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Are Prices or Biology Driving the Short-Term Supply of Farmed Salmon?

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Abstract *The short-term relationships between the supply of farmed salmon and its market and biological determinants are not fully understood. In this article an econometric model of salmon supply is estimated exploiting monthly data on Norwegian salmon aquaculture. Our estimates indicate that supply has shifted over time due to innovations in several areas. We find that the price of farmed salmon has a limited effect on supplied quantity, giving a highly inelastic short-run supply elasticity. The biomass and seasonal factors are the main determinants of shifts in salmon supply in the short term.*

Key words Atlantic salmon, supply, biomass, innovation.

JEL Classification Codes D22, Q11, Q22.

Introduction

Salmon, together with shrimp, are the leading aquaculture species, as these two species make up about 30% of global production value. Several species of salmon is farmed, with Atlantic salmon as the most successful. In 2010, Atlantic salmon represented about 75% of the approximately two million tonnes of farmed salmon production. The main reason for the growth in salmon production has been a tremendous productivity growth amplified by a substantial demand growth (Asche 2008). On the supply side, innovations in many areas have led to increased productivity and reductions in unit production costs. This process has been investigated in a number of productivity studies (Tveteras 1999, 2000;

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Guttormsen 2002; Tveteras and Heshmati 2002; Andersen, Roll, and Tveteras 2008; Asche, Roll, and Tveteras 2009; Nilsen 2010; Vassdal and Sørensen Holst 2011). Tveteras (2002) and Tveteras and Battese (2006) also show that there are external economies of scale in salmon aquaculture. However, while these studies provide important insights into the effect of changed input factor composition, scale economies, technological change, inefficiency, and production risk, little attention has been given to their influence on output and the effect of price changes on production. The only partial exceptions are Asche, Kumbhakar, and Tveteras (2007) who derive an estimate of supply elasticity from a cost function, and Andersen, Roll, and Tveteras (2008) who estimate short-run, as well as long-run, supply elasticity based on a restricted profit function.

Hence, we have a limited understanding of short-term supply determinants for salmon, and in particular quantitative relations between the harvest (supply) of farmed salmon and variables such as the salmon market price, salmon feed price, biomass of live fish in the sea, and sea temperature. A main reason for this lack of data is that all productivity studies are conducted using annual data. The only variable that is readily available at a high frequency is price. Price has been used to investigate the relationship between different weight classes (Asche and Guttormsen 2001), price volatility (Oglend and Sikveland 2008), and forecasting (Vukina and Anderson 1993; Guttormsen 1999). Econometric analyses of short-term market dynamics in the salmon market using monthly data have focused on the demand side or pure price effects, as data at a higher frequency have only been available downstream.[1]

We also know little about how technological and organizational innovations in the salmon aquaculture industry have influenced the supply of salmon over time. Salmon prices exhibit substantial volatility in the short and also longer run (Oglend and Sikveland 2008), indicating that the ability of salmon supply to respond to price fluctuations is limited. Innovations in sales and increased use of contracts can limit supply response (Kvaløy and Tveteras 2008; Larsen and Asche 2011).[2]

This article exploits a unique data set of Norwegian salmon aquaculture to examine which factors influence the supply of salmon. The uniqueness applies both to the time frequency and variables of the data set. The data set is monthly, and in addition to price data we also have access to biomass and temperature data as determinants of supply. This allows us to specify a supply equation that accounts for economic as well as biophysical factors, and thereby not only to control for the influence of different factors on short-term dynamics, but also to assess the relative importance of those factors. We know from the literature on harvesting models that at any point in time there is much more salmon available in the pens than what is being harvested (Guttormsen 2008), and that the supply chain can create distortions between consumer demand and the derived demand facing the salmon farmer (Asche, Roll, and Tveteras 2007).

The article is organized as follows. First we provide a background discussion on the production and supply of farmed salmon. Next, we present the econometric model specification, followed by empirical results. Finally, we provide a summary and conclusions.

The Production Process

To understand what factors influence salmon supply, and how those factors influence supply, it is useful to know the biological production process in salmon farming. The process can be divided into three steps: production of brood stock, roe, and fry; production of

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[1] However, several studies have shown that long-run demand elasticities have a higher magnitude than short-run elasticities (Asche, Salvanes, and Steen 1997) and investigated for market integration (Asche, Bremnes, and Wessells 1999; Asche *et al*. 2002) and market power (Fofana and Jaffry 2008).

[2] Short-run supply response can also be influenced by the product mix (Asche 2009).

smolts;[3] and production of farmed fish (Asche and Bjørndal 2011). These three stages are generally undertaken in distinct plants. We are concerned with the production of farmed fish; *i.e.*, the last step in the biological production process.

Smolts are transferred from a producer that can be independent or integrated into a larger company and released into pens between spring and early fall. A cohort of salmon is kept in the pens and fed for a period 16–22 months before harvesting. The growth rate of the fish is mainly determined by feeding intensity and sea temperature. As our focus is the short-run production process, we will treat the number of smolts released into the pens, as well as the pens themselves and other capital equipment, as given. A detailed description of the biological production process can be found in Guttormsen (2008) and Asche and Bjørndal (2011). Given the number of smolts released, the key parameters are mortality and growth rates. The stock of salmon in cohort *c* at the end of month *t* is defined by:

$$w_{c,t}n_{c,t} = (1 - m_{c,t} - h_{c,t})(1 + g_{c,t})w_{c,t-1}n_{c,t-1},$$

where $g_{c,t}$ is the growth rate in month *t*, $m_{c,t}$ is the mortality rate of cohort *c* in month *t*, $h_{c,t}$ is the harvest rate in month *t* (with the restriction $(1 - m_{c,t} - h_{c,t})\ 0$), $n_{c,t-1}$ is the initial number of fish in cohort *c* in month *t*, and $w_{c,t-1}$ is the initial average weight of the fish.[4]

Production in a given period is defined as the change in total biomass from the beginning to the end of the period plus the harvested biomass in the period. It is interesting to note that, in general, harvest is not equal to the level of production. The above definition also implies that production can be negative for a period; for instance if the mortality rate is extremely high. The recent disease outbreak in Chilean salmon aquaculture provides a clear example of such a situation (Asche *et al.* 2009).

Our only variable input factors are feed cost and the value of time. Feed cost makes up almost 60% of total cost, and Guttormsen (2002) argues that in the short run, it can be treated as the only variable factor. However, the actual quantity of feed used in the production process also depends to some extent on stochastic biophysical variables (or shocks), such as disease and water temperature. If the survival rate of the fish is lower than expected; *e.g.*, due to unexpected disease losses, the feed consumption rate will also be lower than expected. If sea temperatures during the year are lower than expected, then feed consumption will also be less, since the appetite of the fish depends on sea temperature (Austreng, Storebakken, and Åsgård 1987). The time preference is included because in all harvesting models this is a key parameter in determining when to harvest the fish.

The salmon farming company's problem is to maximize the net present value (NPV) from its operations. Since risk is present in salmon farming, the objective is to maximize the expected utility of NPV if the decision maker is risk averse. If the decision maker is risk neutral, maximiation of the expected NPV should be the objective (Kumbhakar 2002; Kumbhakar and Tveteras 2003; Forsberg and Guttormsen 2006; Guttormsen 2008).

Over time, the Norwegian salmon farming industry has faced different sets of regulations aimed at limiting production both at the industry and farm levels (Kinnucan and Myrland 2002; Tveteras 2002; Asche and Bjørndal 2011). Since the early days of the industry, the Norwegian government has limited the total number of farms through regulation of the number of farm production licenses issued. In the 1980s the government introduced a restriction on total fish cage volume for each farm. In 1991 a fish density restriction per cubic meter of cage volume was introduced. Together, the two regulations limited total production at a farm site. In 1996 the restriction on production at the farm

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

[4] This definition of production implies that salmon in the same cohort is homogenous; *i.e.*, the initial weight and growth rate are identical across all individuals for all periods.

and industry levels was strengthened when a farm-level feed quota regulation was introduced that stated the maximum volume of feed to be used at the farm through the year. In 2005 the cage volume and feed quota restrictions were replaced with a 'maximum allowable standing biomass' (MASB) restriction that stated the maximum volume of live fish (in tonnes) that could be present in the cages at any time. Unlike previous regulations, this restriction would force the salmon farmer to harvest fish whenever the standing biomass exceeded the MASB level.[5]

The consequence of these regulations is that fish biomass is a quasi-fixed factor in the production process. A salmon company has to take into consideration that available biomass capacity and pen volume is needed for the new cohort each year, and the farmer has to form expectations on salmon prices in the relevant periods when making his harvesting profile decision (Forsberg and Guttormsen 2006; Guttormsen 2008). In some periods salmon prices have exhibited large short-run fluctuations, as depicted in figure 1, and consequently the choice of harvesting profile can have significant effects on the profitability of salmon farms.

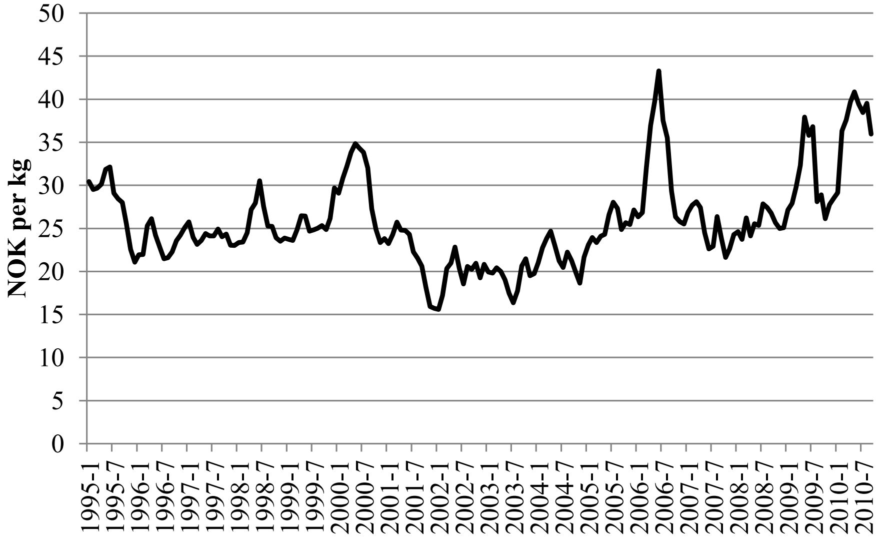

Figure 1. Norwegian Atlantic Salmon Spot Price

Source: NOS Clearing <http://www.nosclearing.com>.

Salmon farming can be characterized as a competitive industry with many companies supplying a fairly homogeneous commodity (Asche and Bjørndal 2011). There are at least three important observations concerning the development of salmon prices over time. First, the productivity growth from the 1980s that is reflected in declining real unit production costs also contributed to a reduction in real prices (Asche 2008). Second, as shown in figure 1, real salmon prices have not continued to trend downward after 2000,

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[5] The regulatory system has changed over time, and various measures have been used to regulate the size of each production license (Asche and Bjørndal 2011). However, it should be noted that these measures do not reduce the size of each plant, as several licenses can be operated at the one plant. This has led to the number of plants in Norway being reduced over time.

as the salmon farming industry has not managed to keep up its pace of cost reducing innovations (Larsen and Asche 2011). Third, there are substantial cycles around the long-run price trend line, as shown by Oglend and Sikveland (2008).

The main cause for high price volatility is inelastic short-run supply, which is likely to be constrained because of the nature of the salmon production process. This implies that prices can have limited effect on the supply of salmon in the short-run. On the other hand, market prices can have a much larger effect on fry and smolt production and on grow-out farms' smolt purchase decisions. However, the effect of these decisions on the supply and prices of salmon is typically not observed until 1.5–2 years later. The inelastic salmon supply in the short run is supported by Andersen, Roll, and Tveteras (2008), who found a short-run output price elasticity of only 0.05, based on econometric estimates on a large panel of annual observations of Norwegian salmon farms. They estimated long-run supply elasticity in an output price of 1.40, suggesting a much higher response in the long run, which is in line with our arguments above.

Some companies have entered into contracts with buyers who specify both the timing and volume of deliveries (Kvaløy and Tveteras 2008; Larsen and Asche 2011). These contractual obligations obviously have some impact on the harvest decision. In general, contractual obligations reduce the responsiveness of supply to changes in the spot price of salmon.

Future growth potential and sexual maturity of the salmon cohort should influence the harvest decision. As the salmon grows above the minimum harvest weight of 2–3 kg, the growth rate potential will, on average, tend to decline, which means that the marginal economic benefit (in terms of NPV) of keeping and maintaining the biomass capital declines and eventually becomes negative. The increased risk of sexual maturation as the fish gets bigger, which means a value reduction for the fish, gives the farmer added incentives to harvest.

Sea temperature and other biophysical conditions also influence production and production decisions. The growth rate of salmon increases with sea temperature up to some level. Oxygen consumption also increases with rising sea temperature, while the availability of oxygen in the seawater decreases. When the sea temperatures are sufficiently high, the farm may face constraints in terms of oxygen availability. For high summer temperatures, the salmon may grow at a slower rate and become more susceptible to stress-related diseases. This can give incentives to harvest during the summer months (Reithe and Tveteras 2000). During the cold winter months, the low growth rates for fish of harvest-ready weight may also provide incentives to harvest.

Other factors influencing supply are harvesting and processing costs and capacities (Kvaløy and Tveteras 2008). There are economies of scale in several of the processes from harvesting to transportation to primary processing. This gives farmers incentives to reduce the number of harvests for a cohort of fish. On the other hand, there may also be capacity constraints in transportation vessels and processing plants that limit how much fish can be received in the short run.

All these factors imply that the salmon farms have limited intertemporal flexibility in their harvesting decisions after they have released smolts into the pens, and that farms often face a time window of only a few months during which the fish must be harvested. In particular, there is limited flexibility to respond to expectations on future price increases or reductions.

Salmon Supply Model Specification

Nerlove (1956, 1958) has provided the most influential model of farmer supply. He presented a partial adjustment-adaptive expectations model for selected crops. The so-called Nerlove model, hypothesizing farmer responses in terms of price expectations and/or partial area (or production) adjustments, has been adopted, modified, and extensively revised by many later authors that have examined supply response in agriculture (Askari and Cummings 1977).

For the econometric estimation of salmon supply models, the empirical literature on livestock supply may be more relevant in several respects than studies that focus on crop supply. Econometric studies on livestock supply have been provided by Heien (1975) on pork and Epple and McCallum (2006) on poultry. Asche (2009) provided estimates of wild fish supply responses.

Nerlove's model focused on the supply side of an agricultural commodity market. However, it is natural to specify a model that also accounts for the demand side and possibly other relations that determine market quantity and price outcomes. As maintained by Epple and McCallum (2006) specifying such models is not a trivial exercise. Apple and McCallum surveyed 26 textbooks for simultaneous equation models of supply and demand and found that it is not easy to obtain proper signs and statistical significance for crucial parameters.

The monthly dataset we will analyze has been collected by the Norwegian Seafood Export Council, Kontali AS, and Marine Harvest AS.[6] It spans the time period from January 1995 to December 2007, a total of 168 observations. Some variables are missing observations resulting in a somewhat smaller set of 135 observations.

Our model accounts for the influence of biomass, as discussed previously, the simultaneous determination of price and quantity by the demand and supply side, and changes in the price margins in the international value chain. Hence, we estimate an econometric system of four simultaneous dynamic equations: (1) Norwegian salmon harvest supply, (2) biomass of salmon at Norwegian farms, (3) global demand for Norwegian salmon, and (4) 'price margin' for Norwegian salmon, as specified in equations (1)–(4) below:

$$\ln H_t^S = \alpha_0 + \alpha_{HS1} \ln H_{t-1}^S + \sum_{m=2}^{12} \alpha_m D_m + \alpha_P \ln P_t + \alpha_{F1} \ln P_{t-1}^F + \alpha_{B1} \ln B_{t-1} + \alpha_c \ln C_t \\ + \alpha_t t + \alpha_{tt} t^2 \tag{1}$$

$$\ln B_{t-1} = \beta_0 + \beta_{B2} \ln B_{t-2} + \beta_{B3} \ln B_{t-3} + \sum_{m=2}^{12} \beta_m D_m + \\ \beta_{C1} \ln C_{t-1} + \beta_{P1} \ln P_{t-1} + \beta_{P2} \ln P_{t-2} + \beta_t t + \beta_{tt} t^2 \tag{2}$$

$$\ln H_t^D = \delta_0 + \sum_{m=2}^{12} \delta_m D_m + \delta_{HD1} \ln H_{t-1}^D + \sum_{c=1}^{4} \delta_{PE_c} \ln PE_{c,t} + \sum_{c=1}^{4} \delta_{PE1_c} \ln PE_{c,t-1} \\ + \delta_I \ln I_t + \delta_{I1} \ln I_{t-1} + \delta_t t + \delta_{tt} t^2 \tag{3}$$

$$\ln P_t = \theta_0 + \sum_{m=2}^{12} \theta_m D_m + \theta_{P1} \ln P_{t-1} + \sum_{s=0}^{1} \theta_{PEN_{t-s}} \ln PE_{N,t-s} + \sum_{s=0}^{1} \theta_V \ln V_{t-s} \\ + \theta_t t + \theta_{tt} t^2 \tag{4}$$

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[6] The data set was collected and compiled in a joint research project with these companies funded by the Norwegian Research Council.

Subscript t represents time (in months) and represents the month of the year (m=1 is January, m=2 is February, etc.). In the third equation subscript c represents country (Norway, Chile, UK, and Canada). The choice of lags for the explanatory variables has been determined by tests of individual significance and autocorrelation.

Supply, equation (1), is specified with harvest quantity (H) as the dependent variable. The endogenous variable harvest quantity is included as a lagged explanatory variable to capture differences in short-run and long-run supply responses to changes in explanatory variables. In the supply equation, harvest quantity is dependent on the sales price at farm gate in Norwegian kroner (P), feed price (P_F) in the previous month, sea temperature (C), and biomass of live fish in the sea cages, (B), in the previous month. As predicted by theory, we expect a positive relationship between sales price and salmon supply, and a negative relationship with the price of the most important input in terms of cost share, feed price. We also expect a positive relationship between the biomass of live fish in the cages and salmon supply. A high biomass may give incentives to harvest due to high, unsustainable fish densities in the cages, or because the biomass approaches the government's regulatory constraints. It should also be noted that the trend development of the biomass of live fish over time, which can be viewed as the farmers' biological capital, is correlated with the development of the amount of fixed capital in production equipment, and thus the production capacity of the salmon farmers.

Monthly dummy variables, (D), are incorporated as to capture seasonal factors that influence supply, but which are not captured by the other variables. Time trend variables, (t), are also included to capture the effects of innovations (technological change) over time on salmon supply. The rate of technical change is defined as $e_{TS} = \alpha_t + 2\alpha_t t$ and $e_{TL} = (\alpha_t + 2\alpha_t t)/(1 - \alpha_{HS1})$ in the short and long run, respectively.

We use a double-log supply model. This implies that the estimated parameters, with the exception of those associated with the dummies and time trend, can be interpreted as short-run elasticities. The own-price elasticity of salmon supply is $e_{HS} = \alpha_P$ and $e_{HL} = \alpha_P / (1 - \alpha_{HS1})$ in the short and long run, respectively. Analogous short- and long-run elasticity measures apply to the other explanatory variables feed price, biomass, and temperature.

Biomass, equation (2), has biomass of live salmon in farm cages lagged one month as the dependent variable. Explanatory variables are the sales price at the farm gate in Norwegian kroner (P), sea temperature (C), and biomass of live fish (B). Furthermore, monthly dummy variables are included to account for seasonal effects on the stock of live salmon not captured by other variables. Time trend variables are also included to account for effects of innovations on the stocking of live fish.

Supply and demand quantity and price are jointly determined in the salmon market. As the third equation, we have consequently included global quantity demanded of Norwegian salmon. Salmon demand and markets have been analyzed in several studies (Wessells and Wilen 1994; Asche, Salvanes, and Steen 1997; Asche, Bjørndal, and Salvanes 1998; Eales and Wessells 1999; Xie, Kinnucan, and Myrland 2009). The demand for Norwegian Atlantic salmon is specified as a function of the own price of Norwegian salmon and the prices of Atlantic salmon substitutes from Chile, UK, and Canada in USD (PE_C). Finally, the consumers' salmon budget is represented by the global expenditures on salmon in USD (I).

The price margin, equation (4), is specified with sales price at farm gate in Norwegian kroner as the dependent variable. Among the explanatory variables is the Norwegian export price in USD (PE) and the exchange rate between Norwegian kroner (NOK) and USD (V).[7] As in the other equations we have included monthly dummy variables and time trend variables to account for seasonal effects and structural changes over time, respectively. We calculate the price transmission elasticity, which is given by $\varepsilon = 1/((\theta_{\mathrm{PEN}} + \theta_{\mathrm{PEN1}})/(1 - \theta_{\mathrm{P1}}))$, to test the hypothesis that it is different from one.

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[7] Asche and Tveterås (2008) analyzed the influence of exchange rates on international fish trade, including salmon.

Our system is estimated by three-stage least squares (3SLS). The endogenous variables in the model are Norwegian harvest quantity supply and demand (H^S and H^D), farm gate price (P), biomass (B), and Norwegian export price in USD (PE_N).

Empirical Results

Although we estimate a system that also includes a biomass equation, a demand equation, and a margin equation, our focus is on the estimates from the supply equation. Hence, our discussion of the empirical results will primarily focus on this equation.

Table 1 presents the Breusch-Godfrey LM test for first-order serial correlation in the error term for each of the four equations. We see from the *p*-value that autocorrelation is rejected at conventional confidence levels by the chi-square test of the null hypothesis of no serial correlation. Hence, there is no evidence of dynamic misspecification.

Table 1
Breusch-Pagan LM Test of First-Order Autocorrelation*

Equation	Chi-square	p-value
(1) Supply	1.932	0.1645
(2) Biomass	0.131	0.7177
(3) Demand	0.101	0.7505
(4) Price margin	2.106	0.1467

* H0: No serial correlation.

Table 2 presents the econometric estimates from our model (1)–(4). The total explanatory power of the four equations is good. For the supply equation the R^2 is 0.94, while for the other equations the R^2 is above 0.97. In all equations several of the lagged variables are statistically significant, indicating the importance of a dynamic specification.

In the supply equation we detect significant exogenous shifts in harvest during the year. The coefficients associated with the monthly dummy variables state that harvest supply exhibits a particularly large positive shift compared with the base month January in the last three months of the year, especially in December, due partly to the Christmas holiday. Harvest supply also has a positive shift in March, which can be attributed to Easter.

Table 3 shows the short-run and long-run elasticities for the continuous explanatory variables of the supply equation and the rate of technical change. We see from the table that although several of the elasticities are statistically significant at conventional confidence levels (10% and below), the magnitude of the estimated elasticities is generally small. This is also the case for salmon price. A 1% increase in the sales price gives a 0.091% increase in harvest in the short-run, and a 0.141% increase in harvest in the long-run. If we compare our estimate to Andersen, Roll, and Tveteras (2008) supply elasticities, it should be noted that their output price elasticity of 0.048 in the short-run and 1.415 in the long-run were based on annual data. It should also be noted that their supply elasticities are related to 'production,' which is defined as the harvest of salmon plus the change in biomass from the beginning to the end of the year, while our supply elasticities are only related to harvest.

The elasticity of salmon harvest supply with respect to the price of feed input is negative, as predicted by theory, –0.052 in the short run and –0.082 in the long run. However, none of these estimates are significantly different from zero at conventional confidence levels.

Table 2

3SLS Estimates of the Econometric Model

Supply Equation (1)

Parameter	Coeff.	St.err.	t-val.	p-val.
α_{HS1}	0.358	0.074	4.87	0.000
α_2	0.122	0.044	2.74	0.006
α_3	0.362	0.047	7.71	0.000
α_4	0.215	0.038	5.63	0.000
α_5	0.271	0.048	5.68	0.000
α_6	0.298	0.058	5.17	0.000
α_7	0.221	0.066	3.36	0.001
α_8	0.278	0.068	4.1	0.000
α_9	0.337	0.062	5.44	0.000
α_{10}	0.353	0.052	6.73	0.000
α_{11}	0.361	0.041	8.75	0.000
α_{12}	0.456	0.032	14.07	0.000
α_P	0.091	0.044	2.09	0.037
α_{F1}	–0.053	0.089	–0.59	0.553
α_C	–0.006	0.055	–0.11	0.914
α_{B1}	0.086	0.036	2.4	0.016
α_0	0.004	0.001	3.7	0.000
α_0	0.000	0.000	–1.44	0.149
α_0	5.039	0.917	5.49	0.000

$R^2 = 0.942$

Biomass Equation (2)

Parameter	Coeff.	St.err.	t-val.	p-val.
β_2	–0.007	0.041	–0.18	0.861
β_3	–0.113	0.048	–2.35	0.019
β_4	–0.230	0.053	–4.36	0.000
β_5	–0.216	0.049	–4.45	0.000
β_6	–0.187	0.051	–3.66	0.000
β_7	0.006	0.068	0.08	0.933
β_8	0.347	0.083	4.19	0.000
β_9	0.400	0.089	4.49	0.000
β_{10}	0.243	0.083	2.93	0.003
β_{11}	0.264	0.062	4.27	0.000
β_{12}	0.115	0.045	2.54	0.011
β_{B2}	1.071	0.079	13.62	0.000
β_{B3}	–0.335	0.078	–4.28	0.000
β_{P1}	–0.242	0.132	–1.83	0.067
β_{P2}	0.221	0.127	1.74	0.082
β_C	–0.232	0.084	–2.77	0.006
β_t	0.003	0.001	3.12	0.002
β_{tt}	0.000	0.000	–1.18	0.237
β_0	3.227	0.640	5.04	0.000

$R^2 = 0.975$

Table 2 (continued)

Demand Equation (3)

Parameter	Coeff.	St.err.	t-val.	p-val.
δ_{HD1}	0.489	0.068	7.14	0.000
δ_{PENOR}	–0.615	0.135	–4.56	0.000
δ_{PENOR1}	0.299	0.132	2.26	0.024
δ_{PECHI}	–0.085	0.059	–1.45	0.146
δ_{PECHI1}	0.127	0.057	2.24	0.025
δ_{PEUK}	–0.010	0.068	–0.15	0.879
δ_{PEUK1}	0.046	0.064	0.72	0.470
δ_{PECAN}	–0.124	0.085	–1.45	0.146
δ_{PECAN1}	0.059	0.088	0.67	0.503
δ_{I}	0.734	0.078	9.39	0.000
δ_{I1}	–0.363	0.095	–3.82	0.000
δ_2	0.101	0.030	3.41	0.001
δ_3	0.212	0.033	6.47	0.000
δ_4	0.124	0.024	5.17	0.000
δ_5	0.143	0.026	5.51	0.000
δ_6	0.158	0.026	6.01	0.000
δ_7	0.100	0.026	3.82	0.000
δ_8	0.137	0.029	4.65	0.000
δ_9	0.216	0.027	8.15	0.000
δ_{10}	0.191	0.027	7.08	0.000
δ_{11}	0.188	0.027	6.99	0.000
δ_{12}	0.224	0.032	6.97	0.000
δ_t	0.000	0.002	–0.24	0.812
δ_{tt}	0.000	0.000	0.86	0.392
δ_0	0.956	1.070	0.89	0.371

$R^2 = 0.976$

Price Margin Equation (4)

Parameter	Coeff.	St.err.	t-val.	p-val.
θ_{P1}	0.654	0.073	8.93	0.000
θ_{PEN}	1.733	0.131	13.26	0.000
θ_{PEN1}	–1.296	0.107	–12.12	0.000
θ_{V}	1.731	0.186	9.29	0.000
θ_{V1}	–1.408	0.173	–8.14	0.000
θ_2	0.008	0.014	0.60	0.552
θ_3	0.025	0.014	1.75	0.080
θ_4	0.020	0.014	1.38	0.169
θ_5	0.020	0.015	1.36	0.175
θ_6	0.011	0.015	0.78	0.436
θ_7	0.011	0.015	0.74	0.457
θ_8	0.040	0.014	2.79	0.005
θ_9	0.005	0.015	0.36	0.718
θ_{10}	0.001	0.014	0.07	0.947
θ_{11}	–0.001	0.014	–0.08	0.939
θ_{12}	0.014	0.014	1.02	0.308
θ_t	0.000	0.001	–0.54	0.586
θ_{tt}	0.000	0.000	–0.12	0.903
θ_0	–0.061	0.097	–0.63	0.532

$R^2 = 0.973$

N = 135 observations.

Table 3
Short- and Long-run Elasticities in the Harvest Supply Equation

	Short Run		Long Run	
Variable	Estimate	p-value	Estimate	p-value
Salmon farm gate price	0.091**	0.037	0.141**	0.036
Feed price	–0.052	0.553	–0.082	0.553
Sea temperature	–0.005	0.914	–0.009	0.914
Biomass of live fish	0.086**	0.016	0.134**	0.020
Technical change	0.003***	0.0001	0.005***	0.0001

** Significant at the 5% level; *** significant at the 1% level.

Sea temperature is generally expected to lead to an increase in salmon production, but not necessarily harvest, as salmon grows faster at higher temperatures up to a certain level. When temperatures are at their highest levels during the summer, farmers may have incentives to harvest, since high densities of salmon in the cages lead to conditions that may increase mortality and/or reduce growth rates, or because government regulations become binding. But according to our estimates, sea temperature seems to have no statistically significant effect on harvest supply. It may well be the case, however, that some of the effects of temperature on harvest supply are captured by the monthly dummy variables.

A variable that matters more than temperature is the biomass of live salmon in the previous month. The short-run elasticity is 0.086 and the long-run elasticity is 0.134%, and both are statistically significant at the 5% level. Hence, an increase in biomass in the previous month leads to a higher harvest of salmon, although the effect is rather small in relative terms.

Innovations are expected to influence the supply of salmon over time. Our time trend variables measure the effect of technological progress, and possibly innovations in organizational or market factors, on salmon supply over time as the level of the other explanatory variables; *e.g.*, biomass of live fish, are held constant. The rate of technical change is 0.3% in the short run and 0.5% in the long run, and both are statistically significant at the 1% level. Although the estimated rates of technical change seem small, one must remember that these are monthly figures—translated to 12 months, the rate of technical change in the short run is 3.7%. Hence, there has been a significant influence from different innovations on the harvest supply of salmon during the data period. This is in line with recent parametric productivity studies (Asche, Roll, and Tveteras 2009; Nilsen 2010).

According to the estimated biomass, equation (2), the stock of live salmon in cages is strongly positively related to the biomass in the previous month, as could be expected *a priori*. However, the relationship with the stock of live fish two months prior is negative. The price of salmon has an ambiguous effect, as the current monthly price negatively influences biomass, while the price in the prior month has a positive effect. There is a significant negative relationship between the stock of live fish and sea temperature. This may be due to farmers harvesting fish because of unsustainable concentrations of fish with higher temperature, and/or because government regulations on fish densities or total biomass become binding in periods with higher temperature. It is interesting to note that sea temperature seems to have more influence on the farms' total biomass of live fish than their harvest supply. The time trend variables indicate that innovations have contributed to an increase in biomass conditional on the other variables (*e.g.*, biomass in previous month), but the rate of technical progress has declined over time. Finally, monthly dummy variables indicate that the stock of live fish is generally kept below the January reference month level in the first half of the year—conditional on the level of the other explanatory variables—while it is generally above the January reference level in the last six months of the year.

The estimated demand equation (3) provides short- and long-run own-price elasticities of –0.32 and –0.62, respectively, as shown in table 4. These are somewhat lower than what has commonly been reported in the literature, but given that the demand for salmon is becoming more inelastic and that demand elasticity is measured higher upstream than in other studies, these estimates are reasonable. The elasticities associated with the price of substitutes from other salmon-producing countries are generally not significantly different from zero. Again, this is not surprising at this level in the supply chain. An increase in income, as proxied by the global salmon expenditures variable, leads to a positive shift in salmon demand. The short-run and long-run income elasticities are 1.47 and 2.87, respectively. The coefficients associated with the monthly dummy variables suggest higher demand in March and the last three months of the year.

Table 4

Short- and Long-run Elasticities in the Harvest Demand Equation

	Short Run		Long Run	
Variable	Estimate	p-value	Estimate	p-value
Norway salmon export price	–0.316***	0.001	–0.618***	0.0001
Chile salmon export price	0.042	0.231	0.082	0.226
UK salmon export price	0.036	0.589	0.070	0.584
Canada salmon export price	–0.064	0.459	–0.127	0.460
Income	1.468***	0.0001	2.869***	0.0001
Trend	0.0004	0.584	0.001	0.583

*** Significant at the1% level.

According to the estimated price margin, equation (4), the long-run price transmission elasticity is 0.79, and not statistically different from 1. This is in line with the high price transmission elasticity reported in Asche, Jaffry, and Hartman (2007). It is also as expected, given that there is only one variable input factor in the short run (Asche *et al*. 2002). The long-run effect of depreciation of the Norwegian krone relative to the USD also has a positive effect in the long run. This is as expected given the high degree of exchange rate transmission in the salmon market (Asche and Tveterås 2008).

Summary and Conclusions

The global supply of Atlantic salmon has increased from almost nothing in the early 1980s to a current level of about 1.5 million metric tonnes, with a farm gate sales value of 8–9 billion USD. It is important to understand the short-term supply side determinants of this growing industry, as this is an industry characterized by much volatility in supply and price. Until now, econometric analyses of short-term market dynamics in the salmon market using monthly data have focused mostly on the demand side. The volatility in supply and price entails costs for agents in the value chain, particularly since the salmon industry increasingly has been expected by processors and retail buyers to provide a steady and predictable supply of salmon during the year with prices that do not fluctuate too much.

In this article we have exploited a unique monthly data set to estimate a system of equations that include Norwegian farmed salmon supply. We find that there has been a significant positive influence from different innovations on the harvest supply of salmon during the data period. According to the estimated model, the farm gate sales price has limited influence on the short-term monthly harvest supply of salmon as measured by short- and long-run own price elasticities. The price of feed, the most important input in salmon farming with a cost share of around 60%, has no significant effect on the short-term harvest supply. Sea temperature influences the growth rate of salmon, but according to our empirical estimates, this variable has no significant effect on monthly harvest supply. According to the estimated biomass equation, sea temperature seems to have a more influential effect on the farms' total biomass of live fish than their harvest supply. As could be expected *a priori*, our estimated biomass equation also shows that the current biomass is largely determined by the biomass in the previous month.

The biomass of live salmon has a statistically significant influence on harvest, but again the effect on harvest supply is small as measured by the short- and long-run elasticities. The coefficients associated with the monthly dummy variables in the estimated supply model suggest that there are large seasonal exogenous shifts in supply that cannot be explained by other variables. We suspect that the monthly dummy variables partly account for biological factors that provide incentives or disincentives to harvest, and partly account for changing supply obligations manifested in contracts and changing market conditions through the year.

An understanding of the role of prices in the supply of farmed salmon in the shorter and longer term is best obtained by combining the findings from this article with the findings from Andersen, Roll, and Tveteras (2008). In the short run, a time horizon of a few months, the price of salmon has limited influence on salmon supply, as it is largely determined by the existing stock of live salmon in the sea and exogenous factors in the market. However, in reality salmon price provides farmers with strong incentives to adjust supply. For the longer run, a time horizon of around a year or more, the increased ability to invest in fixed capital equipment and new biomass provides the farmer with greater ability to act upon these incentives, as Andersen, Roll, and Tveteras (2008) have found. Hence, as our time horizon moves from months to year, the importance of biological and other constraints is reduced, and salmon price becomes more influential as a determinant of salmon supply.

Future innovations and sources of productivity growth that may influence supply can come from a number of sources. Among the most interesting areas of innovation, but also most controversial, is genetically modified fish (Smith *et al*. 2010). Innovation is expected to increase the salmon growth rate and reduce mortality rates, thus increasing productivity in salmon farm supply. However, it remains to be seen to what extent innovation will change the price elasticity of supply in the short and long run.

References

Andersen, T.B., K.H. Roll, and S. Tveteras. 2008. The Price Responsiveness of Salmon Supply in the Short and Long Run. *Marine Resource Economics* 23:425–38.

Asche, F. 2008. Farming the Sea. *Marine Resource Economics* 23:527–47.

_____. 2009. Adjustment Cost and Supply Response: A Dynamic Revenue Function. *Land Economics* 85:201–15.

Asche, F., and T. Bjørndal. 2011. *The Economics of Salmon Aquaculture*, 2nd edition. Oxford, UK: Wiley-Blackwell.

Asche, F., T. Bjørndal, and K.G. Salvanes. 1998. The Demand for Salmon in the European Union: The Importance of Product Form and Origin. *Canadian Journal of Agricultural Economics* 46:69–82.

Asche, F., H. Bremnes, and C.R. Wessells. 1999. Product Aggregation, Market Integration and Relationships between Prices: An Application to World Salmon Markets. *American Journal of Agricultural Economics* 81:568–81.

Asche, F., O. Flaaten, J.R. Isaksen, and T. Vassdal. 2002. Derived Demand and Relationships between Prices at Different Levels in the Value Chain: A Note. *Journal of Agricultural Economics* 53:101–07.

Asche, F., and A.G. Guttormsen. 2001. Patterns in the Relative Price for Different Sizes of Farmed Fish. *Marine Resource Economics* 16:235–47.

Asche, F., H. Hansen, R. Tveteras, and S. Tveterås. 2009. The Salmon Disease Crisis in Chile. *Marine Resource Economics* 24:405–11.

Asche, F., S. Jaffry, and J. Hartman. 2007. Price Transmission and Market Integration: Vertical and Horizontal Price Linkages for Salmon. *Applied Economics* 39:2535–45.

Asche, F., S.C. Kumbhakar, and R. Tveteras. 2007. Testing Cost Versus Profit Functions. *Applied Economics Letters* 14:715–18.

Asche, F., K.H. Roll, and R. Tveteras. 2007. Productivity Growth in the Supply Chain—Another Source of Competitiveness for Aquaculture. *Marine Resource Economics* 22:329–34.

_____. 2009. Economic Inefficiency and Environmental Impact: An Application to Aquaculture Production. *Journal of Environmental Economics and Management* 58:93–105.

Asche, F., K.G. Salvanes, and F. Steen. 1997. Market Delineation and Demand Structure. *American Journal of Agricultural Economics* 79:139–50.

Asche, F., and S. Tveterås. 2008. International Fish Trade and Exchange Rates: An Application to the Trade with Salmon and Fishmeal. *Applied Economics* 40:1745–55.

Askari, H., and J.T Cummings. 1977. Estimating Agricultural Supply Response with the Nerlove Model: A Survey. *International Economic Review* 18:257–92.

Austreng, R., T. Storebakken, and T. Åsgård. 1987. Growth Rate Estimates for Cultured Atlantic Salmon and Rainbow Trout. *Aquaculture* 60:157–60.

Eales, J., and C.R. Wessells. 1999. Testing Separability of Japanese Demand for Meat and Fish within Differential Demand Systems. *Journal of Agricultural and Resource Economics* 24:114–26.

Epple, D., and B.T McCallum. 2006. Simultaneous Equation Econometrics: The Missing Example. *Economic Inquiry* 44:374–84.

Fofana, A., and S. Jaffry. 2008. Measuring Oligopsony Power of UK Salmon Retailers. *Marine Resource Economics* 23:485–506.

Forsberg, O.I., and A.G. Guttormsen. 2006. The Value of Information in Salmon Farming, Harvesting the Right Fish at the Right Time. *Aquaculture Economics and Management* 10:183–200.

Guttormsen, A.G. 1999. Forecasting Weekly Salmon Prices: Risk Management in Salmon Farming. *Aquaculture Economics and Management* 3:159–66.

_____. 2002. Input Factor Substitutability in Salmon Aquaculture. *Marine Resource Economics* 17:91–102.

_____. 2008. Faustmann in the Sea—Optimal Rotation in Aquaculture. *Marine Resource Economics* 23:401–10.

Heien, D. 1975. An Econometric Model of the U.S. Pork Economy. *The Review of Economics and Statistics* 57:370–75.

Kinnucan, H.W., and Ø. Myrland. 2002. The Relative Impact of the Norway–EU Salmon Agreement: A Mid-term Assessment. *Journal of Agricultural Economics* 53:195–219.

Kumbhakar, S.C. 2002. Specification and Estimation of Production Risk, Risk Preferences and Technical Efficiency. *American Journal of Agricultural Economics* 84:8–22.

Kumbhakar, S.C., and R. Tveteras. 2003. Risk Preferences, Production Risk and Firm Heterogeneity. *Scandinavian Journal of Economics* 105:275–93.

Kvaløy, O., and R. Tveteras. 2008. Cost Structure and Vertical Integration between Farming and Processing. *Journal of Agricultural Economics* 59:296–311.

Larsen, T.A., and F. Asche. 2011. Contracts in the Salmon Aquaculture Industry: An Analysis of Norwegian Salmon Exports. *Marine Resource Economics* 26:141–49.

Nerlove, M. 1956. Estimates of the Elasticities of Supply of Selected Agricultural Commodities. *Journal of Farm Economics* 38:492–509.

_____. 1958. Distributed Lags and the Estimation of Long-run Supply and Demand Elasticities. *Journal of Farm Economics* 40:301–11.

Nilsen, O.B. 2010. Learning-by-doing or Technological Leapfrogging: Production Frontiers and Efficiency Measurement in Norwegian Salmon Aquaculture. *Aquaculture Economics and Management* 14:97–119.

Oglend, A., and M. Sikveland. 2008. The Behaviour of Salmon Price Volatility. *Marine Resource Economics* 23(4):507–26.

Reithe, S., and R. Tveteras. 2000. Productivity in Organic and Conventional Salmon Aquaculture. *Stiftelsen for Samfunns- og Næringslivsforskning,* Report no. 34.

Smith, M.D., F. Asche, A.G. Guttormsen, and J.B. Wiener. 2010. Genetically Modified Salmon and Full Impact Assessment. *Science* 330:1052–3.

Tveteras, R. 1999. Production Risk and Productivity Growth: Some Findings for Norwegian Salmon Aquaculture. *Journal of Productivity Analysis* 12:161–79.

_____. 2000. Flexible Panel Data Models for Risky Production Technologies with an Application to Salmon Aquaculture. *Econometric Reviews* 19:367–89.

_____. 2002. Industrial Agglomeration and Production Costs in Norwegian Salmon Aquaculture. *Marine Resource Economics* 17:1–26.

Tveteras, R., and G.E. Battese. 2006. Agglomeration Externalities, Productivity and Technical Inefficiency. *Journal of Regional Science* 46:605–25.

Tveteras, R., and A. Heshmati. 2002. Patterns of Productivity Growth in the Norwegian Salmon Farming Industry. *International Review of Economics and Business* 49:367–93.

Vassdal, T., and H.M. Sørensen Holst. 2011. Technical Progress and Regress in Norwegian Salmon Farming: A Malmquist Index Approach. *Marine Resource Economics* 26:329–41.

Vukina, T., and J. L. Anderson. 1993. A State-Space Forecasting Approach to Optimal Intertemporal Cross-Hedging. *American Journal of Agricultural Economics* 75:416–24.

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

Xie, J., H.W. Kinnucan, and Ø. Myrland. 2009. Demand Elasticities for Farmed Salmon in World Trade. *European Review of Agricultural Economics* 36:425–45.