Marine Resource Economics, Volume 23, pp. 425–437
0738-1360/00 $3.00 + .00

The Price Responsiveness of Salmon Supply in the Short and Long Run

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Abstract *Productivity growth and competitiveness indicate that salmon supply is price responsive. However, in the short run supply is likely to be constrained by the biological production process, regulations, and capacity constraints. In this article, we estimate a restricted profit function for Norwegian salmon producers, which allows us to examine the industry's short-run and long-run supply responsiveness separately. Using data spanning 1985 to 2004, we find that there is close to zero, own-price supply responsiveness in the short run. In the long run, this changes substantially as supply becomes elastic. This result can contribute to explaining the observed cyclical profitability in the salmon farming industry.*

Key words Restricted profit function, supply, salmon farming, profit cycles.

JEL Classification Codes D24, Q21, Q22.

Introduction

Since the beginning of the 1980s, the salmon industry has been characterized by a high degree of technological innovation. Both public and private R&D as well as on-farm learning have contributed to the innovations, which have resulted in the development of farmed salmon as one of the most successful aquaculture species. Production increased from virtually nothing in the early 1980s to about 1.6 million tonnes by 2006, and farmed salmon is now traded and consumed globally. Together with the increased production of salmon, the general production cost has decreased substantially, such that by 2004 real cost was only a quarter of the cost in the mid-1980s. The reduced production costs have been important in several ways for making the salmon industry more competitive, as a lower output price has been vital in generating greater consumption of salmon (Asche 1997).

Despite the fact that the salmon industry has experienced substantial productivity growth that has led to a decreasing trend in prices, there seems to be substantial cycles in prices around this long-run trend (Øglend and Sikveland 2008). One important factor contributing to these cycles is that the short-run supply response is likely to be constrained, meaning that the reaction of producers to high prices will be delayed. In the long run, this can lead to an overshooting supply response, de-

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pressing prices to unprofitable levels. This misalignment between supply and demand has led to substantial variations in industry profitability.

Several studies of salmon aquaculture have documented the large productivity growth and the subsequent lowering of costs and output prices (Asche and Tveteras 1999, Tveteras 1999, Guttormsen 2002, Kumbhakar 2002, Tveteras and Heshmati 2002, Tveteras and Battese 2006, Asche 2008). However, few studies have analyzed how production possibilities and relative prices affect salmon producers' supply responsiveness.[1] In this paper, we estimate a restricted profit function for Norwegian salmon producers, which allows us to separate the industry's short- and long-run responsiveness.

The theoretical framework for the restricted or partial static equilibrium approach was developed by Lau (1976), Mork (1978), and Brown and Christensen (1981).[2] By specifying a restricted profit function instead of using the more commonly used cost function, a more general representation of the firm's production technology is provided. In contrast to the full equilibrium models, the restricted equilibrium model allows for partial adjustment of supply in the short run, and hence is able to separate short- from long-run effects. This identification of short- and long-run flexibility may help to explain why we observe cycles in industry profitability.

We estimate a restricted translog profit function based on a sample of over 500 Norwegian salmon farms during a 20-year period. In line with several earlier studies, we assume that capital is fixed in the short run (Salvanes 1993, Kouka and Engle 1998, Guttormsen 2002, Tveteras 2002). Based on the estimated profit function, short- and long-run elasticities are derived as shown by Squires (1987).

While greater knowledge of the supply response in salmon farming is interesting in itself, it is also interesting from the perspective that the industry has faced different sets of regulations aimed at limiting production (Bjørndal and Salvanes 1995, Kinnucan and Myrland 2002). For instance, the Norwegian salmon industry has faced minimum import price restrictions from the European Union as well as restrictions on capital and feed use by Norwegian authorities. Therefore, knowledge about the supply response and the interaction between production and input factor use is of interest in relation to the impact of the regulations.

The article proceeds as follows. The next section elaborates on some of the issues that constrain short-run supply of farmed salmon, before we go on to discuss the theoretical model underlying the restricted profit function. We then present the data used for empirical analysis, followed by a presentation and discussion of the empirical results. The article concludes with some observations regarding the model and results.

Background

Productivity growth and competitiveness among salmon producers have been instrumental in the development of salmon aquaculture. Figure 1 shows how real production costs have decreased since the end of the 1980s, owing to productivity

[1] Steen, Asche, and Salvanes (1997) estimated a short-run elasticity of about 1.0 and a long-run supply elasticity of about 1.5 for the Norwegian salmon industry using annual aggregated data. Asche, Kumbhakar, and Tveteras (2007) reported a long-run supply elasticity of about 1.5 derived from a cost function.

[2] The approach has been applied by Schankerman and Nadiri (1986), Kulatilaka (1985), Morrison (1985), Halvorsen and Smith (1986), and Hazilla and Kopp (1986) in the framework of a restricted cost function, and by Squires (1987) in the framework of a restricted profit function.

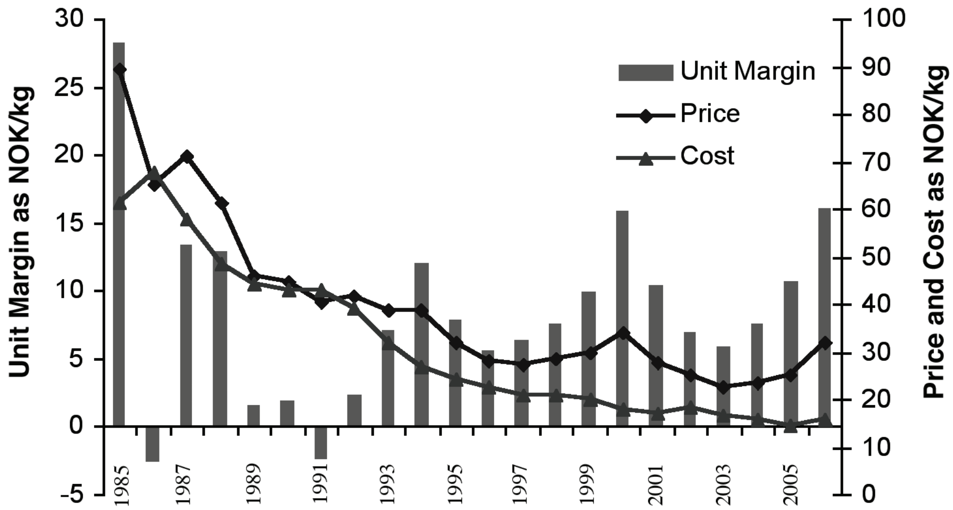

Figure 1. Average Production Cost, Export Price and Profits in Norwegian Salmon Aquaculture, 1985–2006

growth. Prices have followed suit, as shown by the decreasing export price of salmon in the figure, indicating that a large part of the efficiency gains have been transferred to consumers. The high degree of competition evident from the price reductions suggests that salmon supply is responsive to changes in the marketplace. In other words, to remain in the marketplace, salmon producers must be able to supply salmon at competitive prices.

Another feature of the industry displayed in figure 1 is shifts between prolonged periods of low and high profits. This is an indication that salmon supply does not easily adjust in the short run.[3] Supply responsiveness depends to a large degree on production technology, but also on market structure. In an industry that is highly concentrated and where some firms have market power, supply will be less responsive than in a competitive market. Although consolidation activity has created a few very large companies, indicating that the industry is reaching a more mature stage in the life cycle, there are strong reasons to believe that the Norwegian salmon industry remains competitive. There are still many small- and medium-sized firms operating. In 2005, there were 88 firms with between one and nine licenses each, eight firms with 10–19 licenses, and nine firms with more than 20 licenses. Hence, even though the firm size distribution has become more skewed towards the largest firms, the number of producers still suggests that we are dealing with a competitive industry. For that reason, we argue that limited short-run supply responsiveness is mainly caused by restrictions on technology, input availability, and regulations.

To understand the supply responsiveness of salmon producers, it is necessary to consider the biological production process. Salmon production is carried out in two

[3] This cyclical pattern became apparent after the mid-1990s. In the early years of the Norwegian salmon industry, producers experienced widespread disease outbreaks, which led to erratic changes in profitability. The introduction of vaccines at the beginning of the 1990s reduced these problems and the supply of farmed salmon became more stable, followed by the emergence of profit cycles. Such cycles are common in many commodity markets.

phases. The first is a freshwater phase, where the ova are hatched and the smolts are reared in tanks or in cages in freshwater lakes. This takes around 11–12 months. The second phase involves growing the smolts in cages in seawater until they reach market size, which may take between 10 and 18 months. In practice, when the production of a cohort has commenced, there is little room for adjustments in production until the next cohort is introduced. Because of the biological production cycle, the short-run response to price signals from the market is likely to be limited. Therefore, one would expect the supply to be substantially more flexible and therefore more elastic in the long run, as farmers can then adjust to the new economic signals.

Regulation is another factor that restricts short-run supply. In most countries with salmon aquaculture, governments have imposed regulations on production technology and farming activity. This is the case for Norwegian salmon producers. Initially, the industry was regulated as a result of environmental concerns and because of concerns about population dispersion, as the Norwegian government has a vested interest in maintaining employment and settlement in rural areas. Farming licenses have been one of the main tools used to regulate the industry. Although each license is a permit to produce, it also restricts production possibilities by limiting fish density, location, production volume, depth of cages in the sea, amount of feed, *etc.* Initially, there were also ownership regulations stating that a salmon producer could own only one license, but this restriction was removed in the 1990s. Ownership regulations can explain why there are still many small- and medium-sized salmon producers operating in Norway despite over a decade of consolidation activities.

If production capacity depends critically on some fixed factors, there will be limited opportunities to respond to increasing prices in the short run. Both production and marketing of farmed salmon are associated with sunk costs in the form of investment in education and training of personnel, capital equipment, market research, and advertisements. As the level of investment is chosen based on the information available before production begins, it may later turn out to be suboptimal compared with the realized output level and market prices. Furthermore, if capital clearly defines production capacity and it is being fully utilized, there will be limited opportunity to respond to increasing prices in the short run. This is in line with other studies, which have found that capital represents a considerable capacity restriction in aquaculture production (Salvanes 1993, Kouka and Engle 1998, Guttormsen 2002, Tveteras 2002).

The Model

Following Squires (1987), the most general form of the restricted profit function can be specified as HR (p; z), where HR is the restricted profit, defined as total revenue minus total variable cost; p is a vector of positive input and output prices; and z is a vector of quasi-fixed inputs. The function is restricted in the sense that firms are assumed to be in a static equilibrium with respect to a subset of variable inputs, conditional upon the existing levels of the quasi-fixed factors.

At the observed level of quasi-fixed factors, total profit can be written as the sum of the restricted profit function less the expenditure for the quasi-fixed factors, or HT (p, p_z, z) = HR (p; z) – $p_z'z$, where HT is total short-run profit, and p_z is the market price of the quasi-fixed factors. The total short-run profit function describes the technology and profit of a temporary equilibrium, where departure from full equilibrium arises as a result of firms employing non-optimal levels of quasi-fixed factors. Long-run equilibrium is achieved by optimally adjusting the quasi-fixed inputs until total profits are maximized. Consequently, the definition of the long run is only a construct to distinguish the temporary short-run equilibrium from the desired long-run equilibrium where total profits are maximized without prior assumption of exogenous factors.[4]

Because the long-run profit is a special case of HT, the long-run profit function can be derived from the total short-run profit function, using the full static equilibrium condition. The condition states that in optimum, the market price of the quasi-fixed factor, p_z, is equal to the shadow price of the quasi-fixed factors, HR_z (which is the first partial derivative of the restricted equilibrium profit function with respect to the quasi-fixed factors). This condition can be expressed formally as: $p_z = \mathrm{HR}_z(p, z^*)$, where z^* is the optimal level of the quasi-fixed factors. Hence, long-run equilibrium implies equality between the shadow value of the quasi-fixed factor and its market price. A deviation between p_z and $\mathrm{HR}_z(p, z^*)$ reflects the difference between the short- and long-run (marginal) profit functions and represents the potential to obtain greater profits in the long run by adjusting the quasi-fixed input levels. When $\mathrm{HR}_z(p, z^*) > p_z$, the valuation of an incremental unit of the quasi-fixed factor is higher than the market rental price, and a higher profit is attainable by increasing the level of the quasi-fixed factor. Alternatively, when $\mathrm{HR}_z(p, z^*) < p_z$, the marginal unit of the quasi-fixed factor has a low valuation relative to its market value, and it is possible to increase profits by reducing the level of the quasi-fixed factor. Only when $\mathrm{HR}_z(p, z^*) = p_z$ is there no incentive for the firm to change the level of the quasi-fixed factor, as the equality implies full equilibrium and long-run profit maximization. For a particular profit function, it is possible to solve this equality for z^* and, by substituting z^* into HT, to obtain the long-run profit function: $\mathrm{H}(p, p_z,) = \mathrm{HR}(p, z^*) - p_z' z^*$. Hence, the long-run profit, H, is derived by maximizing HT with respect to the quasi-fixed inputs, while holding output and variable inputs at their restricted profit-maximizing levels.

As the restricted equilibrium approach does not explicitly specify the adjustment cost of the quasi-fixed factors, there are no details about the adjustment path and the firm's inter-temporal behavior in the model.[5] Detailed information on how long it takes for the quasi-fixed factor to reach optimum, what intertemporal path it takes, and what criteria are used in determining this adjustment path is not provided (Kulatilaka 1985). However, what can be established are the differences between the short-run and long-run elasticities, which accordingly can be used to indicate substitution and transformation possibilities.

To estimate the model, we specify a translog functional form for the restricted profit function. The translog specification is part of a group of flexible functional forms, which allows for a complete specification of substitution patterns among variable and quasi-fixed factors. Given panel data and only one quasi-fixed factor, the translog restricted profit function becomes:

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[4] If no difference can be found between the observed and optimal long-run levels of the quasi-fixed factors, the HT model becomes identical to the H model (Kulatilaka 1985). A number of testing procedures for the divergence between observed and optimal z are possible. Bootstrap and jackknife procedures can be used. Kulatilaka (1985) applied the delta method to form a test for departure between the actual and optimal long-run level of quasi-fixed factors.

[5] By using the dynamic equilibrium approach rather than the static equilibrium approach, the cost of adjusting the quasi-fixed factor can be recognized explicitly. The firms are assumed to be continuously in a dynamic equilibrium, and the approach offers insights into the intertemporal factor substitution possibilities. Berndt, Morrison, and Watkins (Chapter 12, 1981) provided a brief review of an empirical application based on this approach.

$$\ln HR = \sum_r \beta_r \ln D_r + \sum_i \beta_i \ln p_i + 0.5 \sum_i \sum_j \beta_{ij} \ln p_i \ln p_j \qquad (1)$$
$$+ \beta_z \ln z + 0.5\beta_{zz} \ln z^2 + \sum_i \beta_{iz} \ln p_i \ln z$$
$$+ \beta_t t + 0.5\beta_{tt} t^2 + \sum_i \beta_{it} \ln p_i t + \beta_{zt} \ln zt,$$

where i and j represent inputs and outputs, respectively; t is a time trend, included to control for technological changes; and D_r denotes region-specific dummy variables included to account for differences in biophysical factors among the sample farms. The corresponding revenue and cost-share equations given by Hotelling's lemma are:

$$S_i = \frac{\partial \ln HR}{\partial \ln p_i} = \beta_i + \sum_i \beta_{ij} \ln p_j + \beta_{iz} \ln z + \beta_{it} t, \qquad (2)$$

which are positive for outputs and negative for inputs. Restrictions of symmetry and linear homogeneity in prices are directly imposed through the parameter restrictions:

$$\beta_{ij} = \beta_{ji} \;\; i \neq j, \; \sum_i \beta_i = 1, \; \sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \beta_{iz} = \sum_i \beta_{it} = 0.$$

The restricted profit function (1) will be jointly estimated with the restricted revenue and cost-share equations (2), from which the supply and demand elasticities will be derived. Partial static equilibrium own- and cross-price elasticity can be computed as $\varepsilon_{ii} = (\beta_{ii} + S_i^2 - S_i)/S_i$ and $\varepsilon_{ij} = (\beta_{ij} + S_i S_j)/S_i$, respectively. These elasticities are valid only for the level of the quasi-fixed factors at which they are evaluated and do not provide any information on substitution possibilities among quasi-fixed and variable factors. On the other hand, by using the theoretical relationship between the derivatives of HR and H, first established by Lau (1976) and discussed further by Brown and Christensen (1981), full equilibrium long-run, own-, and cross-price elasticities of supply and demand can be derived as follows:

$$\varepsilon_{ii} = \frac{(\beta_{ii} + S_i^2 - S_i)}{S_i} - \frac{(\beta_{iz} + S_i S_z)^2}{S_i(\beta_{zz} + S_z^2 - S_z)}, \qquad (3)$$

$$\varepsilon_{ij} = \frac{(\beta_{ij} + S_i S_j)}{S_i} - \frac{(\beta_{iz} + S_i S_z)(\beta_{jz} + S_j S_z)}{S_i(\beta_{zz} + S_z^2 - S_z)}, \qquad (4)$$

$$\varepsilon_{zz} = \frac{S_z}{(\beta_{zz} + S_z^2 - S_z)}, \qquad (5)$$

$$\varepsilon_{iz} = \frac{S_z(\beta_{iz} + S_i S_z)}{S_i(\beta_{zz} + S_z^2 - S_z)}, \qquad (6)$$

$$\varepsilon_{zi} = \frac{(\beta_{iz} + S_i S_z)}{(\beta_{zz} + S_z^2 - S_z)}, \tag{7}$$

where $S_z \equiv \partial \ln \mathrm{HR}/\partial \ln z = -p_z z/\mathrm{HR}$ by Hotelling's lemma.

The first term of equations (3) and (4) is identical to the partial static equilibrium own- and cross-price elasticities. Consequently, these terms reflect the short-run price responsiveness, where variable inputs and outputs are chosen conditional on the short-run level of quasi-fixed factors. As these conditional elasticities do not allow for the effects of changes in the quasi-fixed factor, this has to be accounted for in the long run by appending the changes in demand for the quasi-fixed factor to the direct short-run impact. The second term of equations (3) and (4) represents the long-run impact of the quasi-fixed factor. Expression (3) can also be used to demonstrate the Le Chatelier principle. The principle states that the own-price elasticity of variable factors decreases in absolute value with the number of factors that are quasi-fixed. Owing to concavity of the restricted profit function in the quasi-fixed factors, the second term in (3) is negative for outputs and positive for inputs. Therefore, the restricted own-price short-run elasticities are smaller than the unrestricted long-run elasticities, which is consistent with the principle. Equations (5)–(7) are pure long-run elasticities as the quasi-fixed factor is adjustable only in the long run. Equation (5) represents the own-price elasticity of the quasi-fixed factor, whereas (6) and (7) represent the cross-price elasticities, or substitution possibilities, between variable and quasi-fixed factors.

The system of equations is estimated using the generalized least square technique, which is equivalent to maximum likelihood. Before estimation, a classical additive disturbance term is appended to the restricted profit function and each of the share equations. As the cost shares sum to unity, one of the profit shares is dropped before estimation and its parameters are identified through linear homogeneity and symmetry restrictions. The results are invariant to the choice of equation dropped.

Data

The dataset is provided by the Norwegian Directorate of Fisheries, which has collected data annually since 1982 on Norwegian salmon farms' production and profitability. As all Norwegian salmon farms are obliged by law to report their annual accounts along with several firm characteristics, the dataset is fairly extensive.[6] All size groups and regions along the Norwegian coast are covered in the sample, and more than 50% of the total Norwegian salmon production is included in most of the sample years. Roughly 80 variables are reported for each farm, including age of the farm, regional location, production level, input level, cost, and revenues.

Unbalanced panel data with farm level observations for the period 1985–2004 are available for our research.[7] The data are unbalanced because the same farms are not systematically reported year after year. The observation time span varies from one to 20 years among the individual farms, with the average farm being observed for 6.1 years. In total, the dataset consists of 3,580 observations, distributed among

[6] Before a firm is included in the final dataset, its returned report is subjected to a quality assessment process, where farms are included if they have been in production for two preceding years, were in full operation for the entire period, and have returned annual accounts of sufficient quality.

[7] The sample years 1982 and 1983 were dropped from the analysis because of differences in cost categories.

Table 1
Summary Statistics of the Data

	HR	Revenue	Feed Cost	Labor Cost	Salmon Price	Feed Price	Labor Price	Capital
Mean	6,664,222	12,878,090	5,160,891	1,053,706	28.12	7.15	134.14	3,752,981
St. Dev.	9,584,776	17,656,183	7,739,879	1,148,993	7.88	1.84	62.40	5,237,581

583 farms. Summary statistics are presented in table 1.

To estimate the model defined by equations (1) and (2), we make use of data on output prices, variable input prices for feed and labor, and a capital stock variable. In addition, a time trend and region-specific dummy variables were added to control for technological change and differences in biophysical factors. All variable and quasi-fixed inputs included in the model are implicitly assumed to be weakly separable from other possible inputs in the production process.

The variables were defined as follows. Output price is constructed by dividing sales revenue by the total quantity of fish sold. The feed price is defined as the annual expenses on feed divided by the quantity used. As we did not have quantity data for the years 1985–1993, a feed quantity index was calculated as the product of the output and the feed conversion ratio for this period (Salvanes 1989). The labor price is obtained by dividing annual labor expenses by hours worked at the farm by owner and workers. Previous studies have found input fixities to be present in Norwegian salmon production (Salvanes 1993, Tveteras 2002). Consequently, capital is measured in physical quantities, where capital equipment such as pens, buildings, feeding equipment, *etc*., is represented by the actual replacement value.[8]

Empirical Results

Table 2 reports the estimated technology parameters from the translog restricted profit function and the related share equations for feed and labor.[9] Subscripts f, l, and y represent feed, labor, and the salmon price, respectively; z symbolizes capital; and t is a time trend where 1985 = 1. The D_r parameters represent the region-specific dummy variables, where the subscript specifies the regions Rogaland and Vest-Agder (R), Hordaland (H), Sogn og Fjordane (SF), Møre og Romsdal (MR), Sør-Trøndalag (ST), Nord-Trøndelag (NT), Nordland (N), Troms (T), and Finmark (F). The regions are listed according to their location south to north, from the southernmost region of Vest-Agder and Rogaland to the northernmost region of Finmark. An R^2 of 0.625 suggests the profit function has reasonable explanatory power. Nearly all variables are statistically significant, including the trend terms, which indicate that it is important to account for technological change. As expected, the technological change is non-neutral.

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[8] Following previous productivity and supply studies in aquaculture, we have treated capital as quasi-fixed in the short run (Salvanes 1993, Kouka and Engle 1998, Guttormsen 2002, Tveteras 2002). Other inputs, in particular fingerlings, could also have served as a quasi-fixed factor in the estimation. Although this could have been interesting to investigate, there are some data issues regarding quantities for fingerlings that can introduce serious measurement errors. Consequently, we have not followed this route.

[9] The share equation for output was dropped to avoid singularity.

Table 2
Parameter Estimates of the Restricted Profit System

Parameter	Estimate	Standard Error
β_f	–1.891	0.0497*
β_l	–0.765	0.0185*
β_y	3.656	0.0638*
β_{ff}	–1.509	0.0419*
β_{fl}	–0.230	0.0137*
β_{fy}	1.739	0.0506*
β_{ll}	–0.257	0.0092*
β_{ly}	0.487	0.0176*
β_{yy}	–2.226	0.0635*
β_z	0.492	0.0325*
β_{zz}	0.112	0.0110*
β_{fz}	–0.008	0.0151
β_{lz}	–0.002	0.0056
β_{yz}	0.010	0.0193
β_t	0.441	0.0104*
β_{tt}	–0.026	0.0009*
β_{ft}	0.105	0.0048*
β_{lt}	0.056	0.0018*
β_{yt}	–0.161	0.0062*
β_{zt}	–0.004	0.0025
D_R	12.854	0.0635*
D_H	12.931	0.0595*
D_{SF}	12.920	0.0618*
D_{MR}	12.862	0.0602*
D_{ST}	12.760	0.0630*
D_{NT}	12.802	0.0647*
D_N	12.890	0.0604*
D_T	12.740	0.0644*
D_F	12.664	0.0757*

* Denotes significance at the 5% level.

With the estimated parameters from the translog profit function, we can calculate the sample mean price elasticities of derived demand and supply using equations (3) to (7). The short-run elasticities reported in table 3 are calculated based on the first term of the right-hand side expression of equations (3) and (4). The long-run elasticities presented in table 4 are calculated using the entire expressions in equations (3) to (7).

The own-price elasticity of supply in table 3 indicates that the producers' ability to respond to changes in output prices in the short run is negligible. A 1% increase in the output sales price will induce only about a 0.05% increase in supply. Hence, in the short run, salmon producers are unable to respond to changes in output prices. In the short run, supply is also unresponsive to changes in input prices. As expected, there is a positive relationship between the sales price and the use of variable inputs in production, where input demand seems quite responsive to changes in output prices. When salmon price increases by 1%, the quantities of feed and labor increase by 0.5% and 1.6%, respectively. The own-price elasticities are negative for both feed and labor, implying downward-sloping input demand schedules.

Table 3
Short-run Supply and Derived Demand Elasticities

	Output Price	Feed Price	Labor Price
Salmon	0.0484	–0.048	–0.001
Feed	0.516	–0.487	–0.029
Labor	1.618	–0.672	–0.946

Table 4
Long-run Supply and Derived Demand Elasticities

	Output Price	Feed Price	Labor Price	Capital Price*
Salmon	1.415	–0.767	–0.080	–0.568
Feed	1.827	–1.191	–0.098	–0.538
Labor	2.943	–1.378	–1.024	–0.541
Capital	5.810	–1.575	–1.201	3.034

* Capital price is a component of the capital's profit share, S_Z, which is the basis for calculation of the elasticities. Although capital price is not explicitly accounted for, it can be derived from Hotelling's Lemma as shown in the discussion of the model.

The results change significantly when we allow adjustments in the amount of capital. When all inputs can be adjusted, the own-price of salmon supply is 1.4. This suggests that salmon production is much more price-responsive in the long run. These results support previous findings that suggested capital is a major capacity restriction in aquaculture production (Salvanes 1993, Kouka and Engle 1998, Guttormsen 2002, Tveteras 2002). The cross-price elasticities suggest that in the long run, an increase in output price increases the use of variable inputs. Furthermore, we note that supply is more responsive to input prices in the long run. Feed price, in particular, becomes a restriction on output, as a 1% increase in feed price will reduce supply by 0.8%. This suggests that the introduction of feed quotas, which have been applied in Norway, is a relatively effective tool when one wishes to limit production. Also note that input demand for feed reacts with almost the same magnitude to a change in output price as output supply, which emphasizes the relationship between feed usage and output. We may interpret this in accordance with a fixed-proportion technology as suggested by Guttormsen (2002).

Table 5 presents estimates that measure the differences in the efficiency and biophysical factors among the sample regions. The estimates are derived relative to the most efficient region, namely Hordaland (H), which has been normalized to one. The ratios of these coefficient estimates provide a direct measure of the relative differences among regions and are calculated as $TE_i = D_i/D_H$, where $0 \leq i < 1$ $i \neq H$. The estimates reveal that production levels are lower in the northern regions. The colder sea temperatures in the north make it reasonable to assume that the biological production process will be slower, leading to lower productivity. As illustrated in table 5, the most northern region is operating at only about 75% of the level of the most effective region, which is located much farther south.

Table 5
Regional Differences in Efficiency and Biophysical Factors

TE_i	Estimate	p-value
TE_R	0.925	0.010*
TE_H	1.000	
TE_{SF}	0.989	0.708
TE_{MR}	0.933	0.009*
TE_{ST}	0.842	0.000*
TE_{NT}	0.879	0.000*
TE_N	0.959	0.098
TE_T	0.826	0.000*
TE_F	0.765	0.000*

* Denotes significant differences between actual and optimal efficiency at the 5% level.

Concluding Remarks

There is a rich literature on productivity growth in salmon aquaculture, but few studies have addressed supply responsiveness. This is of interest because of the technological innovations that have influenced the production process in salmon farming. In this article, we estimated a restricted profit function for Norwegian salmon farms for the period 1985 to 2004. Based on the restricted profit function, we derived both demand and supply elasticities, taking into account the differences in factor adjustments in the short and long run.

In accordance with our prior beliefs, the results indicated that salmon producers have limited possibilities to respond to price changes in the short run. The supply elasticity of salmon is close to zero, implying that there is no immediate response to output price changes. Furthermore, both feed and labor own-price elasticities are inelastic in the short run. In the long run, the supply elasticity increases to 1.4, indicating that production has become flexible. Price responsiveness also increases relative to input prices, in particular for feed price, where the own-price elasticity increases from 0.5 to 1.2.

With limited short-run responsiveness, there will be a lag in the adjustment of output to the optimum level, given exogenous prices. The delayed response may cause an overshooting in production in the long run, which will depress prices, causing a fall in profits. This recurring pattern goes a long way towards explaining the cyclical variations around the profit trend. Consequently, the observed volatility in industry profits might be explained by the combination of high responsiveness in the long run and limited responsiveness in the short run. If the industry remains competitive, with many producers, it is likely that profits will continue to be volatile, as individual producers will have limited incentives to restrict supply when prices are high.

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