

**Working Paper No. 52/00**

**Patterns in the Relative Price for Different  
Sizes of Fish: Biological Price Generating  
Processes in Fish Farming**

**by**

**Frank Asche  
Atle G. Guttormsen**

SNF-project No. 5050  
"Strategisk program i markedsforskning"

The project is financed by the Research Council of Norway  
and the Norwegian Seafood Exports Council

Centre for Fisheries Economics  
*Discussion paper No. 6/2000*

FOUNDATION FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION  
BERGEN, SEPTEMBER 2000

ISSN 0803-4028

© Dette eksemplar er fremstilt etter avtale  
med KOPINOR, Stenersgate 1, 0050 Oslo.  
Ytterligere eksemplarfremstilling uten avtale  
og i strid med åndsverkloven er straffbart  
og kan medføre erstatningsansvar.

**Patterns in the Relative Price for Different Sizes of Fish:  
Biological Price Generating Processes in Fish Farming\***

Running title: **Relative Salmon Prices**

by

**Frank Asche**

Stavanger University College and

Centre for Fisheries Economics,

Norwegian School of Economics and Business Administration

and

**Atle G. Guttormsen**

Department of Economics and Social Sciences

Agricultural University of Norway

The authors wish to acknowledge the financial support of the Norwegian Research Council and the Norwegian Seafood Exports Council. The views expressed herein are those of the authors, and not necessarily of those organizations. We also wish to thank Trond Bjørndal and Kyrre Rickertsen for helpful comments. Any mistakes, however, are the responsibility of the authors.

## **Abstract**

Fish farming is a biological production process dependent upon biological and environmental conditions. These constraints imply that fish farmers are likely to have a quite similar distribution of different sizes of fish over time. If there are no perfect substitutes for the different sizes of fish in the short-run, this production cycle can cause different relative prices between the different sizes over the year. By studying prices for different sizes of salmon for the period 1992-1998 we show that such relationship exist. This can have important implications when studying aquaculture industries and markets. We look closer at two issues – optimal harvesting decisions and aggregation. Optimal harvest models generally assume this relationship to be constant, and may therefore give incorrect recommendations. Patterns in the relative prices may also make it questionable whether one can aggregate the different sizes into one product.

Keywords: Salmon aquaculture, relative prices, production planning, aggregation.

## **Patterns in the Relative Price for Different Sizes of Fish:**

### **Biological Price Generating Processes in Fish Farming**

Markets for agricultural commodities are often characterized by price cycles resulting from the biological production process and uncertain weather conditions. Even though farmed fish is not an agricultural commodity, farmed fish shares many features with such products. It is a biological production process dependent upon biological and environmental conditions. These constraints imply that fish farmers are likely to have a quite similar distribution of different sizes of fish over time. If there are no perfect substitutes for the different sizes of fish in the short-run, this production cycle can also cause different relative prices between the different sizes of fish over the year. Moreover, if there are patterns in the relative price relationships, some farmers might have the opportunity for profitable production planning by taking this pattern into account. Even though “out of phase” production might be more costly and risky than traditional production, an out of phase premium might account for that.<sup>1</sup> However, the existence of cycles in the relative prices for different sizes may also create additional problems in economic analysis of such industries. We will here look closer at two such issues – optimal harvesting models and aggregation.

During the last decade, there has been developed a number of models for optimal harvesting of farmed fish.<sup>2</sup> In these studies, seasonal patterns in relative price relationship in general and the biology’s influence on this relationship in particular has been neglected. While all these studies conclude that prices are an important factor in the optimality condition, little attention has been given to what this

relationship actually looks like. If there are variations in relative prices, this will then add a new dimension to the optimal harvesting problem.

While differences in the relative prices for different size classes of farmed fish might give farmers profit opportunities, it can create problems in several venues of traditional analysis of the market. During the last decade there has been published a number of studies on demand, forecasting and market structure for farmed fish.<sup>3</sup> In these studies fish of different sizes are treated as one product. Also here, changes in the relative prices for different sizes might be important, since in the extreme, the different sizes might be supplied to different market segments. If differences exist in relative prices for different sizes of fish, it is important to investigate whether one can aggregate over the different sizes. This can be done utilizing only price information by testing for the generalized composite commodity theorem (Lewbel, 1996).

In this paper we will investigate whether there are any patterns in the relative prices for different sizes of salmon in Norway. Salmon is maybe the most successful farmed fish species during the last decades, as global production has increased from a few thousand tonnes in 1980 to about one million tonnes in 1999. Norway is the largest producer with more than 45% of total production. To test for regularities we are using a new data set containing weekly observations of salmon prices for different sizes from 1992 to 1998. Salmon is a temperate species, where the different seasons influence growth strongly. An indication that there exist patterns in the relative prices for different sizes for salmon farmers in Norway is that it is common knowledge that fish farmers in the northern and southern ends of Norway tend to get the best prices for their fish. This is not to surprising since these farmers, because of the weather

conditions, will have fish ready for market at a different time than the average producer. Patterns in the relative prices for different sizes also gives another possible venue for southern producers like Chile to optimize their market behavior when they export to markets where their salmon competes with salmon produced in the northern hemisphere.

Since it is the biology and the farming practices that may lead to patterns in the relative price relationship, we will in the next section give a primer in salmon farming and salmon biology. We continue by presenting the data and testing for regularities in the relative price between different sizes of salmon. We then discuss the implications of the possible patterns in the relative prices; first in a production planning/optimal harvesting context and second, aggregation issues. The last section provides some concluding remarks and policy consequences.

## **Background**

Since the early 1980s there has been a tremendous growth in farmed salmon and salmon trout production. Global production increased from about 12,000 tons in 1980 to about 1,010,000 tons in 1999. Atlantic salmon is the main species with a production of 790,000 tons in 1999, but the quantity of Pacific salmon (mostly coho) is also substantial with a production of about 90,000 tonnes in 1999. Recently production of farmed salmon trout has also become an important part of the salmon market, with a produced quantity of 130,000 tonnes in 1999.<sup>4</sup> In 1997, total production of farmed salmon and salmon trout was for the first time higher than total landings of wild Pacific salmon, and due to further increase in the farmed salmon production, the difference increase.

The main reason for the increased production of farmed salmon is a substantial productivity increase. In Norway, real production cost in 1995 was only 36% of the cost in 1982 (Asche, 1997). Real price has been reduced by a similar magnitude. Norway has always been the largest producer of farmed salmon, although its share of the production has been declining since the early 1980s. In 1999, about 450,000 tonnes of salmon and salmon trout was produced in Norway. Chile has been the fastest growing producer during the 1990s, and produced about 230,000 tonnes of salmon and salmon trout in 1999. Also the UK and Canada are major producers, and smaller quantities are produced in a number of countries.<sup>5</sup>

The production process for farmed salmon is in principle fairly simple. At a hatchery, the salmon eggs and fry are nurtured in freshwater tanks. About 15 months after they hatch, the smolts are transferred to pens immersed in saltwater. There, the fish are fed for up to two years. The salmon can be harvested already at a weight of 1-2 kilos but are normally substantially larger. The most common harvesting weight is 3-5 kilos, but the fish are marketed as large as 8 kilos. The above stages are normally undertaken in distinct plants. The analysis in our study are, in common with most other studies of salmon production, concerned only with the production of farmed fish – the last step in the biological production process.

The farmer's two most important decisions in the production process are: 1) When to transfer the smolts to seawater and 2) when to harvest the fish, i.e. when to start and when to end the rotation.<sup>6,7</sup> Due to biological reasons, smolts can only be transferred to sea during a certain period of the year (March-October). In nature, salmon spawn during late spring, and normally hatch in January. Therefore, all salmon produced in

Norway "are born" in January. Smolts transferred to sea the same year during fall (0 years) is normally smaller than smolts transferred to sea the following year in March-April (1 years). Although smolts in principle can be transferred to sea during all the summer months, the economics of the process makes May the latest time when smolts are actually transferred to sea.<sup>8</sup>

To understand the production cycle in salmon farming, it is necessary to have some knowledge about salmon growth and growth functions. Growth is a function of several biological factors. We can express growth,  $w'(t)$ , as follows

$$w'(t) = f(w(t), temp, light, N(t), F(t), BF(t)) \quad (1)$$

where  $w(t)$  is weight,  $N(t)$  is density,  $F(t)$  is feed and  $BF(t)$  are other biophysical factors. Based on a model of Iwama and Tautz (1981) we can simplify the above by making all other factors than than temperature site specific. This site-specific factor (growth coefficient, GC) is then calculated from empirical salmon growth observations as follows:

$$GC = \left( w_T^{1/3} - w_0^{1/3} \right) 1000 / \sum_{i=0}^T temp_i \quad (2)$$

where  $\sum_{i=0}^T temp_i$  is sum of the average daily temperatures from time  $i = 0$  to  $T$ . From

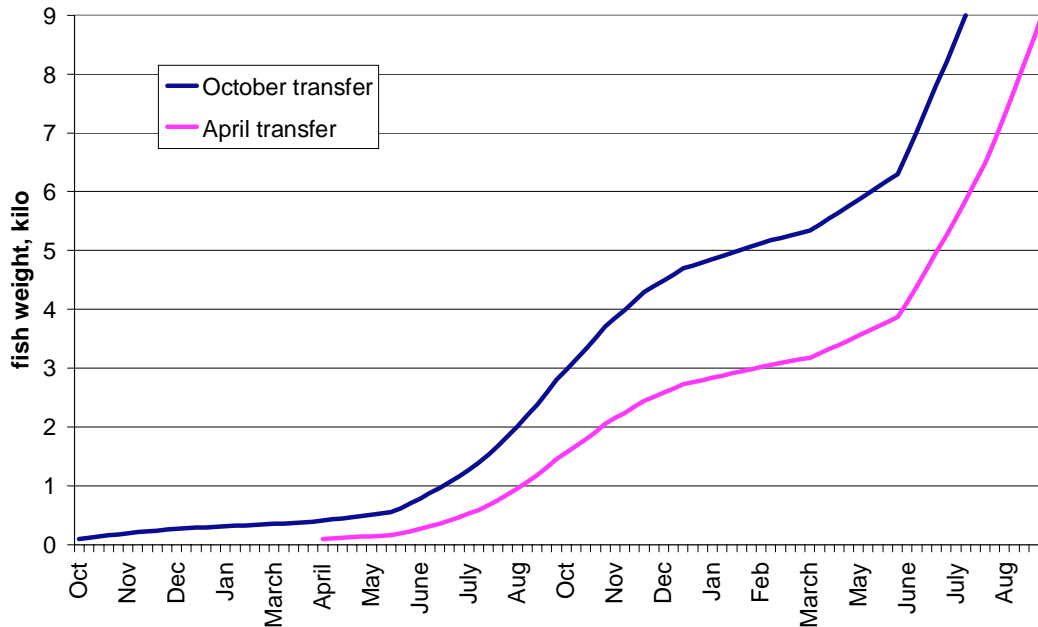
this GC weight at time  $t$  can be calculated as:

$$w_t = \left( w_0^{1/3} + GC \sum_{i=0}^t temp_i / 1000 \right)^3 \quad (3)$$

Depending on when the fish are transferred to sea and where the farm is located, the above equation will give different weight curves. To exemplify, we have estimated weight curves for a typical farm located near Bergen (figure 1).<sup>9</sup> Two curves are



simulated; one is for smolts transferred to seawater in March and the other when transferred in October. The simulated growth-functions show that most of the growth occurs during the summer half of the year and that growth during winter is limited.<sup>10</sup>



**Figure 1.** Example of growth curves. Average fish size for the April and October cohorts, respectively.

Before we turn to the availability of different sizes, some words about sexual maturity for salmon. Atlantic salmon can become sexual mature several times during their lifetime. A sexual mature fish gets a characteristic look and the flesh deteriorates. This fish are not suitable for human consumption and accordingly, its value is close to zero. Hence, sexual maturity of the fish puts a limit on how long a farmer can keep the fish in the pens. Even though sexual maturity can be controlled to some extent, most fish become sexually mature when they are around 5-7 kilo and the water temperature is high.

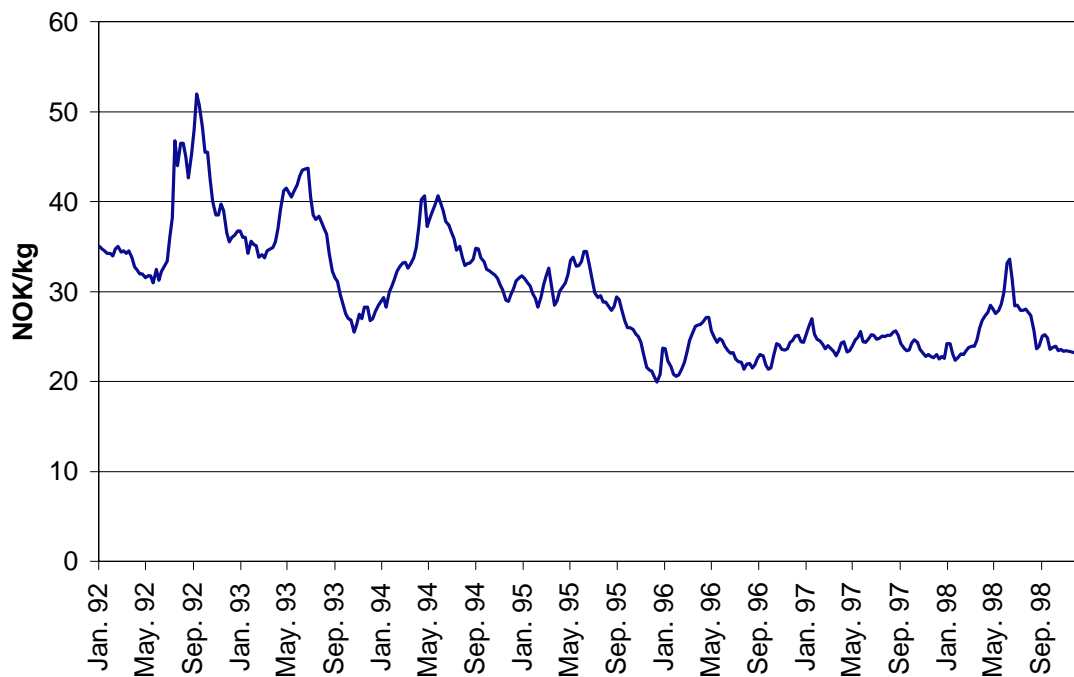
Given that sexual maturity reduces the fish value to basically zero, this puts a limit on the availability of large fish. In particular, independently of their release time, salmon in Norway will have highest risk for sexual maturity during August-September because the water temperature then is at its highest (after two years for fall smolts, and 1.5 years for spring smolts). The smolts transferred to sea during fall will reach 5-6 kilo in April-May, their second year in sea, while the spring smolts will reach the same weight approximately 4 months later. Hence, both groups of fish will have a high probability of reaching sexual maturity in August-September. As a consequence, most farmers will harvest nearly all the large fish during summer, and there will be very little large fish available during fall.

Let us then turn to the availability of small fish. The spring-smolts reaches 1-3 kilo marketing weight between September and December their first year in sea. In January most "spring-fish" is larger than 3 kilos, whereas the "fall-fish" does not reach 1-3 kilo until June. This means that there is little small fish available from December to March. On the other hand, the availability of small fish will be high during early summer. Hence, in periods the availability of both large and small fish will be limited.

### **Regularities in Relative Salmon Prices**

Most farmers face similar environmental/biological conditions and consequently similar biological constraints. If they also have the same objective function (e.g. profit maximization), optimization will give the same production plan and timing for all farmers. The salmon is set out in sea at approximately the same time for all locations. The temperature profile through the year is also very similar, although there are

systematic geographical differences.<sup>11</sup> The most cost-effective plan will then be similar for most producers, resulting in cycles in supply for the different weight classes of salmon. We will in this section examine whether this leads to cycles in the relative price for different weight classes.



**Figure 2.** Nominal salmon prices 3-5 kg. Weekly observations, January 1992-December 1998

Our data set includes weekly producer prices from 1992 to 1998 for the quality category superior salmon.<sup>12</sup> Prices are collected from newsletters from the *Norwegian Fish Farmers Association*. Prices are quoted for different weight classes: 1-2 kg; 2-3 kg; 3-4 kg; 4-5 kg; 5-6 kg and 6-7 kg. The prices for the average of 3-4 kg and 4-5 kg (from now denoted 3-5 kg) are charted in figure 2, and some descriptive statistics are reported in table 1. We see that larger fish on average fetch a somewhat higher price

than smaller fish. Moreover, there is no clear seasonality in the prices. This is also supported when tested for in Bjørndal (1988, 1990) and Asche, Salvanes and Steen (1995).<sup>13</sup> This is as expected based on economic theory, since in a market with well-informed traders arbitrage smooth out systematic seasonal components of price fluctuations. Several studies also find that salmon prices are nonstationary (e.g. Gordon, Salvanes and Atkins (1993); Asche (1996); Asche, Salvanes and Steen (1997) and Asche, Bremnes and Wessells (1999)). This also provides evidence against deterministic seasonality, since a stochastic trend will dominate systematic components.<sup>14</sup>

**Table 1:** Descriptive statistics, absolute prices. Weekly observations, Jan'92-Dec 98

Weight	Average	St.dev	CV	Min.	Max
1-2 kg	27.95	4.97	5.62	17.69	40.25
2-3 kg	27.88	5.60	4.98	18.19	44.00
3-4 kg	29.35	6.35	4.62	20.04	51.00
4-5 kg	30.10	6.66	4.52	19.48	53.00
5-6 kg	30.29	6.80	4.45	18.87	54.00
6-7 kg	30.33	6.74	4.50	18.74	56.50
3-5 kg	29.73	6.46	4.60	19.96	52.00

To investigate the hypothesis that there should exist dependence between the prices of different weight classes of salmon, we calculated correlation's (table 2). There is quite high correlation between prices in levels and first differences for sizes that are close to each other, whereas the correlation between e.g. 1-2 kilos and 5-6 kilos is lower.

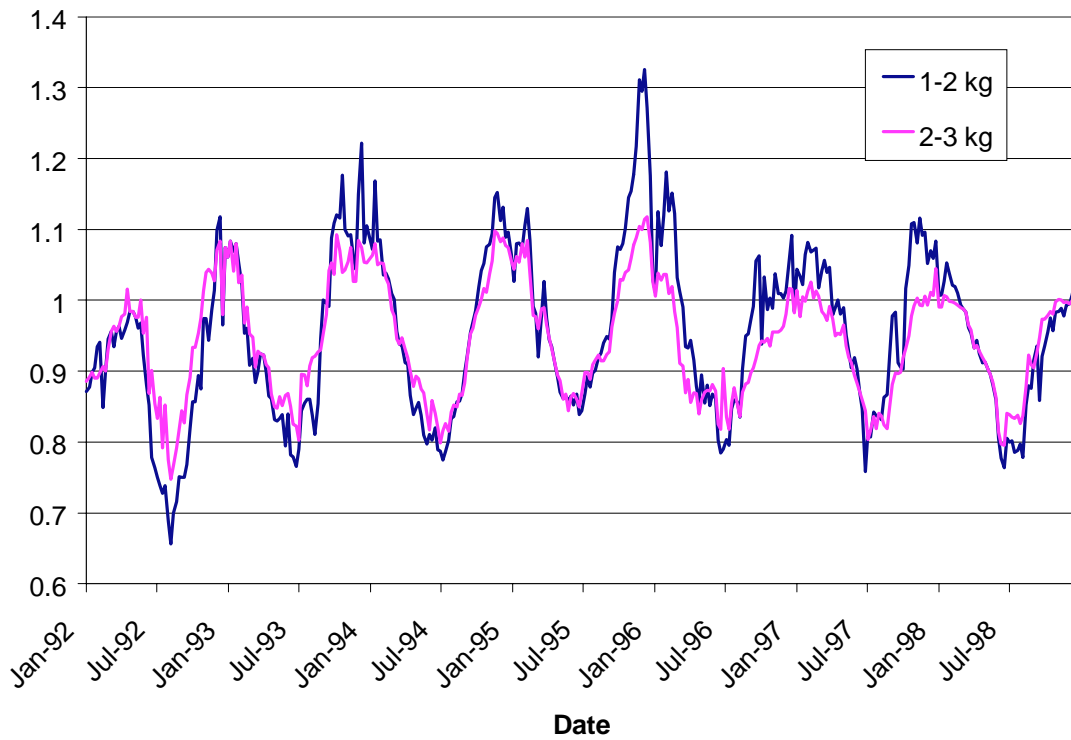
**Table 2.** Price correlations. Weekly observations, Jan '92-Dec 98.

Correlations of prices in levels						
	1-2 kg	2-3 kg	3-4 kg	4-5 kg	5-6 kg	6-7 kg
2-3 kg	0.96	1.00				
3-4 kg	0.84	0.93	1.00			
4-5 kg	0.76	0.87	0.97	1.00		
5-6 kg	0.72	0.83	0.93	0.98	1.00	
6-7 kg	0.71	0.81	0.89	0.94	0.98	1.00
3-5 kg	0.81	0.91	0.99	0.99	0.96	0.92

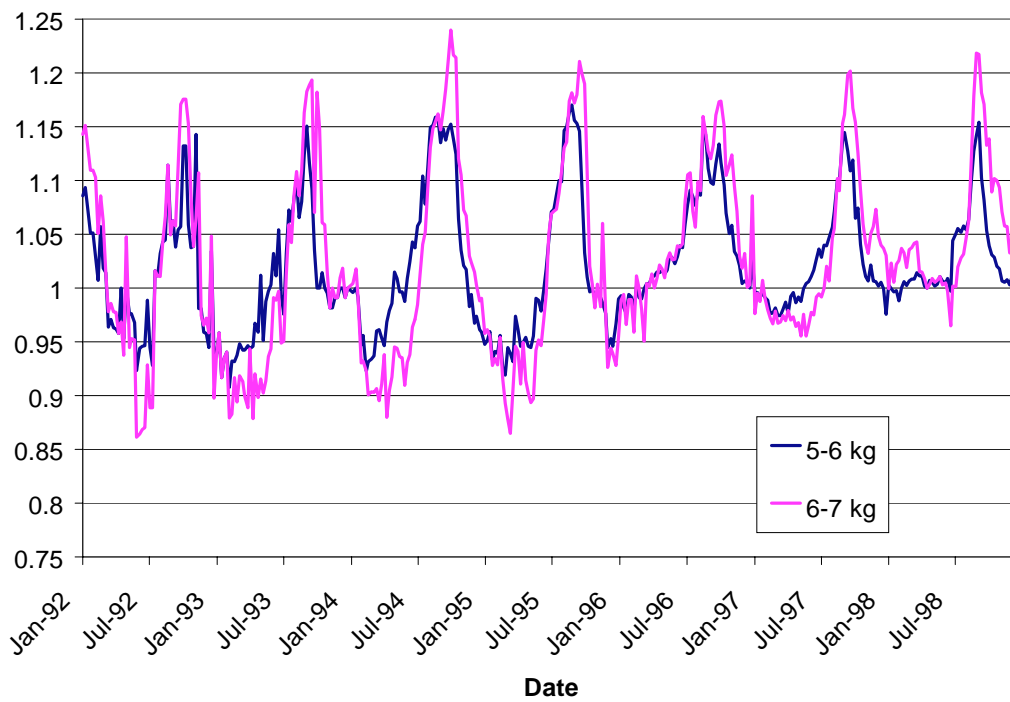
  

Correlations of prices in first differences.						
	1-2 kg	2-3 kg	3-4 kg	4-5 kg	5-6 kg	6-7 kg
2-3 kg	0.52	1.00				
3-4 kg	0.44	0.69	1.00			
4-5 kg	0.32	0.55	0.79	1.00		
5-6 kg	0.28	0.47	0.72	0.79	1.00	
6-7 kg	0.21	0.38	0.59	0.67	0.79	1.00
3-5 kg	0.40	0.65	0.94	0.95	0.80	0.67

We then construct relative prices by dividing the prices for 1-2 kg, 2-3 kg, 5-6 kg and 6-7 kg on 3-5 kg. We use 3-5 kg fish as a "benchmark" for two reasons. First, 3-5 kilos are the most sold weight classes, and second, 3-5 kilos is some sort of an average fish according to production time (it lives around one year in sea, independent of which time we transfer the smolts to sea). Relative prices are shown in figures 3 and 4 for the weight classes smaller than and larger than 3-5 kilos, respectively.



**Figure 3:** Relative salmon prices of 1-2 kilo and 2-3 kilo relative to 3-5 kilo. Weekly observations, January 1992-December 1998



**Figure 4:** Relative salmon prices 5-6 kilo and 6-7 kilo relative to 3-5 kilo. Weekly observations, January 1992-December 1998

The insight from figures 3 and 4 is quite clear. We can see cycles lasting for approximately one year. Salmon in the higher weight classes are relatively more expensive during August and September. In these months 6-7 kilos salmon are sold for about 120% of the prices for 3-4 kilos. In February and March the price of large salmon is about 90-95 percent of 3-4 kilos. The pattern for the smaller salmon is different. The smallest weight classes are relatively most expensive in November, December and January, and relatively cheapest in May, June and July. This corresponds closely to the availability of the different sizes, as discussed in the previous section. The smaller fish is relatively most expensive in January. Then the fall smolts have not yet reached marketable weight, while a major part of the spring smolts is greater than 1-3 kilo. The supply of small fish is relatively low, and the exporters have to pay extra for the farmers to harvest and give up the growth potential for several of the months with the highest growth rate. The prices decrease after January “gradually” relative to the prices of 3-5 kg and reach its “bottom” in June and July.

To formalize the findings in the graph we estimated the regularities statistically for each relative price. Doing this will also help us in eventually forecasting relative prices. There exist several econometric methods for estimation of seasonality. We have estimated a model where seasonality are modeled with trigonometric trends<sup>15</sup>.

The model estimated is then:

$$\frac{p_i}{p_{3-5kilo}} 100 = \beta_0 + \beta_1 \sin \frac{2\pi t}{L} + \beta_2 \cos \frac{2\pi t}{L} + \varepsilon_t \quad (4)$$

With  $p_i$  as the price of fish in weight class  $i$  and  $L$  the number of “seasons” in the year. Hence, in this equation we have the relative price between fish of size  $i$  and 3-5 kg

salmon on the left hand side, and with the exception of the error term only deterministic terms on the right hand side.

**Table 3.** Trigonometrical seasonal functions (relative prices Jan 92-Dec 98)<sup>a</sup>.

$$\frac{P_i}{P_{3-5kilo}} 100 = \beta_0 + \beta_1 \sin \frac{2\pi t}{L} + \beta_2 \cos \frac{2\pi t}{L} + \varepsilon_t$$

Price relations	$\beta_0$	$\beta_1$	$\beta_2$	$R^2$	DW
(1-2 kilos/3-5 kilos)	0.95 (76.10)	-0.01 (-0.44)	0.12 (8.86)	90%	2.01
(2-3 kilos/3-5 kilos)	0.94 (119.5)	0.00 (-0.22)	0.10 (10.08)	92%	2.23
(5-6 kilos/3-5 kilos)	1.02 (163.3)	-0.06 (-7.02)	-0.03 (-3.79)	85%	2.16
(6-7 kilos/3-5 kilos)	1.03 (103)	0.01 (-7.55)	-0.0063 (-0.55)	86%	2.14

<sup>a</sup> Cochrane - Orcutt adjusted for first order autocorrelation.

Table 3 gives the estimation results from equation (4). We can see that our model fits the data very well. An  $R^2$  higher than 0.80 as well as mostly highly significant parameters, indicate that the forecasting ability of our model is fairly good. Hence, the relative price between different sizes is predictable. Given the patterns in figures 3 and 4 this came as no surprise. We can conclude that there are strong regularities in relative prices. The cycles have a time interval of approximately one year.



The existence of cycles in the relative prices may be important in several contexts. We will now turn to two of them – production planning and aggregation.

### **Production planning**

We have by the use of data disaggregated on size shown that there exist systematic patterns in the relative prices between different sizes of salmon. A natural question is then; will this have influence on production planning and optimal harvesting time? The answer to such a question is best illustrated by discussing some concepts of production planning.

Production planning is an integrated process. From restrictions given by environmental conditions, technical installations and other factors of relevance to the business, decisions are taken about release of smolts (number, size and time), and marketing/harvesting (number, size and time). There exist several studies that examine the questions of when to harvest the fish and also related questions as optimal culling and optimal feeding.<sup>16</sup> Most of these studies follow the seminal work by Bjørndal (1988). Bjørndal uses static optimization and comparative statics to explain what happens with the time of harvest under different assumptions about costs, insurance and so fourth. We will use a simple version of Bjørndal's model to illustrate the importance of knowledge of relative price relationships. Bjørndal is looking at one cohort of fish and his analysis concerns a one-time investment.<sup>17</sup>

He starts with the value of a yearclass of fish. This value,  $V(t)$ , is found by multiplying price times quantity, defined by

$$V(t) = p(w)B(t) = p(w)Re^{-Mt}w(t) \quad (5)$$

where  $p(w)$  is the price per kilo fish of weight  $w$ ,  $B(t)$  is the biomass,  $R$  is number of recruits released, and  $M$  is natural maturity.  $M$  can be treated as constant or vary through time with respect to fish size and/or time of the year. Assuming zero cost, the fish farmer will harvest at the time that maximizes the present value of the biomass value as considered at the time of releasing the fish.

$$\underset{\{0 \leq t \leq T\}}{\text{Max}} \pi(t) = V(t)e^{-rt} \quad (6)$$

The first order condition is

$$\pi'(t) = V'(t)e^{-rt} - rV(t)e^{-rt} = 0 \quad (7)$$

and the optimal harvesting time thus satisfies

$$V'(t^*) = rV(t^*) \quad (8)$$

By finding the changes in  $V(t)$  over time and evaluating the separate elements in the biomass value more closely, we can acquire a better understanding of the harvesting rule. This rule says that the fish must be harvested when the marginal increase in the value of the "natural capital" (i.e., fish in the sea) equals the opportunity cost:

$$V'(t^*) = \left\{ \frac{p'(w)}{p(w)} w'(t^*) - M + \frac{w'(t^*)}{w(t^*)} \right\} V(t^*) = rV(t^*) \quad (9)$$

The above expression can be rewritten as

$$\frac{p'(w)}{p(w)} w'(t^*) + \frac{w'(t^*)}{w(t^*)} = r + M \quad (10)$$

We have now arrived at a crucial point. We can see from equation (10) the importance of relative prices, here in the form of change in prices as a function of changes in weight  $p'(w)$ . Most papers typically assume this relationship to be constant and independent of time.<sup>18</sup> However, our results indicate that the sign of  $p'(w)$  varies

through the year, making  $p'(w)$  dependent of time (i.e.  $p'(w,t)$ ). This changes the optimization problem, and can have important implications for calculation of optimal slaughtering time and for the transfer of smolts to sea in spring or fall. A drawback with the fact that the relative price changes between different sizes over the year is that the mathematics becomes less tractable. If one is to take the pattern in relative prices between sizes into account, it will be impossible to find analytical solutions, and we need to use numerical methods to solve the problem. This also means that we cannot say anything in general about the direction of the changes in the rotation time due to the cycles in the relative prices.

### **Aggregation**

The existence of cycles in the relative prices also raises the possibility that there is not a single market for salmon, but several markets for different sizes of salmon. It is therefore of interest to test whether the cycles in the relative price between sizes imply different markets, or if the different sizes can be aggregated into one good.<sup>19</sup> The first criterion used for aggregation in economics is the composite commodity theorem of Hicks (1936) and Leontief (1936). This criterion states that if prices of a group of goods move proportionally over time, these goods can be represented by a single price and quantity. Hence, only information about prices is necessary to investigate whether the goods can be aggregated – one does not need information about consumer preferences as with different separability concepts.

A problem with the composite commodity theorem in empirical work is that for the theorem to hold, the prices must be exactly proportional. However, Lewbel (1996) provides an empirical useful generalization of the theorem that allows for some

deviations from proportionality.<sup>20</sup> There are several ways to test for the generalized composite commodity theorem. One simple way when prices are nonstationary is to investigate whether the ratio of any two prices is stationary. If so, these two goods can be aggregated according to the generalized composite commodity theorem.<sup>21</sup>

**Table 4.** Dickey fuller tests for unit roots. Weekly observations, Jan'92-Dec 98

Weight	$\tau$
1-2 kg	-1.95 (2)
2-3 kg	-1.74 (2)
3-4 kg	-2.16 (2)
4-5 kg	-2.22 (2)
5-6 kg	-2.46 (2)
6-7 kg	-2.69 (2)
3-5 kg	-2.18 (2)
Relative prices	
1-2 kg/3-5 kg	-3.352*(3)
2-3 kg/3-5 kg	-3.353*(3)
5-6 kg/3-5 kg	-3.954**(3)
6-7 kg/3-5 kg	-4.222**(3)

$\tau$  is the test statistic for the null hypothesis  $\rho=0$ , i.e., at least one unit roots, with number of lags in the test in the parenthesis. Critical values are given in MacKinnon (1991)

\*Reject the null hypothesis at 10% level of significance

\*\*Reject the null hypothesis at 5% level of significance.

As mentioned above, several studies have indicated that salmon prices are nonstationary. When we test the prices used here for stationarity using Dickey-Fuller tests, we also find the prices to be nonstationary in levels (table 4). As the relative prices are the ratios between the prices of salmon of different sizes and the 3-5 kilo salmon, a test for whether the relative prices are stationary is then a test for the generalized composite commodity theorem. All the relative prices are stationary (table 4), and we can therefore conclude that one can aggregate salmon of different sizes and treat them as one commodity even if there are cycles in the relative prices. This is good news, since it implies that even if there are cycles in the relative prices of salmon of different sizes, one need not be concerned with them when carrying out market analysis.

### **Concluding Remarks**

Biological and environmental constraints in fish farming indicate that there may exist a production cycle for different sizes of the fish. Provided that there are no perfect substitutes for the different sizes in the short-run, this can also create regularities in the relative prices for different sizes. When investigating whether there are patterns in the relative price for different sizes of salmon using weekly prices for different sizes of salmon for the period 1992-1998, our results indicate that cycles in the relative prices are present. The cycles may have important implications for analysis of the production process and for market analysis. We look closer at two such issues, optimal harvesting and aggregation.

We have by the use of a simple harvesting model, developed by Bjørndal (1988), illustrated the importance of relative price relationship in determining the optimal

harvesting times. Most papers assume the relative price relationship to be constant. We will argue that this, in many cases, is done more for the sake of mathematical convenience rather than being based on studies of the actual price relationships. Making a harvesting model where the relative prices of different sizes vary through the year will give different results from one with constant relationship. However, the changes will differ from case to case, and we cannot say anything in general about the direction since the problem must be solved numerically.

Patterns in relative prices may create problems for traditional analysis of the market, as this might imply a segmented market for fish of different sizes. However if one can aggregate over the different sizes, this potential problem disappears. We have tested if this is possible by testing for the generalized composite commodity theorem. The results indicate that the generalized composite commodity theorem holds. Hence, one can treat salmon as one commodity despite the cycles in relative prices.

One further issue that patterns in relative prices for different sizes might have implications for is regulations of the industry. Most places, salmon farmers face a set of regulations that influence their production decisions.<sup>22</sup> There are several reasons for this, including environmental concerns, regional policy and market stabilization. Norwegian farmers in particular face some special regulations as Norway as the largest producer has been the target for a number of trade complaints.<sup>23</sup> As a response to pressures from the European Union (EU) to help stabilizing salmon prices in the EU, nontradable feed quotas that limit the amount of feed per farm were introduced. Given that the farmers can substitute between different input factors, these quotas are not technologically neutral.<sup>24</sup> Moreover, since there are a number of different varieties

of feed, substitution inside the category feed may be more important than substitution between feed and other inputs. The constraint that feed quotas puts on the technology will lead to a more homogenous production, as it makes deviations from the production technology that maximize output per kilo of feed more costly. Hence, it works against production out of phase, and accordingly, market based production planning by exploiting the patterns in the relative prices for different sizes. Given the scope of the feed regulations, to help stabilizing the salmon prices in the EU by restricting supply, this regulation is even more interesting. In the EU market one tends to prefer the average sized fish, while other markets, and particularly Japan and the Far East often prefer large or small fish. Hence, in a situation where it would be useful for the Norwegian industry to be able to sell more fish outside Europe, the feed quotas make it optimal for farmers to produce more salmon that is better suited for the European market. The main reason for this is that the regulations restrict how much the farmers can exploit the market opportunities caused by regularities in the relative prices between different sizes.

## References

- Anderson, J. L., and Q. S. W. Fong. 1997. Aquaculture and International Trade. *Aquaculture Economics and Management* 1:29-44.
- Arnason, R. 1992. Optimal Feeding Schedules and Harvesting Time in Aquaculture. *Marine Resource Economics* 70:15-35.
- Asche, F. 1996. "A System Approach to the Demand for Salmon in the European Union. *Applied Economics* 28:97-101.
- Asche, F. 1997. Trade Disputes and Productivity Gains: The Curse of Farmed Salmon Production. *Marine Resource Economics* 12:67-73.
- Asche, F., T. Bjørndal, and K. G. Salvanes. 1998. The Demand for Salmon in the European Union: The Importance of Product Form and Origin. *Canadian Journal of Agricultural Economics*. 46:69-82.
- Asche, F., H. Bremnes, and C. R. Wessells. 1999. Product Aggregation, Market Integration and Relationships Between Prices: An Application to World Salmon Markets. *American Journal of Agricultural Economics* 81:568-581.
- Asche, F., K. G. Salvanes, and F. Steen. 1995 Er mere regulering svaret på utfordringene i norsk oppdrettsnæring? : en teoretisk og empirisk analyse av laksesykluser (in Norwegian) Are more regulations the answer to the challenges for Norwegian Salmon Farming ? An analysis of salmon cycles. SNF-report no. 44/1995. SNF: Bergen.
- Asche, F., K. G. Salvanes, and F. Steen. 1997. Market Delineation and Demand Structure. *American Journal of Agricultural Economics* 79:139-50.
- Asche, F., and R. Tveterås 1999. Modeling Production Risk with a Two-Step Procedure. *Journal of Agricultural and Resource Economics*. 24 424-39.
- Bjørndal, T. 1988. Optimal Harvesting of Farmed Fish. *Marine Resource Economics* 50:139-59.
- Bjørndal, T., 1990 *The Economics of Aquaculture*. Blackwell Scientific Publications, Oxford.
- Bjørndal, T., and K. G. Salvanes. 1995. Gains from Deregulation? An Empirical Test for Efficiency Gains in the Norwegian Fish Farming Industry. *Journal of Agricultural Economics* 46:113-126.
- Bjørndal, T., K. G. Salvanes, and J. Andreassen. 1992. The Demand for Salmon in France: Effects of Marketing and Structural Change. *Applied Economics* 24:1027-34
- Bowerman, B. L., and R. T. O'Connell. 1993. *Forecasting and time series: An applied approach*. Duxbury Press, Belmont, California.



- Cacho, O. J., H. Kinnucan, and U. Hatch. 1991. Optimal Control of Fish Growth. *American Journal of Agricultural Economics* 73:174-83.
- DeVoretz, D. J. and K. G. Salvanes. 1993. Market Structure for Farmed Salmon. *American Journal of Agricultural Economics* 75:227-33.
- Eales, J., C. A. Durham, and C. R. Wessells. 1997 General Models of Japanese Demand for Fish. *American Journal of Agricultural Economics* 79:1153-63.
- Einen, O., I. Holmefjord, T. Åsgård, and C. Talbot. 1995. Auditing Nutrient Discharges from Fish Farms: Theoretical and Practical Considerations. *Aquaculture Research* 26:701-713.
- Forsberg, O. I. 1999. Optimal Harvesting of Farmed Atlantic Salmon a Two Cohort Management Strategies and Different Harvest Operation Restrictions. *Aquaculture Economics and Management* 3:143-158.
- Gordon, D. V., K. G. Salvanes, and F. Atkins. 1993. A Fish is a Fish is a Fish: Testing for Market Linkage on the Paris Fish Market. *Marine Resource Economics* 8:331-343.
- Gu, G. and J. L. Anderson. 1995. Deseasonalized State-Space Time Series Forecasting with Application to the US Salmon Market. *Marine Resource Economics* 10:171-85.
- Guttormsen, A. 1999. Forecasting Weekly Salmon Prices, Risk Management in Fish Farming. *Aquaculture Economics and Management*. 3:159-166.
- Hean, R. L. 1994. An Optimal Management Model for Intensive Aquaculture -An Application in Atlantic Salmon. *Australian Journal of Agricultural Economics* 38:31-47.
- Heaps, T. 1995. Density Dependent Growth and the Culling of Farmed Fish. *Marine Resource Economics* 10:285-298.
- Herrmann, M., R. C. Mittelhammer, and B. H. Lin. 1992 Applying Almon-Type Polynomials in Modelling Seasonality of the Japanese Demand for Salmon. *Marine Resource Economics* 7:3-13.
- Herrmann, M., R. C. Mittelhammer, and B. H. Lin. 1993. Import Demand for Norwegian Farmed Atlantic Salmon and Wild Pacific Salmon in North America Japan and the EC. *Canadian Journal of Agricultural Economics* 41:111-125.
- Hicks, J. 1936. *Value and Capital*, London: Oxford University Press.
- Hylleberg, S. 1992 *Modelling Seasonality*, London: Oxford University Press.
- Iwama, G. K., and A. F. Tautz. 1981 A Simple Growth Model for Salmonids in Hatcheries. *Canadian Journal of Fisheries and Aquatic Sciences* 38:649-656.
- Karp, L., A. Sadeh, and W. L. Griffin. 1986 Cycles in Agricultural Production: The

- Case of Aquaculture. *American Journal of Agricultural Economics* 68: 553-561.
- Kinnucan, H. W., and Y. Miao. 1999. Media-Specific Returns to Generic Advertising: The Case of Catfish. *Agribusiness* 15:81-99.
- Kinnucan, H. W., and M. Thomas (1997) Optimal Media Allocation Decisions for Generic Advertiser, *Journal of Agricultural Economics* 48:425-441.
- Leontief, W. 1936 Composite Commodities and the Problem of Index Numbers. *Econometrica* 4:39-59.
- Lewbel, A. 1996. Aggregation without Separability: A Generalized Composite Commodity Theorem. *American Economic Review* 86:524-561.
- Lillestøl, J. 1986. On the Problem of Optimal Timing of Slaughtering in Fish Farming. *Modeling, Identification and Control* 7:199-207.
- MacKinnon, J. 1991. Critical Values for Co-integration Tests. In *Long Run Economics Relationship*, RF. Engle and C. W. J. Granger (eds) Oxford University Press, Oxford.
- Mistiaen, J.A., and I. Strand 1998 Optimal Feeding and Harvest Time for Fish with Weight-Dependent Prices. *Marine Resource Economics* 13:231-246.
- Osborn, D. R. 1993 Discussion: Seasonal Cointegration. *Journal of Econometrics*, 55:299-304.
- Salvanes, K. G. 1989. The Structure of the Norwegian Fish Farming Industry: An Empirical Analysis of Economics of Scale and Substitution Possibilities. *Marine Resource Economics* 6:349-373
- Salvanes, K. G. 1993 Public Regulation and Production Factor Misallocation, a Restricted Cost Function for the Norwegian Aquaculture Industry. *Marine Resource Economics* 8:40-64.
- Steen, F., and K.G. Salvanes 1999. Testing for Market Power using a Dynamic Oligopoly Model. *International Journal of Industrial Organization* 17:147-177.
- Talbot, C. 1993. Some Aspects of the Biology and Feeding and Growth in Fish. *Proceedings of the Nutrition Society* 52:403-316.
- Tveterås, R. 1999. Production Risk and Productivity Growth: Some Findings for Norwegian Salmon Aquaculture. *Journal of Productivity Analysis* 12:161-179.
- Vukina, T., and J.L. Anderson. 1994 Price Forecasting with State-Space Models of Nonstationary Time Series: Case of the Japanese Salmon Market. *Computers and Math, with Applications* 27:45-62.
- Wessells, C, R, and J. E. Wilen. 1993. Economic Analysis of Japanese Household

Demand for Salmon. *Journal of the World Aquaculture Society* 34:361-378.

Wessells, C. R. and J. E. Wilen 1994. Seasonal Patterns and Regional Preferences in Japanese Household Demand for Seafood. *Canadian Journal of Agricultural Economics* 42:87-103.

Zidack, W., H. W. Kinnucan, and U. Hatch. 1992. Wholesale- and Farm-level impacts of Generic Advertising: The Case of Catfish. *Applied Economics* 24:959-968.

## Fotnotes

---

<sup>1</sup> For a discussion of production risk in fish farming, see Asche and Tveterås (1999) and Tveterås (1999).

<sup>2</sup> See e.g. Karp, Sadeh and Griffin (1986), Lillestøl (1987), Bjørndal (1988, 1990), Arnason (1991), Cacho, Kinnucan and Hatch (1991), Hean (1994), Heaps (1995), Mistiaen and Strand (1998), Forsberg (1999).

<sup>3</sup> See e.g. Bjørndal, Salvanes and Andreassen (1992), Zidack, Kinnucan and Hatch (1992), DeVoretz and Salvanes (1993), Gordon, Salvanes and Atkins (1993), Herrmann, Mittelhammer and Lin (1992; 1993), Gu and Anderson (1994), Wessells and Wilen (1993; 1994), Vukina and Anderson (1995), Asche (1996; 1997), Asche, Salvanes, and Steen (1997), Eales, Durham and Wessells (1997), Kinnucan and Thomas (1997), Asche, Bjørndal and Salvanes (1998), Steen and Salvanes (1999), Asche, Bremnes and Wessells (1999) and Kinnucan, and Miao (1999). The only study concerned with size dependent prices is Guttormsen (1999).

<sup>4</sup> The source for these statistics are Bill Atkinson's News Report.

<sup>5</sup> In 1999, the UK production was about 126,000 tonnes and the Canadian production was about 73,000 tonnes. The Faroe Islands and the US are also relatively important producers with a production of respectively 34,000 and 22,000 tonnes in 1999.

<sup>6</sup> This problem can be denoted as a rotation problem, very similar to the well known forestry rotation problem first solved by Faustmann in 1849.

<sup>7</sup> The farmer can to some degree also control growth by the amount of feed, but studies by Talbot (1993) and Einen, Holmefjord, Åsgård and Talbot (1995) shows that all other feeding regimes than "feeding to saturation" will increase feed conversion ratio and consequently also cost substantially.

---

<sup>8</sup> The most important issue here is to make room for the next generation of fish in the freshwater tanks that are used to bring the salmon fry up to smolts. However, the forgone growth during a part of the best growing season also plays a part.

<sup>9</sup> Approximately 70% of Norwegian fish farms are located in areas with climatic conditions that are very similar to the conditions around Bergen.

<sup>10</sup> The growth function stops rather abruptly, since growth after fall in the second year is irrelevant due to the fact that the fish then become sexually mature (see discussion in the next paragraph)

<sup>11</sup> The water temperatures are lower the further north one gets. Hence, growth tends to be slower at northern farms.

<sup>12</sup> Superior salmon is most common quality category, and makes up more than 80% of the production.

<sup>13</sup> However, it should be noted that Gu and Anderson (1995) find seasonality to have some importance in studies of wholesale salmon price indices.

<sup>14</sup> It is also possible to have stochastic seasonal components. However, it is not likely to be an important issue, since it in most cases are difficult to find economic explanations for such components (Osborn, 1994).

<sup>15</sup> This method is suggested in Bowerman and O'Connell (1993). Econometric modeling of seasonality is thoroughly presented in Hylleberg (1992).

<sup>16</sup> See footnote 2.

<sup>17</sup> Bjørndal also illustrates the optimal harvesting when a new cohort is released immediately after harvesting, i.e., the rotation problem.

<sup>18</sup> Mistiaen and Strand (1998) consider the question when prices for different sizes are piecewise continuous.

---

<sup>19</sup> A discussion of the relationship between market integration and aggregation is provided in Asche, Bremnes and Wessells (1999).

<sup>20</sup> As always, there is some cost involved. Aggregates constructed using the generalized composite commodity theorem cannot be used in welfare comparisons.

<sup>21</sup> A similar, but alternative way to test for the generalized composite commodity theorem when prices are nonstationary is to investigate whether the Law of One Price hold for the prices in question (Asche, Bremnes and Wessells, 1999).

<sup>22</sup> See Salvanes (1989; 1993) and Bjørndal and Salvanes (1995) for a discussion of the various regulations of the fish farming industry, and their effects on efficiency etc.

<sup>23</sup> For a discussion of trade issues, see Asche (1997) and Anderson and Fong (1997). Also, although Norway has received most attention in the context, an anti-dumping complaint was filed against Chilean farmers in the US in 1998.

<sup>24</sup> Studies that provides evidence of input factor substitutability in salmon farming are Salvanes (1988; 1993), Bjørndal and Salvanes (1995), Asche and Tveterås (1999) and Tveterås (1999).