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Patterns in the Relative Price for Different Sizes of Farmed Fish

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Abstract *Fish farming is a biological production process dependent upon biological and environmental conditions. These constraints imply that different fish farmers are likely to have a 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 1992–98, we show that such patterns exist. This can have important implications when studying aquaculture industries and markets. We look closer at two issues — optimal harvesting decisions and aggregation.*

Key words Aggregation, optimal harvesting, relative prices, salmon aquaculture.

Introduction

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, the industry faces many of the same issues characteristic of producers of terrestrial based products. Fish farming is a biological production process dependent upon biological and environmental conditions. These constraints imply that different fish farmers are likely to have a 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 different sizes of fish over the year. Moreover, if there are patterns in the relative price relationships, some farmers may be able to increase profits by taking this information into account. Even though "out-of-phase" production might be more costly and risky than traditional production, an out-of-phase premium can provide the necessary incentives. However, the existence of cycles in the relative prices for different sizes may also create additional problems in economic analysis of such industries. In this paper, we examine two issues that are likely to be impacted by relative prices — optimal harvesting and aggregation.

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During the last decade, a number of models have been developed to determine optimal harvest time for farmed fish (*e.g.*, Karp, Sadeh and Griffin 1986; Bjørndal 1988, 1990; Arnason 1992; Cacho, Kinnucan and Hatch 1991; Hean 1994; Heaps 1995; and Mistiaen and Strand 1998). In these studies, seasonal patterns in relative price relationships, in general, and biology's influence on this relationship, in particular, have been neglected. While all these studies conclude that prices are an important factor in the optimality condition, little attention has been given to the form of this relationship. If there are variations in relative prices for different sizes of fish over time, this will 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 additional profit opportunities, they can also create problems in several venues of traditional analysis of the market. During the last decade, a number of studies have been published on demand, forecasting, and market structure for farmed fish.[1] In these studies, fish of different sizes are treated as one product. However, 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 investigate whether there have been any patterns in the relative prices for different sizes of salmon in Norway. Salmon has been perhaps the most successful farmed fish species during the last decades, as global production has increased from a few thousand tons in 1980 to about one million tons in 1999. Norway is currently the largest producer, with more than 45% of total production. Salmon is a temperate species, where the different seasons strongly influence growth. An indication of patterns in relative prices of different sizes for salmon in Norway is that fish farmers in the northern and southern ends tend to receive the highest prices. This is likely due to the time of the year these farmers harvest. Patterns in the relative prices for different sizes also give 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 farming practices that may lead to patterns in the relative price relationship, a primer in salmon farming and salmon biology will be provided in the next section. 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 relation to aggregation and then in relation to production planning and optimal harvesting. The last section provides some concluding remarks and policy consequences.

Background on Salmon Farming

Since the early 1980s, there has been 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. In 1999, Atlantic salmon was the main species with a production of 790,000 tons. Pacific salmon (mostly coho) accounted for a total of about 90,000 tons. Recently, production of farmed salmon trout has also

[1] See *e.g.*, Gordon, Salvanes and Atkins (1993); Herrmann, Mittelhammer, and Lin (1992, 1993), Gu and Anderson (1994); Wessells and Wilen (1994); Vukina and Anderson (1994); Asche (1996, 1997); Asche, Salvanes, and Steen (1997); Eales, Durham and Wessells (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).

become an important part of the salmon market, with a produced quantity of 130,000 tons in 1999 (Atkinson 2000). In 1997, total production of farmed salmon and salmon trout was, for the first time, higher than total landings of wild Pacific salmon. Due to further increase in the farmed salmon production, the difference continues to widen.

The main reason for the increased production of farmed salmon is substantial productivity increase (Tveterås 2000). In Norway, the 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 production has been declining since the early 1980s. In 1999, about 450,000 tons of salmon and salmon trout was produced in Norway. Chile was the fastest growing producer during the 1990s, and produced about 230,000 tons 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.[2]

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. Salmon can be harvested at a weight of 1–2 kilos, but are usually harvested at larger sizes. The most common harvesting weight is 3–5 kilos. However, fish are marketed as large as 8 kilos. The above stages are normally undertaken in distinct plants. This analysis, as is common in most studies of salmon production, is concerned only with the last step in the production process.

Two of the 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 end the rotation.[3] Due to biological reasons, smolts can only be transferred to sea during a certain period of the year (March-October in Norway). 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) are normally smaller than smolts transferred to sea the following year in March-April (1 year). Although smolts can be transferred to sea during all the summer months, the economics of the process make May the latest month that smolts are actually transferred to sea.[4]

To understand the production cycle in salmon farming, it is helpful 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:

$$w'(t) = f\left[w(t), temp, light, N(t), F(t), BF(t)\right] \tag{1}$$

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 factors, with the exception of temperature, site specific. This site-specific factor (growth coefficient, GC) can then be calculated from empirical observations of salmon growth as follows:

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[2] In 1999, UK production was about 126,000 tons and Canadian production was about 73,000 tons. The Faroe Islands and the US are also relatively important producers, with production of 34,000 and 22,000 tons, respectively, in 1999.

[3] The farmer can, to some degree, also control growth by the amount of feed, but studies by Talbot (1993) and Einen, *et al*. (1995) show that all other feeding regimes than "feeding to saturation" will substantially increase the feed conversation ratio and consequently cost.

[4] 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.

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

where $\sum_{i=0}^{T} temp_i$ is the sum of the average daily temperatures from time i = 0 to T. From equation (2) weight at time t can be calculated as:

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

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, Norway (figure 1).[5] Two curves are simulated; one is for smolts transferred to seawater in March, the other when smolts are transferred in October. The simulated growth-functions show that most of the growth occurs during the summer and that growth during winter is limited.[6]

Before we turn to the availability of different sizes of fish, some words about sexual maturity of salmon are in order. Atlantic salmon can become sexual mature

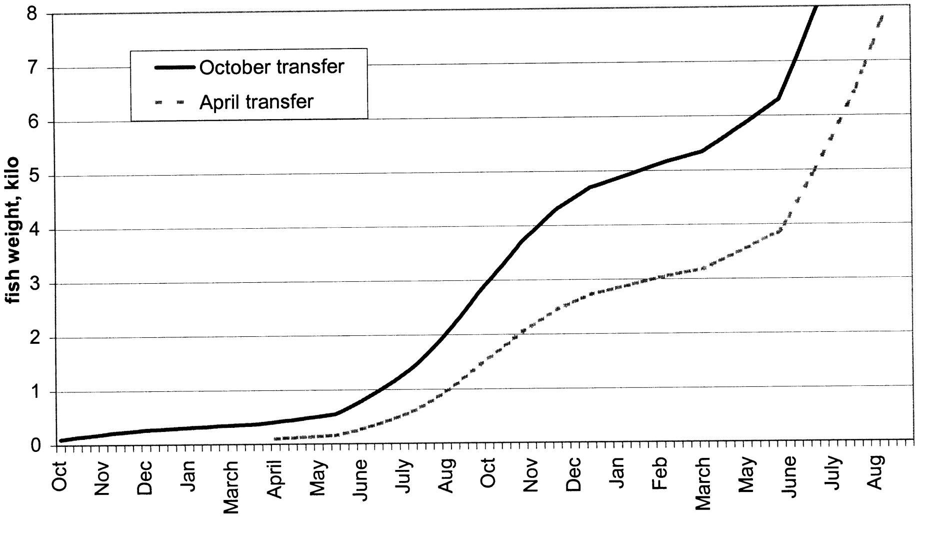

Figure 1. Average Growth Curves for the April and October Cohorts

[5] Approximately 70% of Norwegian fish farms are located in areas with climatic conditions that are very similar to the conditions around Bergen.

[6] The growth function stops rather abruptly, reflecting when the fish become sexually mature (see discussion in the next paragraph).

several times during their lifetime. A sexually mature fish is visibly identifiable and its flesh detoriates. Such fish are not suitable for human consumption and, accordingly, their 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 weight reaches between 5 and 7 kilos and the water temperature is relatively high.

Given that sexual maturity reduces the fish's value to basically zero, this puts a limit on the availability of large fish. Independent of their release time, salmon in Norway have the highest probability of reaching for sexual maturity during August-September, because the water temperature 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. The spring smolts will reach the same weight approximately 4 months later. Hence, both groups of fish will have a higher probability of reaching sexual maturity in August-September. As a consequence, most farmers harvest nearly all the large fish during the summer, leaving few large fish to be marketed later in the year.

Let us then turn to the availability of small fish. The spring-smolts reach 1–3 kilo market weight between September and December of their first year in sea. In January, most "spring-fish" are larger than 3 kilos, whereas the "fall-fish" will not reach 1–3 kilos until June. Thus, relatively few small fish are available from December to March. On the other hand, the availability of small fish will be high during early summer. Hence, the availability of both large and small fish is expected to vary during the year.

Regularities in Relative Salmon Prices

Most farmers face similar environmental and 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 will be set out in seawater at approximately the same time for all locations. Given that the temperature profile through the year will also be similar, the most cost-effective plan will be similar for most producers, resulting in cycles in supply for the different weight classes of salmon.[7] In this section, we examine whether this leads to cycles in the relative prices for different weight classes of fish.

Our data set includes weekly producer prices from 1992 to 1998 for the quality category "superior salmon." Superior salmon is the most common quality category, and makes up more than 80% of the production. Prices were collected from newsletters of the *Norwegian Fish Farmers Association*. Prices were quoted for six weight classes: 1–2 kg, 2–3 kg, 3–4 kg, 4–5 kg, 5–6 kg, and 6–7 kg. The average prices for 3–4 kg and 4–5 kg fish (from now denoted 3–5 kg) are charted in figure 2. Some descriptive statistics are reported in table 1. We aggregate 3–4 kg and 4–5 kg fish for use as a "benchmark" category for two reasons. First, 3–5 kilos is the most common weight classes, and second, 3–5 kilos is an average fish according to production time (it lives around one year in the sea, independent of which time we transfer the smolts to sea).

The data reveals that larger fish, on average, fetch a somewhat higher price than smaller fish. Moreover, there was no clear seasonality in the prices. The lack of sea-

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[7] The water temperatures are lower the further north one gets. Hence, growth tends to be slower at northern farms.

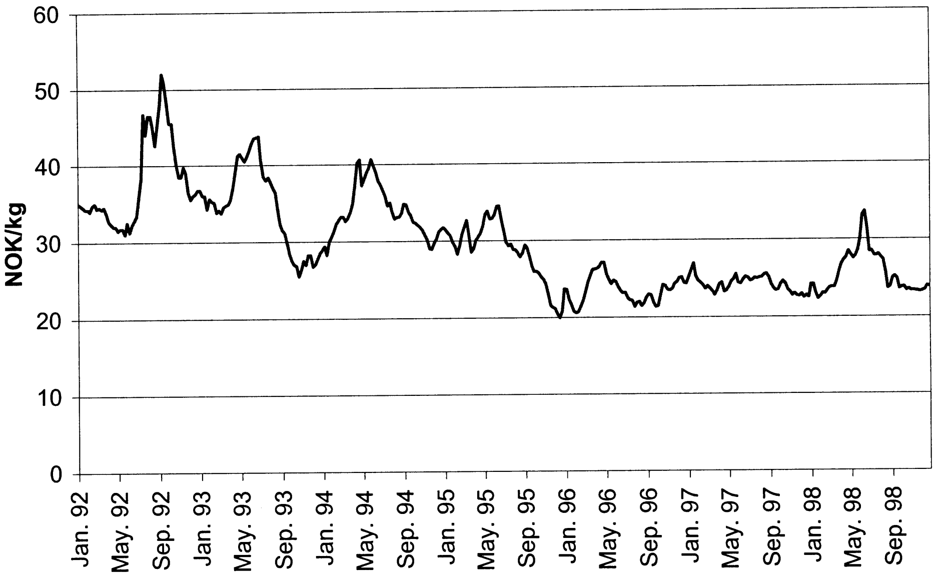

Figure 2. Nominal Prices for 3–5 kg Norwegian Salmon

sonality was also supported in tests conducted by Bjørndal (1988, 1990).[8] This is as expected based on economic theory, since in a market with well-informed traders, arbitrage should smooth out systematic seasonal components of price fluctuations. Several studies also find that salmon prices are nonstationary (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.[9]

To get an indication of whether there has been dependence between the prices of different weight-classes of salmon, we calculated correlations (table 2).[10] There is quite a high correlation between prices in levels and first differences for sizes that are close to each other, whereas the correlation between 1–2 kg fish and 5–6 kg fish is lower. We then constructed relative prices by dividing the prices for 1–2 kg, 2–3 kg, 5–6 kg, and 6–7 kg by the benchmark 3–5 kg. The resulting relative price series are shown in figure 3. The insight from figure 3 is clear. We 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 kilo salmon are sold for about 120% of the price of 3–5 kilo fish. In February and March, the price of large salmon is about 90–95% that of the 3–5 kilo fish. 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. These pat-

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[8] However, it should be noted that Gu and Anderson (1995) found seasonality in studies of wholesale salmon price indices.

[9] It is also possible to have stochastic seasonal components. However, it is not likely to be an important issue, since, in most cases, it is difficult to find economic explanations for stochastic seasonal components (Osborn 1993).

[10] This is a much used method for preliminary analysis of the existence of relationships between prices, see Vukina and Anderson (1993).

Table 1
Descriptive Statistics for Weekly Norwegian Salmon Prices, 1992–98

Weight	Average[a]	St. dev	CV	Min.	Max.
1–2 kg	27.95	4.97	0.18	17.69	40.25
2–3 kg	27.88	5.60	0.20	18.19	44.00
3–4 kg	29.35	6.35	0.22	20.04	51.00
4–5 kg	30.10	6.66	0.22	19.48	53.00
5–6 kg	30.29	6.80	0.22	18.87	54.00
6–7 kg	30.33	6.74	0.22	18.74	56.50
3–5 kg	29.73	6.46	0.22	19.96	52.00

[a] Prices are nominal NOK per kg.

Table 2
Price Correlations by Weight Class for Norwegian Salmon

	1–2 kg	2–3 kg	3–4 kg	4–5 kg	5–6 kg	6–7 kg
Correlation of prices in levels:						
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:						
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

terns correspond closely to the availability of the different sizes, as discussed in the previous section. The smaller fish are relatively most expensive in January, because at that time the fall smolts have not yet reached marketable weight, while a major portion of the fish based on the spring smolts is greater than 1–3 kilos. Thus, the supply of small fish is relatively low, and exporters have to pay a premium to entice farmers to harvest and forego future growth during a time when growth rates are the highest. Prices for small fish gradually decrease after January relative to the price for 3–5 kilo fish. They reach their “bottom” in June and July.

To formalize the findings, we estimated the patterns statistically for each relative price. Doing this will also help us in eventually forecasting relative prices. There are several econometric methods for estimating seasonality. We estimated a model where seasonality is represented with trigonometric trends. The model estimated is then:

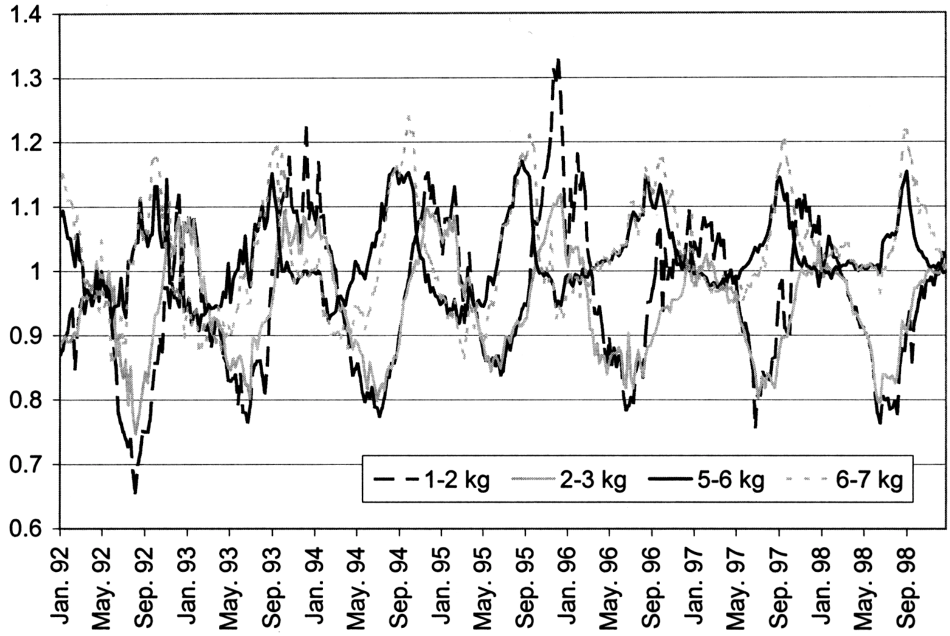

Figure 3. Prices of 1–2, 2–3, 5–6, and 6–7 kg Norwegian Salmon Relative to 3–5 kg

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

where p_i is the price of fish in weight class i, and L the number of seasons in the year (which in this case is 52, since we are working with weekly data).

Table 3 gives the estimation results from equation (4). Note that the model fits the data very well, with an R^2 higher than 0.80 and mostly statistically significant parameters. Hence, the relative price between different sizes is predictable. Given the patterns in figure 3, this came as no surprise. We conclude that there are strong regularities in relative prices, with cycles having a time interval of approximately one year.

Consequences of Patterns in Relative Prices

The existence of cycles in the relative prices may be important in several contexts. We will now look closer at two such issues — aggregation and production planning.

Aggregation

The existence of cycles in the relative prices 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 indicate different markets, or if the different sizes can be aggregated into one good. There is a close

Table 3
Estimation Results for Equation[a]

Price Relations	β_0	β_1	β_2	R^2	DW
(1–2 kg/3–5 kg)	0.95 (76.10)	–0.01 (–0.44)	0.12 (8.86)	90%	2.01
(2–3 kg/3–5 kg)	0.94 (119.5)	0.00 (–0.22)	0.10 (10.08)	92%	2.23
(5–6 kg/3–5 kg)	1.02 (163.3)	–0.06 (–7.02)	–0.03 (–3.79)	85%	2.16
(6–7 kg/3–5 kg)	1.03 (103)	0.01 (–7.55)	–0.0063 (–0.55)	86%	2.14

[a] Cochrane-Orcutt adjusted for first order autocorrelation.
t-values in parentheses.

relationship between market integration and aggregation, as discussed in Asche, Bremnes, and Wessells (1999). In fact, one can show that if the markets for two or more goods are perfectly integrated so that the relative prices are constant (*i.e.*, the Law of One Price holds), one can also aggregate the products into a single good with a single price. This is only natural, since one would expect that one should be able to aggregate identical goods into a generic good. The key to this relationship is the first criterion used for aggregation in economics — the composite commodity theorem of Hicks (1936) and Leontief (1936). This criterion states that if the 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, and 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 (*i.e.*, the generalized composite commodity theorem) that allows for deviation from proportionality when not used for welfare comparisons. There are several ways to test for this theorem. Here, we carry out the test by investigating whether the relative prices are stationary.[11] If so, the goods can be aggregated according to the generalized composite commodity theorem.

As mentioned above, several studies have indicated that salmon prices are nonstationary. When we test the prices for Norwegian salmon for the period 1992–98 for stationarity using Dickey-Fuller tests, we also find the prices to be nonstationary in levels. Since the relative prices are ratios between the price of different sized salmon and 3–5 kilo salmon, a test for whether the relative prices are stationary is then a test for the generalized composite commodity theorem. Since all the test statistics in table 4 are less than the critical value, relative prices are stationary, and we can conclude that salmon of different sizes can be aggregated and treated as one commodity despite patterns in the relative prices. Thus, even if there are regularities in the relative prices of Norwegian salmon of different sizes, one need not be concerned with them when carrying out market analysis.

[11] 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 holds for the prices in question (Asche, Bremnes, and Wessells, 1999).

Table 4
Dickey-Fuller Tests for Unit Roots. Weekly Observations, Jan. 1992 – Dec. 1998

Variable	Test Statistic
Price Levels	
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)

τ is the test statistic for the null hypothesis $\rho = 0$; *i.e.*, one unit root. Critical values are given in MacKinnon (1991). Parentheses contain the number of lags in the test.
* Reject the null hypothesis at 10% level of significance.
**Reject the null hypothesis at 5% level of significance.

Production Planning

A different context where regularities in relative prices might play an important role is with respect to the decision of when to harvest the fish. The general answer to the harvesting question is that you should refrain from harvesting when the marginal revenue from waiting is greater than the marginal cost. Bjørndal (1988) establishes the link to the classical forestry problem, and uses static optimization and comparative statics in order to explain what happens with the time of harvest under different assumptions about costs. Bjørndal based his model on a relationship between unit price and fish size. In particular, he assumed that unit price was a positive linear function of the weight of the individual fish. Arnason (1992), Hean (1994), and Heaps (1995) used a similar structure for relative prices. Mistiaen and Strand (1998) recognized that the relationship between individual fish weight and unit prices may not be continuous, but subject to discrete jumps at given thresholds (*i.e.*, the price function is piecewise continuous). However, Mistiaen and Strand, as well as Bjørndal, base their definition of the price processes on observations from one market day, but fail to observe the dynamics in relative prices. Hence, all these studies assume that the relationship between the prices (per kilo) of different sizes of fish is stable; *i.e.*, that relative prices are constant over time.[12]

We have shown the relationship between unit prices for different sized Norwegian salmon varies over time with yearly cycles. At some times of the year, small fish have higher unit prices than large fish, while the relationship is opposite at

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[12] As noted by one of the reviewers, the importance of the relationship between prices (and weights) of different cohorts at a specific time can be illustrated by extending Bjørndal's (1988) single-cohort model to a multiple-cohort solution. However, this still does not take into account the time dimension of the problem, which is the primary focus of this paper.

other times of the year. This seasonality will likely impact the determination of marginal value of delaying harvest, and consequently, the optimal harvest time. This is because when relative prices are not constant over time, the marginal value of delaying harvest is dependent upon future prices, as well as on future weight of the fish. This implies that the optimal harvest decision for a 2.5 kilo fish might be to harvest if the month is January, while it might be to wait if it is June.

The formulation and calculation of the harvesting rule is straightforward when price per kilo is a function only of fish-weight and independent of date. However, when relative prices vary over the year, this implies that the rate of marginal increase in value from delaying harvest will be a function not only of fish size, but of time of year as well. This fact makes the calculation much more difficult, because if the pattern in relative prices between sizes is taken into account, it will be impossible to find analytical solutions to the optimization problem. Hence, numerical methods are necessary to solve the problem in any specific case. Moreover, this also means that we, in general, cannot say anything about the direction of the changes in the harvesting time due to cycles in the relative prices.

Concluding Remarks

Biological and environmental constraints may produce identifiable production cycles in fish farming. Provided there are no perfect substitutes for different sized fish in the short-run, this can create patterns in the relative prices for fish of different sizes. When investigating whether there are patterns in the relative price for different sizes of Norwegian salmon (using weekly prices for different sizes of salmon for the period 1992–98), our results indicate that there are cycles in the relative prices. These cycles may have important implications for analysis of production decisions and for market analysis.

We have, by looking at the rule for optimal harvesting of farmed fish, discussed the importance of relative price relationship in determining the optimal harvesting times. Most papers assume that the relative price relationship is constant. We will argue that this, in many cases, is done more for mathematical convenience rather than to represent actual price relationships. Making a harvesting model where the relative prices of different sizes vary through the year will yield different results than one with a constant relationship. However, the results 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. Whether one can aggregate is checked by testing for the generalized composite commodity theorem. The results indicate that the generalized composite commodity theorem holds and hence, one can treat salmon as one commodity, despite the cycles in relative prices.

One further issue that patterns in relative prices for different-sized salmon might have implications for, is regulation of the industry. In most countries, salmon farmers face a set of regulations that influence their production decisions. There are several reasons for such regulations, including environmental concerns, regional policy, and market stabilization. Norwegian farmers, in particular, face some special regulations since Norway, as the largest producer, has been the target of several trade complaints.[13] As a

[13] For a discussion of trade issues, see Asche (1997, 2001) and Anderson and Fong (1997). Although Norway has received the most attention in this context, an anti-dumping complaint was filed against Chilean farmers in the US in 1998.

response to pressures from the European Union (EU) to stabilize salmon prices in the EU, nontradable feed quotas that limit the amount of feed per farm were introduced in 1996. Given that the farmers can substitute between different inputs, these quotas are not technologically neutral. Moreover, since there are a number of different varieties of feed, substitution within the feed category may be more important than substitution between feed and other inputs. The constraint that individual feed quotas put on the firm can lead to a more homogenous production in terms of the availability of different sized salmon, 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 that could exploit the relative price patterns for different sized fish. Given the scope of the feed regulations; *i.e.*, to help stabilize salmon prices in the EU by restricting supply, this regulation is even more interesting. This is because the EU market tends to prefer average-sized fish, while other markets, Japan and the Far East in particular, often prefer large or small. Therefore, in a situation where it could be useful for the Norwegian industry 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 market opportunities caused by patterns in the relative prices between different sized fish.

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