEST      ASY. CRITICAL
  HYPOTHESIS         STATISTIC     VALUE 10%
---------------------------------------------------------------------------
 CONSTANT, NO TREND
 A(1)=0  Z-TEST      -1.6401     -11.2
 A(1)=0  T-TEST      -3.5084     -2.57
 A(0)=A(1)=0          31.732      3.78
                                              AIC =    -4.079
                                               SC =    -3.981
---------------------------------------------------------------------------
 CONSTANT, TREND
 A(1)=0  Z-TEST      -3.2940     -18.2
 A(1)=0  T-TEST      -1.4111     -3.13
 A(0)=A(1)=A(2)=0     20.849      4.03
 A(1)=A(2)=0          6.2765      5.34
                                              AIC =    -4.018
                                               SC =    -3.870
---------------------------------------------------------------------------
```

VARIABLE : 1. DIFFERENCE OF THE LOG-TRANSFORMED PRICE

```
 DICKEY-FULLER TESTS - NO.LAGS =   0   NO.OBS =   23

     NULL              TEST      ASY. CRITICAL
  HYPOTHESIS         STATISTIC     VALUE 10%
---------------------------------------------------------------------------
 CONSTANT, NO TREND
 A(1)=0  Z-TEST      -24.314     -11.2
 A(1)=0  T-TEST      -43.040     -2.57
 A(0)=A(1)=0          962.87      3.78
                                              AIC =    -4.305
                                               SC =    -4.206
---------------------------------------------------------------------------
 CONSTANT, TREND
 A(1)=0  Z-TEST      -24.491     -18.2
 A(1)=0  T-TEST      -40.278     -3.13
 A(0)=A(1)=A(2)=0     632.56      4.03
 A(1)=A(2)=0          912.73      5.34
                                              AIC =    -4.251
                                               SC =    -4.103
---------------------------------------------------------------------------
```

VARIABLE : 1. ORDER DIFFERENCE OF LOG-TRANSFORMED QUANTITY

```
DICKEY-FULLER TESTS - NO.LAGS =   4   NO.OBS =   18

     NULL              TEST      ASY. CRITICAL
  HYPOTHESIS         STATISTIC     VALUE 10%
---------------------------------------------------------------------------
 CONSTANT, NO TREND
 A(1)=0  T-TEST     -0.92292     -2.57
 A(0)=A(1)=0          1.0650      3.78
                                              AIC =    -3.697
                                               SC =    -3.400
---------------------------------------------------------------------------
 CONSTANT, TREND
```

```
 A(1)=0  T-TEST       -2.0245     -3.13
 A(0)=A(1)=A(2)=0      1.8675      4.03
 A(1)=A(2)=0           2.0504      5.34
                                                AIC =    -3.834
                                                 SC =    -3.488
---------------------------------------------------------------------------
```

VARIABLE: 2.ORDER DIFFERENCE OF LOG-TRANSFORMED QUANTITY

```
 DICKEY-FULLER TESTS - NO.LAGS =   1   NO.OBS =   20

     NULL               TEST      ASY. CRITICAL
  HYPOTHESIS          STATISTIC     VALUE 10%
---------------------------------------------------------------------------
 CONSTANT, NO TREND
 A(1)=0  T-TEST       -4.0143     -2.57
 A(0)=A(1)=0           8.0573      3.78
                                                AIC =    -3.485
                                                 SC =    -3.336
---------------------------------------------------------------------------
 CONSTANT, TREND
 A(1)=0  T-TEST       -3.8967     -3.13
 A(0)=A(1)=A(2)=0      5.0678      4.03
 A(1)=A(2)=0           7.6016      5.34
                                                AIC =    -3.386
                                                 SC =    -3.187
---------------------------------------------------------------------------
```

APPENDIC C: TEST FOR LONG RUN RELATIONSHIP BETWEEN PRICE AND QUANTITY BY APPLYING AUGMENTED DICKEY-FULLER TESTS

```
COINTEGRATING REGRESSION - CONSTANT, NO TREND   NO.OBS =   24
 REGRESSAND :  LOG-TRANSFORMED PRICE

  R-SQUARE = 0.9135         DURBIN-WATSON = 0.6284

  DICKEY-FULLER TESTS ON RESIDUALS - NO.LAGS =  0   M =  2

                        TEST      ASY. CRITICAL
                      STATISTIC     VALUE 10%
---------------------------------------------------------------------------
  NO CONSTANT, NO TREND
          Z-TEST       -7.0149     -17.1
          T-TEST       -1.8029     -3.04
                                                AIC =    -4.282
                                                 SC =    -4.233
---------------------------------------------------------------------------

 COINTEGRATING REGRESSION - CONSTANT, TREND      NO.OBS =   24
 REGRESSAND : LOG-TRANSFORMED PRICE

  R-SQUARE = 0.9619         DURBIN-WATSON =  1.416

  DICKEY-FULLER TESTS ON RESIDUALS - NO.LAGS =  4   M =  2

                        TEST      ASY. CRITICAL
                      STATISTIC     VALUE 10%
---------------------------------------------------------------------------
  NO CONSTANT, NO TREND
          T-TEST       -2.0703     -3.50
                                                AIC =    -4.648
                                                 SC =    -4.400
---------------------------------------------------------------------------
```

APPENDIC D: TEST FOR LONG RUN RELATIONSHIP BETWEEN PRICE AND QUANTITY BY APPLYING AUGMENTED DICKEY-FULLER TESTS

```
 COINTEGRATING REGRESSION - CONSTANT, NO TREND   NO.OBS =   23
 REGRESSAND : LOG-TRANSFORMED PRICE

  R-SQUARE = 0.9497         DURBIN-WATSON =  1.885

  DICKEY-FULLER TESTS ON RESIDUALS - NO.LAGS =  0   M =  4

                       TEST      ASY. CRITICAL
                     STATISTIC     VALUE  5%
---------------------------------------------------------------------------
  NO CONSTANT, NO TREND
          Z-TEST       -23.223     -32.4
          T-TEST       -5.4223     -4.10
                                                AIC =    -4.552
                                                 SC =    -4.502
---------------------------------------------------------------------------

 COINTEGRATING REGRESSION - CONSTANT, TREND      NO.OBS =   23
 REGRESSAND : LOG-TRANSFORMED PRICE

  R-SQUARE = 0.9623         DURBIN-WATSON =  1.693

  DICKEY-FULLER TESTS ON RESIDUALS - NO.LAGS =  0   M =  4

                       TEST      ASY. CRITICAL
                     STATISTIC     VALUE  5%
---------------------------------------------------------------------------
  NO CONSTANT, NO TREND
          Z-TEST       -20.111     -38.2
          T-TEST       -4.5234     -4.43
                                                AIC =    -4.754
                                                 SC =    -4.704
---------------------------------------------------------------------------
```

APPENDIX E: RESULTS FROM THE GLS ESTIMATION: UNIT ROOT TEST AND COINTEGRATION TESTS

```
GLS-REGRESSION: COCHRANE-ORCUTT
 DEPENDENT VARIABLE =  LOG OF PRICE
 ..NOTE..R-SQUARE,ANOVA,RESIDUALS DONE ON ORIGINAL VARS

 LEAST SQUARES ESTIMATION            24 OBSERVATIONS
 BY COCHRANE-ORCUTT TYPE PROCEDURE WITH CONVERGENCE = 0.00100

     ITERATION          RHO              LOG L.F.            SSE
         1            0.00000        -76.1362            0.53196
         2            0.69500        -69.4869            0.29737
         3            0.71575        -69.4976            0.29691
         4            0.71883        -69.5007            0.29688
         5            0.71933        -69.5012            0.29687

  LOG L.F. =   -69.5012       AT RHO =     0.71933

                     ASYMPTOTIC  ASYMPTOTIC  ASYMPTOTIC
           ESTIMATE    VARIANCE    ST.ERROR     T-RATIO
 RHO        0.71933     0.02011     0.14180     5.07295

  R-SQUARE =   0.9517     R-SQUARE ADJUSTED =   0.9496
 VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.13494E-01
 STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.11616
```

```
 SUM OF SQUARED ERRORS-SSE=  0.29687
 MEAN OF DEPENDENT VARIABLE =   3.6580
 LOG OF THE LIKELIHOOD FUNCTION(IF DEPVAR LOG) = -69.5012


                     ANALYSIS OF VARIANCE - FROM MEAN
                      SS         DF             MS
 REGRESSION        5.8555          1.         5.8555
 ERROR            0.29687         22.       0.13494E-01
 TOTAL             6.1524         23.       0.26749

                     ANALYSIS OF VARIANCE - FROM ZERO
                      SS         DF             MS
 REGRESSION        327.00          2.         163.50
 ERROR            0.29687         22.       0.13494E-01
 TOTAL             327.30         24.        13.637


 VARIABLE   ESTIMATED  STANDARD   T-RATIO        PARTIAL STANDARDIZED
ELASTICITY
   NAME    COEFFICIENT   ERROR      22 DF   P-VALUE CORR. COEFFICIENT  AT MEANS
 LSUMP    -0.36734     0.4714E-01  -7.792     0.000-0.857    -0.9407    -0.3673
 CONSTANT   5.3726     0.2329       23.07     0.000 0.980     0.0000     5.3726

 VARIANCE-COVARIANCE MATRIX OF COEFFICIENTS
 LSUMP     0.22223E-02
 CONSTANT -0.10367E-01  0.54244E-01
              LSUMP        CONSTANT

 CORRELATION MATRIX OF COEFFICIENTS
 LSUMP      1.0000
 CONSTANT -0.94423       1.0000

 DURBIN-WATSON = 1.7878    VON NEUMANN RATIO = 1.8655    RHO =  0.08410
 RESIDUAL SUM =  0.58666E-01  RESIDUAL VARIANCE =  0.13651E-01
 SUM OF ABSOLUTE ERRORS=   2.2112
 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9521
 R-SQUARE BETWEEN ANTILOGS OBSERVED AND PREDICTED = 0.9378
 RUNS TEST:   11 RUNS,   13 POS,    0 ZERO,   11 NEG  NORMAL STATISTIC = -
0.8059
 DURBIN H STATISTIC (ASYMPTOTIC NORMAL) =  0.57274
  MODIFIED FOR AUTO ORDER=1
 COEFFICIENT OF SKEWNESS =  -0.4384 WITH STANDARD DEVIATION OF 0.4723
 COEFFICIENT OF EXCESS KURTOSIS =   0.2791 WITH STANDARD DEVIATION OF 0.9178

 JARQUE-BERA NORMALITY TEST- CHI-SQUARE(2 DF)=    0.6757 P-VALUE= 0.713

      GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS -  6 GROUPS
 OBSERVED  1.0  1.0  9.0  8.0  5.0  0.0
 EXPECTED  0.5  3.3  8.2  8.2  3.3  0.5
 CHI-SQUARE =    3.5010 WITH  2 DEGREES OF FREEDOM, P-VALUE= 0.174
```

UNIT ROOT AND STATIONARITY TEST OF THE RESIDUAL OF GLS-REGRESSION

```
  TOTAL NUMBER OF OBSERVATIONS =   24

  VARIABLE : RESIDUAL OF THE T1
  DICKEY-FULLER TESTS - NO.LAGS =   1   NO.OBS =   22

      NULL               TEST      ASY. CRITICAL
   HYPOTHESIS          STATISTIC     VALUE 10%
 ---------------------------------------------------------------------------
  CONSTANT, NO TREND
  A(1)=0  T-TEST       -3.2955     -2.57
  A(0)=A(1)=0           5.4368      3.78
```

```
                                                      AIC =    -4.154
                                                       SC =    -4.005
---------------------------------------------------------------------------
 CONSTANT, TREND
 A(1)=0  T-TEST       -4.1492     -3.13
 A(0)=A(1)=A(2)=0      6.2958      4.03
 A(1)=A(2)=0           9.4352      5.34
                                                      AIC =    -4.328
                                                       SC =    -4.129
```

COINTEGRATION TEST OF THE COCHRANE-ORCUTT TRANSFORMED VARIABLES

```
COINTEGRATING REGRESSION - CONSTANT, NO TREND   NO.OBS =   23
REGRESSAND : LOG OF PRICE

 R-SQUARE = 0.5656         DURBIN-WATSON =  1.927

 DICKEY-FULLER TESTS ON RESIDUALS - NO.LAGS =  1   M =  2

                       TEST      ASY. CRITICAL
                     STATISTIC     VALUE 10%
---------------------------------------------------------------------------
 NO CONSTANT, NO TREND
         T-TEST       -3.6780     -3.04
                                                      AIC =    -4.279
                                                       SC =    -4.180
---------------------------------------------------------------------------

COINTEGRATING REGRESSION - CONSTANT, TREND      NO.OBS =   23
REGRESSAND : LOG OF PRICE

 R-SQUARE = 0.6216         DURBIN-WATSON =  2.059

 DICKEY-FULLER TESTS ON RESIDUALS - NO.LAGS =  1   M =  2

                       TEST      ASY. CRITICAL
                     STATISTIC     VALUE 10%
---------------------------------------------------------------------------
 NO CONSTANT, NO TREND
         T-TEST       -4.2990     -3.50
                                                      AIC =    -4.554
                                                       SC =    -4.454
---------------------------------------------------------------------------
```

APPENDIC F: ESTIMATION OF THE ERROR CORRECTING MODEL

Estimation of the following equation:

$$\Delta p_t = \theta_1 \Delta q_t + \theta_2 \varepsilon_{t-1}$$

```
 R-SQUARE =   0.0315     R-SQUARE ADJUSTED =  -0.0146
VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.15143E-01
STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.12306
SUM OF SQUARED ERRORS-SSE=  0.31799
MEAN OF DEPENDENT VARIABLE = -0.75187E-01
LOG OF THE LIKELIHOOD FUNCTION =  16.5984
RAW MOMENT R-SQUARE =   0.3062

MODEL SELECTION TESTS - SEE JUDGE ET AL. (1985,P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR - FPE =     0.16459E-01
    (FPE IS ALSO KNOWN AS AMEMIYA PREDICTION CRITERION - PC)
```

```
 AKAIKE (1973) INFORMATION CRITERION - LOG AIC =  -4.1073
 SCHWARZ (1978) CRITERION - LOG SC =              -4.0086
                     ANALYSIS OF VARIANCE - FROM ZERO
                      SS         DF             MS                 F
REGRESSION       0.14037          2.       0.70184E-01            4.635
ERROR            0.31799         21.       0.15143E-01          P-VALUE
TOTAL            0.45836         23.       0.19929E-01            0.022


VARIABLE   ESTIMATED  STANDARD   T-RATIO        PARTIAL STANDARDIZED
ELASTICITY
  NAME    COEFFICIENT   ERROR      21 DF   P-VALUE CORR. COEFFICIENT  AT MEANS
DQ       -0.30224     0.1080     -2.798     0.011-0.521    -0.3798     0.7480
LR1      -0.19966     0.2291     -0.8716    0.393-0.187    -0.1881     0.0170

VARIANCE-COVARIANCE MATRIX OF COEFFICIENTS
DQ        0.11668E-01
LR1      -0.28365E-02  0.52473E-01
              DQ            LR1

CORRELATION MATRIX OF COEFFICIENTS
DQ         1.0000
LR1      -0.11464       1.0000

DURBIN-WATSON = 1.8119    VON NEUMANN RATIO = 1.8943    RHO =  0.03562
RESIDUAL SUM = -0.40626      RESIDUAL VARIANCE =  0.15143E-01
SUM OF ABSOLUTE ERRORS=   2.2515
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.0792
RUNS TEST:   11 RUNS,   12 POS,    0 ZERO,   11 NEG  NORMAL STATISTIC = -
0.6322
COEFFICIENT OF SKEWNESS =  -0.5691 WITH STANDARD DEVIATION OF 0.4813
COEFFICIENT OF EXCESS KURTOSIS =   0.1407 WITH STANDARD DEVIATION OF 0.9348

     GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS -  6 GROUPS
OBSERVED  1.0  3.0  7.0 10.0  2.0  0.0
EXPECTED  0.5  3.1  7.8  7.8  3.1  0.5
CHI-SQUARE =    2.0471 WITH  2 DEGREES OF FREEDOM, P-VALUE= 0.359
```

Estimation of the following EC-model:

$$\Delta q_t = \theta_1 \Delta p_t + \theta_2 \varepsilon_{t-1}$$

```
|_AUTO DQ DP LR1/NOCONST MAX

REQUIRED MEMORY IS PAR=      10 CURRENT PAR=    4000
DEPENDENT VARIABLE =  DQ
..NOTE..R-SQUARE,ANOVA,RESIDUALS DONE ON ORIGINAL VARS

LEAST SQUARES ESTIMATION             23 OBSERVATIONS
BY COCHRANE-ORCUTT TYPE PROCEDURE WITH CONVERGENCE = 0.00100

    ITERATION          RHO              LOG L.F.           SSE
        1             0.00000         4.06853            0.94538
        2             0.41678         7.61605            0.68870
        3             0.57661         8.29749            0.64309
        4             0.59810         8.33715            0.63980
        5             0.60005         8.34007            0.63953
        6             0.60022         8.34032            0.63951

 LOG L.F. =    8.34032       AT RHO =     0.60022

                    ASYMPTOTIC  ASYMPTOTIC  ASYMPTOTIC
         ESTIMATE    VARIANCE    ST.ERROR     T-RATIO
RHO       0.60022     0.02781     0.16678     3.59892
```

```
 R-SQUARE =  -0.2331     R-SQUARE ADJUSTED =  -0.2918
VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.30453E-01
STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.17451
SUM OF SQUARED ERRORS-SSE=  0.63951
MEAN OF DEPENDENT VARIABLE =  0.18609
LOG OF THE LIKELIHOOD FUNCTION =  8.34032
RAW MOMENT R-SQUARE =   0.5137

MODEL SELECTION TESTS - SEE JUDGE ET AL. (1985,P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR - FPE =     0.33101E-01
    (FPE IS ALSO KNOWN AS AMEMIYA PREDICTION CRITERION - PC)
 AKAIKE (1973) INFORMATION CRITERION - LOG AIC =  -3.4086
 SCHWARZ (1978) CRITERION - LOG SC =              -3.3099
MODEL SELECTION TESTS - SEE RAMANATHAN (1998,P.165)
 CRAVEN-WAHBA (1979)
    GENERALIZED CROSS VALIDATION - GCV =          0.33353E-01
 HANNAN AND QUINN (1979) CRITERION =              0.33918E-01
 RICE (1984) CRITERION =                          0.33659E-01
 SHIBATA (1981) CRITERION =                       0.32641E-01
 SCHWARZ (1978) CRITERION - SC =                  0.36520E-01
 AKAIKE (1974) INFORMATION CRITERION - AIC =      0.33086E-01

                     ANALYSIS OF VARIANCE - FROM ZERO
                      SS         DF             MS
REGRESSION       0.67560          2.       0.33780
ERROR            0.63951         21.       0.30453E-01
TOTAL             1.3151         23.       0.57179E-01


VARIABLE   ESTIMATED  STANDARD   T-RATIO        PARTIAL STANDARDIZED
ELASTICITY
  NAME    COEFFICIENT   ERROR      21 DF   P-VALUE CORR. COEFFICIENT  AT MEANS
DP       -0.44824     0.2786     -1.609     0.123-0.331    -0.3567     0.1811
LR1      -0.18968     0.3317     -0.5718    0.574-0.124    -0.1422    -0.0065

VARIANCE-COVARIANCE MATRIX OF COEFFICIENTS
DP         0.77594E-01
LR1        0.46894E-01  0.11003
              DP           LR1

CORRELATION MATRIX OF COEFFICIENTS
DP          1.0000
LR1        0.50752       1.0000
              DP           LR1

DURBIN-WATSON = 2.2739    VON NEUMANN RATIO = 2.3772    RHO = -0.21916
RESIDUAL SUM =   1.4204      RESIDUAL VARIANCE =  0.32357E-01
SUM OF ABSOLUTE ERRORS=   3.0314
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.0410
RUNS TEST:   15 RUNS,   14 POS,    0 ZERO,    9 NEG  NORMAL STATISTIC =
1.3668
DURBIN H STATISTIC (ASYMPTOTIC NORMAL) =  -1.7511
 MODIFIED FOR AUTO ORDER=1
COEFFICIENT OF SKEWNESS =   0.5266 WITH STANDARD DEVIATION OF 0.4813
COEFFICIENT OF EXCESS KURTOSIS =  -0.3356 WITH STANDARD DEVIATION OF 0.9348

     GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS -  6 GROUPS
OBSERVED  0.0  1.0  8.0  9.0  4.0  1.0
EXPECTED  0.5  3.1  7.8  7.8  3.1  0.5
CHI-SQUARE =    2.8173 WITH  2 DEGREES OF FREEDOM, P-VALUE= 0.244
```