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Input Factor Substitutability in Salmon Aquaculture

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Abstract *The salmon aquaculture industry has experienced substantial expansion during the last two decades. This expansion is largely the result of increased productivity, with a complementary decrease in costs. A general reduction in production costs has been accompanied by substantial shifts in the shares of inputs. Hence, one may question whether the technology has changed so much that some input factors are no longer substitutes in production. In this study, we investigate this by estimating a translog cost function focusing on the difference between full and partial static equilibrium specifications. The results from the different specifications provide evidence of limited or zero substitution possibilities in salmon production. This implies that salmon farming today can be thought of as a converter or refinement industry where less valuable fish (the feed) are converted into higher-valued product.*

Key words Cost functions, productivity, salmon aquaculture, substitution.

Introduction

During the last few decades, the production of farmed salmon has experienced a growth that has been surpassed by few other primary production sectors. Global annual output growth has averaged 27% in the period 1980 to 2000. This growth in production is largely the result of increased productivity, with a complementary decrease in costs (Asche 1997). In 1982, the average salmon farmer produced one kilogram of salmon at a cost of 60 NOK[1] (real price 1998 = base year), while the average farmer today produces at a cost of 17 NOK per kilo. However, along with a general reduction in cost, cost shares have shifted dramatically. From 1986 to 1998, the cost share of feed increased from 27% to approximately 50%, despite a halving of the feed cost per kilo produced. Other inputs, such as labor and capital, have experienced a decrease in cost shares. Hence, it seems like technological change has not been neutral, and changes in relative factor prices have led to a larger increase in the productivity of labor and capital in cost terms.

Salmon farming is, in principle, very simple. The fish farmer buys small salmon called smolts,[2] releases them to seawater, and feeds them for awhile before they are harvested. After the small salmon are released to seawater, quantity produced is determined by the amount of feed consumed and environmental factors which are out-

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[1] NOK 1 = US$ 0.11 per May 2001.

[2] Smolts are juvenile salmon which are able to adapt to seawater, *i.e.*, they have been through the biological process called smoltification.

side the control of the farmer. The amount of feed consumed is a function of amount fed and the farmer's ability to monitor what the fish eat. In the early stages of salmon farming, knowledge of feeding and feed technology was limited. Hence, the farmers manually controlled the feeding procedure to assure that as much feed as possible actually reached the fish. Based on relative prices for feed, labor, and capital, the farmer could substitute between the inputs; *i.e.*, inputs were, to some degree, substitutes. This is supported in previous studies on salmon production, notably Salvanes (1989) and Bjørndal and Salvanes (1995). However, today's fish farms have computerized feeding systems that monitor feeding, assuring that all the feed is eaten before more is provided. Hence, based on this change in production technology, the farmer's substitution possibilities might be reduced.

This study examines the change in technology by testing whether several input factors are substitutes in the production process for farmed salmon. This is done by estimating full static equilibrium translog cost functions and by calculating own- and cross-price elasticities. However, based on the fact that the variability of labor and capital might be limited, the full static specification might provide biased elasticity estimates (Brown and Christensen 1981). As a further investigation of whether substitution possibilities have been reduced, we test the full static equilibrium model against partial static equilibrium specifications. An eventual rejection of the full static equilibrium specifications will then provide evidence on limited substitution possibilities.

Limited substitution possibilities between input factors in salmon farming provide several important policy questions. First, limited or zero substitution combined with steadily increasing cost shares for feed will make the industry more dependent on feed prices. The existence of substitution possibilities in a production with several inputs makes production costs less sensitive to changes in demand and supply for single input factors. Consequently, lack of substitution possibilities will render the industry more vulnerable to such changes.[3] Second, several studies argue that salmon prices are driven by operating cost (Asche 1997; Asche, Bremnes, and Wessells 1999).[4] If feed cost is the major cost component, operating costs will increasingly become a function of feed price. Hence, the supply and demand for salmon feed raw materials will more directly determine salmon prices, and prices of important raw materials, such as fish meal and fish oil, will be leading indicators of future salmon prices. Salmon farming can then be described as a converter or refinement industry, where fish from reduction fisheries; *i.e.*, low-valued species, is refined to salmon, which traditionally is a high-valued species.

The outline of this article is as follows. The next section provides some background on the productivity improvement in Norwegian salmon aquaculture. In the third section, relevant theory is discussed before the dataset is presented. The methodological framework for the study and the empirical results follow in the fifth and sixth sections, and conclusions are drawn in the final section.

Background

As noted above, an increase in productivity is the main factor behind the expansion of farmed salmon production. The improvement in productivity has had a major impact on costs and the cost structure. Most notably, overall costs have declined. Fig-

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[3] For a discussion of biological and technological risk in salmon aquaculture, see Tveterås (1999), Asche and Tveterås (1999), and Kumbhakar (2001).

[4] Asche, Bremnes, and Wessells (1999) shows that there exists one global salmon market and that the price for wild salmon is determined by the price of farmed.

ure 1 shows yearly operating costs from 1982 to 1999 in Norwegian salmon farming measured in 1998 NOK. Total operating cost per kilo of salmon decreased from 59.82 NOK in 1982 to 17.09 NOK in 1999. With the exception of three years, costs have decreased every year.[5] Also included in the figure are export prices, illustrating that productivity improvements have made a substantial price reduction possible.[6] We especially note that the average export price in 1998 was 33% of the price in 1982, and that the operating cost in 1998 was 31% of the cost in 1982; *i.e.*, profit margins have been stable.

Figure 2 displays the development in the cost shares for the period 1986–98. Relative feed costs have increased from 27% in 1986 to approximately 50% in 1998, despite a halving of the feed cost per kilo produced. On the other hand, labor and particularly capital costs, have experienced a relative decrease. Since relative prices for input factors have been relatively stable, this shift indicates a non-neutral technological change.

There are, of course, several sources behind the productivity growth observed in the industry. One source is public research and development (R&D) investments, from which several innovations have been diffused to salmon producers.[7] Another source is on-farm innovations and learning. Farmers have learned from their own production experiences and have also acquired knowledge from other farmers (Tveterås and Heshmati 1998). The technological change can, to a large extent, be attributed to selective breeding and development in feeding and feed technology.

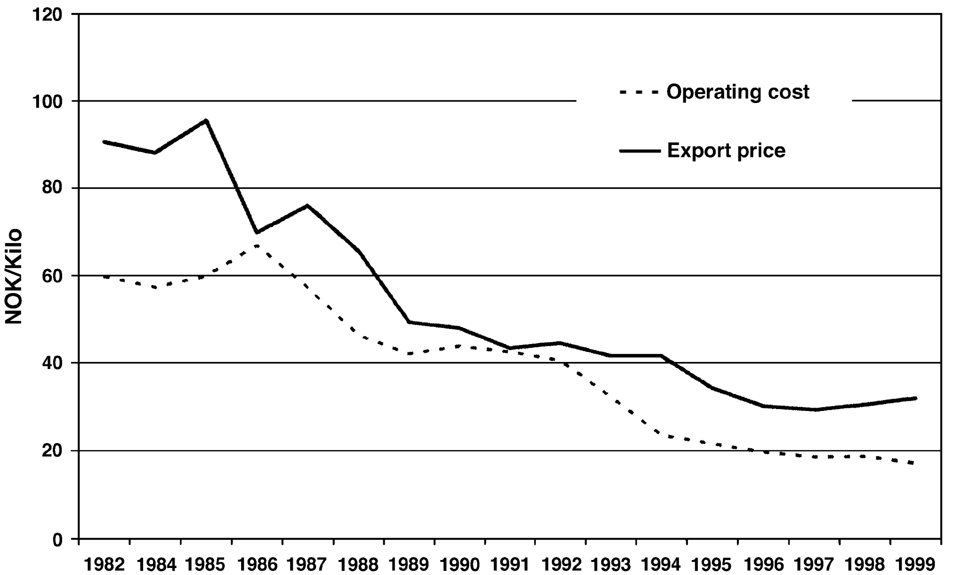

Figure 1. Production Cost and Export Price (per kg)
for Fresh Norwegian Salmon in Real NOK (1998 = base year)

[5] The years that costs increased have all been years with extraordinary events (sickness, algae blooms, *etc.*).

[6] One must be careful when comparing the levels of the data series, as production costs are measured at an earlier stage in the production process than export prices. See Asche (1997) for a more thorough discussion of operating costs versus export prices.

[7] See Asche, Guttormsen and Tveterås (1999) for a discussion of these issues.

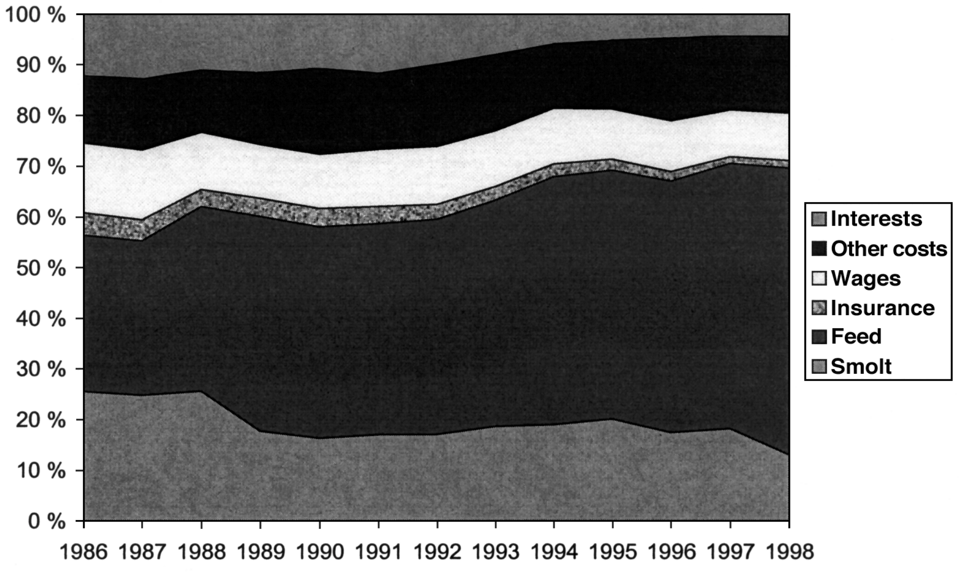

Figure 2. Cost Shares in Norwegian Salmon Farming 1986–98 per kg Salmon Produced

Based on knowledge from traditional terrestrial husbandry, Norwegian salmon farmers established, at an early stage, a large-scale selective breeding program that has generated several noteworthy results with direct implications for productivity. For example, the substantial reduction of production time has made it possible for farmers to produce more fish, without increasing either fish cage volume or labor. Selective breeding has also improved the fish's ability to consume feed. The feed conversion ratio (FCR), which measures the effectiveness of the feed incorporation into fish biomass [the ratio of feed used (kg) to the biomass gain (kg)], has also been reduced. In the early 1980s, around three kilograms of feed were required to produce one kilogram of fish. Today, the best farmers produce one kilogram of fish with less than one kilogram of feed.[8] At the same time, better feeds have been developed, which better fit the nutritional needs of the fish. They also have a design and weight that makes them sink much more slowly. This increases the likelihood that the salmon actually consume the feed. Feeding technology innovations have also improved the ability to monitor whether the salmon are consuming the feed being supplied into the pens, and to cut back on feeding if necessary.

Methodological Framework

Let the characteristics of the production technology, implied by the production function $Q = Q(X)$, be represented by a total cost function:

$$C = C(P, Q), \tag{1}$$

[8] Feed conversion ratios as low as 0.6 have been achieved in laboratory experiments. The average feed conversion ratio for Norwegian fish farms in 1999 was 1.19.

where Q is quantity produced, X is a vector of inputs, and P represents the associated price vector. The total cost function is dual to the production function, positive and non-decreasing in Q and P, positive linearly homogenous in P, and concave and continuous in P. By using Shephard's lemma, input demand equations can be obtained for each factor i as:

$$X_i = \partial C / \partial P_i = f(P, Q). \tag{2}$$

An implicit assumption of the full static model is the complete, instantaneous, and costless adjustment of inputs in response to changes in factor prices. However, if that is not the case, the partial static equilibrium model is an alternative. In such models, all inputs are categorized as either variable or (quasi)-fixed, and the short-run/restricted cost function can be written as:

$$G = G(P_V, K, Q), \tag{3}$$

where P_V is a vector of prices of the variable inputs, and K is the observed level of the fixed/quasi fixed factors. Demand equations for the variable inputs are also obtained by Shephard's lemma:

$$V_i = \partial G / \partial P_i = f(P_v, K, Q). \tag{4}$$

From equation (3), we have that the short-run total cost of producing Q is:

$$C^s = G\big(P_V, K, Q\big) + P_F K. \tag{5}$$

The solutions to the short-run and the long-run optimization problems are not always the same; hence, the behavior of costs in the short run is not the same as in the long run. However, there exists a relationship between the long-run and short-run cost curves. From the definition of the long run, the main difference between equations (1) and (3) is that in equation (3), the fixed inputs do not necessarily minimize cost. However, by definition of $G(P_V, K, Q)$, variable costs are minimized for any choice of K. Hence, if decisionmakers are rational,

$$C(P, Q) = \underset{K}{\mathrm{Min}}\, G(P_V, K, Q) + P_F K. \tag{6}$$

Moreover, the LeChatelier principle implies that:

$$\frac{\partial X_i(P, Q)}{\partial P_i} \leq \frac{\partial X_i\big[P, Q, K(Q)\big]}{\partial P_i}. \tag{7}$$

Hence, long-run derived demand is more own-price elastic than short-run derived demand.

We should also note that if the long- and short-run cost curves are tangential, the long- and short-run average cost curves must also be tangential. This relationship is depicted graphically in figure 3. Here, each point on the long-run average cost curve is also a point on an associated short-run average-cost, where the fixed input bundle is evaluated at its long-run, cost-minimizing value. Farmers who manage to adjust optimally to changes in factor prices will

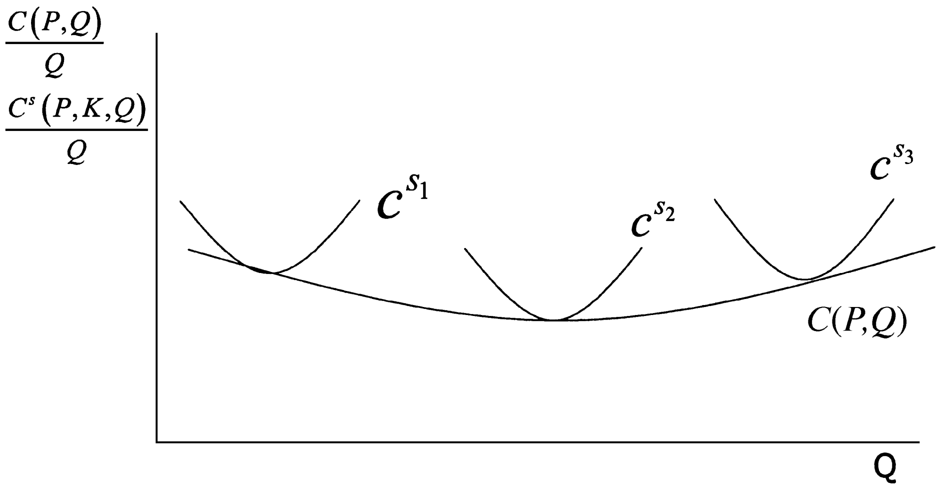

Figure 3. Long- and Short-run Average Costs

move along the long-run average cost curve. However, with limited substitution possibilities, farmers will have to move along the short-run average cost curves. Problems in empirical work arise when estimating a long-run cost function, when the data implies that you should have estimated a short-run function; *i.e.*, trying to estimate the $C(P,Q)$-function while the data are concentrated around the different $C^s(P,K,Q)$ functions. Incorrect specification of the cost function creates a bias in the estimated elasticities. For instance, Brown and Christensen (1981) state, "we conclude that the specification of particular inputs as variable or quasi-fixed may have important consequences in estimation of substitution possibilities," whereas Nelson (1983) found substantial variances between scale elasticities dependent upon whether they were calculated from short- or long-run cost functions.

One should note that when assuming fixed factor prices (both in the short and long run), the optimal quantities of the quasi-fixed input K_j^* are implicitly defined by the envelope condition:

$$-\partial G/\partial K_j^* = R_j \,, \tag{8}$$

which states that a necessary condition for a firm to be in long-run equilibrium is that shadow prices of the quasi-fixed inputs be equal to the observed rental prices R_j (Samuelson 1953). Any differences between observed R_j and optimal R_j values of the quasi-fixed factors represent the level of disequilibrium in the use of these inputs. If the optimal levels of the quasi-fixed inputs are found to be greater than the actual levels, then producers must be placing a greater value on these inputs than the value implied by their rental prices. In other words, if farmers were free to adjust the use of the quasi-fixed inputs, they would increase profits by expanding the use of them. This process would continue up to the point where the shadow prices of the quasi-fixed inputs become equal to their rental price. Looking again at figure 3, this is a case where the short- and long-run average cost functions are tangential.

Data and Data Construction

The Norwegian Directorate of Fisheries collects annual data on salmon farm production and profitability in a survey of independent Norwegian fish farms.[9] Farm-level data for the years 1994–98 have been made available for our research. The empirical analysis is based on one output and three inputs. Output (Q) is defined as sales plus changes in stock during the year. The three inputs in our empirical model are feed, capital, and labor. A feed price index is calculated as feed expenditure divided by feed used (adjusted for changes in stock). Labor prices are calculated as annual expenses on hired labor plus calculated owner salary divided by the number of hours worked by hired labor and hours worked by owners. Finding a unit cost for capital always creates a problem in estimating cost functions. We have followed the suggestion in Salvanes (1989), and calculated a unit capital price as an index of the capital flow of the different capital items divided by total capital. The flow of services was calculated as a user type, including depreciation based on replacement cost and current interest rates. Depreciation data were provided by the Directorate of Fisheries, and calculated by dividing the various subgroups according to the expected economic life of capital. The second part of the user cost of capital was calculated as 7% of total capital annually.[10] Total capital is defined as the value of the capital investment in a plant for a specific year. The unit capital price was then calculated as the capital flow divided by the total capital.

Empirical Specification

To study the cost structure in salmon farming, translog cost functions are estimated. The translog functional form was first introduced by Christensen, Jorgensen, and Lau (1971), and the full static equilibrium cost function can be written as:

$$\ln C = \ln \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln P_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln P_i \ln P_j + \alpha_Q \ln Q + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \sum_{i=1}^{n} \gamma_{iQ} \ln P_i \ln Q. \tag{9}$$

Since we interpret the translog function as an approximation to the true underlying cost function with the sample mean as the point of approximation, each exogenous variable is divided by its sample mean prior to taking the natural logarithms. Symetry requires that $\gamma_{ij} = \gamma_{ji}$ and homogeneity of degree one in prices given, Q implies the following restrictions on equation (9):

$$\sum_{i=1}^{n} \alpha_i = 1 \qquad \sum_{i=1}^{n} \gamma_{ij} = \sum_{j=1}^{n} \gamma_{ji} = \sum_{j=1}^{n} \gamma_{iQ} = 0. \tag{10}$$

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[9] All farms with an aquaculture license receive detailed questionnaires. The returned questionnaires and annual accounts go through a quality assessment process. Only those farms that have been in production the two preceding years, were in full operation for the entire year, and have returned questionnaires and annual accounts of sufficient quality are included in the final data set.

[10] This number is based on Salvanes (1993) and set to 7%, because this figure represents the discount rate for public investments in Norway.

The first derivative of the cost function with respect to input i is the cost shares

$$\frac{\partial \ln C(P,Q)}{\partial \ln P_i} = S_i = \alpha_i + \sum_{j=1}^{n} \beta_{ij} \ln P_j + \beta_{iQ} \ln Q. \tag{11}$$

The cost equation is estimated together with $n - 1$ of the n share equations. The resulting estimates are invariant to which share equation is deleted. To acquire maximum flexibility in the estimation and to compare the results with those from Salvanes (1989), we estimated one cost function for each year in the sample.

Estimated Cost Function and Calculated Elasticities

To compare elasticities with those from Salvanes (1989), the full static equilibrium cost function was estimated. Estimates of the cost function parameters together with standard errors are provided in table 1. From our perspective, the most interesting economic contents are the elasticities. For the translog specifications, elasticities are calculated as:

$$\varepsilon_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i} \tag{12}$$

$$\varepsilon_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i}.$$

Note that homogeneity restrictions can be expressed using the elasticities as $\Sigma\varepsilon_{ij} = 0$. This implies that with no substitution possibilities, the own-price elasticities should also be zero. Own-price elasticities will, hence, provide information on substitution possibilities.

The calculated elasticities are presented in tables 2 and 3. In table 1, own-price elasticities from Salvanes (1989) are included for comparison. With the exception of the elasticities for 1982–83, their magnitudes are all close to zero. The elasticity for labor is the only one significantly different from zero in all the years, while the elasticity for feed is significantly different from zero only in 1996. Note also that the magnitude of the own-price elasticities for feed have decreased from 1982 to the present. In recent years, these own-price elasticities have not been significantly different from zero. Looking at table 3, we also see that the calculated cross-price elasticities are close to zero and, hence, not economically significant.

As mentioned earlier, assuming full static equilibrium when the correct specification is a short-term equilibrium, might lead to biased elasticities (Brown and Christensen 1981). Even though the calculated elasticities might give indications about substitution possibilities or the fixity of some inputs, the results found should be treated with care.

Testing Full-Static versus Short-Run Equilibrium

Own-price elasticities close to zero provide evidence for the lack of substitution possibilities. Limited or zero substitution possibilities indicate that farmers will have problems adjusting to changes in input prices. However, since the elasticities

Table 1
Estimated Parameters, Translog Cost Function

	1994		1995		1996		1997		1998	
Parameter	Est.	St. Error	Est.	St. Error	Est.	St. Error	Est.	St. Error	Est.	St. Error
α_0	15.719	0.014	15.859	0.012	15.989	0.012	16.366	0.013	16.514	0.015
α_1	0.68	0.004	0.708	0.004	0.7	0.004	0.731	0.004	0.742	0.004
α_2	0.164	0.003	0.148	0.002	0.165	0.003	0.146	0.003	0.151	0.004
α_3	0.156	0.003	0.144	0.002	0.135	0.003	0.123	0.003	0.107	0.003
γ_{11}	0.174	0.021	0.166	0.017	0.2	0.018	0.194	0.017	0.171	0.022
γ_{12}	–0.124	0.015	–0.092	0.012	–0.135	0.013	–0.116	0.013	–0.127	0.018
γ_{13}	–0.05	0.013	–0.074	0.01	–0.065	0.01	–0.078	0.01	–0.043	0.011
γ_{22}	0.151	0.015	0.098	0.013	0.142	0.013	0.115	0.013	0.133	0.018
γ_{23}	–0.027	0.009	–0.006	0.007	–0.006	0.007	0.001	0.007	–0.005	0.009
γ_{33}	0.077	0.011	0.08	0.008	0.071	0.009	0.077	0.008	0.049	0.009
α_Q	0.939	0.025	0.912	0.02	0.881	0.016	0.912	0.014	0.935	0.016
α_{QQ}	–0.003	0.059	0.097	0.052	0.087	0.027	0.059	0.022	0.078	0.027
α_{Q1}	0.033	0.008	0.033	0.007	0.02	0.006	0.01	0.005	0.017	0.006
α_{Q2}	–0.012	0.006	–0.009	0.005	–0.002	0.004	–0.001	0.004	–0.002	0.005
α_{Q3}	–0.021	0.006	–0.025	0.005	–0.019	0.005	–0.009	0.004	–0.014	0.004

Table 2
Own-price Elasticities, Standard Error in Parentheses

	1982–83[a]	1994	1995	1996	1997	1998
ε_{feed}	–0.23	–0.07	–0.06[b]	–0.02	–0.003	–0.03
		(0.03)	(0.02)	(0.03)	(0.02)	(0.03)
$\varepsilon_{capital}$	–0.46	0.08[b]	–0.19[b]	0.03	–0.06	0.03
		(0.09)	(0.08)	(0.08)	(0.09)	(0.12)
ε_{labor}	–0.32	–0.35[b]	–0.30[b]	–0.34[b]	–0.26[b]	–0.45[b]
		(0.07)	(0.06)	(0.07)	(0.07)	(0.08)

[a] Source: Salvanes (1989).
[b] Significantly different from zero at the 5% level.

Table 3
Cross-price Elasticities

	1994	1995	1996	1997	1998
$\varepsilon_{feed–labor}$	0.08*	0.04*	0.04*	0.02	0.05*
	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)
$\varepsilon_{labor–feed}$	0.36*	0.20*	0.23*	0.10	0.35*
	(0.08)	(0.07)	(0.07)	(0.08)	(0.10)
$\varepsilon_{feed–capital}$	–0.02	0.02	–0.03	–0.01	–0.02
	(0.02)	(0.17)	(0.02)	(0.02)	(0.02)
$\varepsilon_{capital–feed}$	–0.07	0.08	–0.12	–0.07	–0.11
	(0.09)	(0.08)	(0.08)	(0.09)	(0.12)
$\varepsilon_{capital–labor}$	–0.01	0.11*	0.10*	0.13*	0.07
	(0.05)	(0.05)	(0.05)	(0.05)	(0.06)
$\varepsilon_{labor–capital}$	–0.01	0.11*	0.12*	0.15*	0.10
	(0.06)	(0.05)	(0.05)	(0.06)	(0.08)

Note: Standard Error in Parentheses
* Significantly different from zero at the 5% level.

might be biased, further analysis is needed. Several tests are developed to analyze the validity of static equilibrium models and to eventually define variables as variable or fixed. One such test is presented by Kulatilaka (1985). His point of departure is the result in equation (8), which states that in long-run equilibrium, the shadow price of the jth quasi-fixed input should be equal to its market rental price.[11] If this is not the case, the firms are not optimally adjusted to prices.

Consequently, we perform a test based on the same principle as Kulatilaka. A confidence interval is formed around the observed R_i. It is then tested if R_i falls within this interval, whereby the estimated R_i values are obtained by solving the first-order condition [*i.e.*, equation (8)]. The hypothesis to be tested is H_0: $R_{ik}^* = R_{ik}$. This test is performed at the observed values of the fixed factors. After forming a confidence interval around R_{ik}^*, the computed test statistic is given as:

$$t_1 = (R_i^* - R_i)'V(R_i^*)^{-1}(R_i^* - R_i), \tag{13}$$

which is chi-squared distributed with N degrees of freedom. Our approach is slightly different from that of Kulatilaka, in that we calculate the variance of the estimated R_i by bootstrapping methods instead of the linear approximation presented in Kulatilaka (1985).[12] Kulatilaka suggests initially testing a full-static equilibrium model against a short-run equilibrium model (with one quasi-fixed factor). A repeated application of this process can be used to select the appropriate SRE model. In other words, before accepting the SRE model with a single quasi-fixed factor, we should test this model against an even more general one with two or more quasi-fixed factors. In this second round, the SRE model with a single quasi-fixed factor plays the role of the FSE, and the SRE models with two quasi-fixed factors become analogous to the SRE in the basic scenario. We tested the following models against each other:

$$\begin{aligned} \text{FSE} &= f(P_{feed}, P_{labor}, P_{capital}, Q) \\ \text{SRE}_1 &= f(P_{feed}, P_{labor}, Z_{capital}, Q) \\ \text{SRE}_2 &= f(P_{feed}, P_{capital}, Z_{labor}, Q) \\ \text{SRE}_3 &= f(P_{feed}, Z_{labor}, Z_{capital}, Q). \end{aligned} \tag{14}$$

Table 4 presents χ^2 values from the Kulatilaka test, where χ^2 values larger than the critical values mean that the observed rental price is significantly different from the calculated shadow price. According to table 4, the full-static equilibrium FSE model is rejected for all years. The test statistics also show that we can reject the short-term equilibrium model with capital as fixed and feed and labor as variable (the SRE_1) for all years. These results provide evidence that the only factor that the farmer can adjust during production (after investment in smolts is undertaken) is feed. This supports the finding, based on calculated elasticities, that salmon farmers have very limited substitution possibilities, especially in the short run.

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[11] Kulatilaka (1985) also proposes a test comparing the actual quantities of the quasi-fixed inputs and the static equilibrium quantities implicitly defined by equation (8).

[12] As pointed out in Davidson and MacKinnon (1993), bootstrapping methods might be superior when asymptotic theory may be inadequate.

Table 4
The Kulatilaka Test

Year	SRE_1 versus FSE	SRE_2 versus FSE	SRE_3 versus SRE_2
1994	160	1,219	8,289
1995	1,615	2,050	5,205
1996	532	1,705	9,862
1997	2,446	2,270	6,546
1998	1,010	165	3,847

The numbers are χ^2 distributed, critical value for a 99% level is 158.

Summary and Conclusions

The main objective of this study was to examine whether changes in technology have had consequences on the substitution possibilities for Norwegian salmon farmers. Translog cost functions were estimated, and own- and cross-price elasticities were calculated. The calculated elasticities provided strong evidence of few or nonexistent substitution possibilities. To further investigate these results, we tested the validity of static equilibrium models and different short-term equilibrium models. Our empirical results show that the conditions required for a full-static equilibrium, FSE specification, are violated for all years in the sample. A short-run equilibrium specification, with capital as quasi-fixed is also rejected, indicating that the correct specification is an SRE model with feed as the only variable input.

Beyond the consequences for fish farm management, the growing cost share of feed, together with limited substitution possibilities, have some interesting policy implications. Salmon production has long been an area for trade disputes (Asche 1997; 2001). As a response to international trade tensions, Norwegian production has been regulated with feeding quotas in the last years. Given a production process as outlined in this study, it can be argued that the system of feeding quotas in force for Norwegian salmon farmers today is a very effective way of controlling production.

Several studies provide evidence that operating costs in farming drives salmon prices (Asche 1997; Asche, Bremnes, and Wessells 1999). With feed as the largest part of costs and with zero substitution possibilities, we can conclude also that salmon prices in the future will be even more dependent upon the price of feed, and consequently more dependent upon the price of raw materials of feed. As fish feed consists mostly of fishmeal/oil, salmon farming can be described as a converter industry, where you convert a low-value fish (in the form of fishmeal/oil) to a high-value fish, salmon.

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