Regional Supply Response of Norwegian Farmed Salmon

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Abstract

This study attempts to estimate long- and short-run supply responses for three different regions in Norway. We estimate a supply model in error-correction form with the partial adjustment model nested within it. We find that the salmon producers are responding to price changes in the long run while there are limited responses in the short run. The long-run response differs by region, and the output response is 1.22 for the Northern region, 1.39 for the Central region, and 0.58 for the Southern region, with a national average of 1.06. This may indicate that production conditions in the Central and Northern regions contribute to higher flexibility in supplying salmon to the market, and that producers in Southern Norway to a higher degree need to slaughter their fish independent of the price.

Introduction

It was established early that supply analysis was more complicated and difficult compared to demand analysis (Cassels 1933; Schultz 1956), and this seems to be the case when reviewing the literature in market analysis for farmed salmon. In recent decades, there has been considerable research on demand for salmon (e.g., Asche, Bjørndal, & Salvanes, 1998; Asche, Bremnes, & Wessells, 1999; Asche, Salvanes, & Steen, 1997; Chidmi, Hanson, & Nguyen, 2012; DeVoretz & Salvanes, 1993; Fousekis & Revell, 2004; Muhammad & Jones, 2011; Singh, Dey, & Surathkal, 2012; Tiffin & Arnoult, 2010; Xie, Kinnucan, & Myrland, 2009; Xie & Myrland, 2011). There is also a vast body of literature about different aspects of the production process in farmed salmon (e.g., Asche, Bjørndal, & Sissener, 2003; Asche, Guttormsen, & Nielsen, 2013; Asche, Roll, Sandvold, Sørvig, & Zhang, 2013; Asche & Roll, 2013; Asche, 1997; Guttormsen, 2002; Roll, 2012; Vassdal & Sørensen Holst, 2011).

In contrast to these numerous production and demand studies, there have been few attempts to estimate supply elasticity in the literature. Only three studies report such estimates: Asche, Kumbhakar, and Tveterås (2007); Andersen, Roll, and Tveterås (2008); and Aasheim et al. (2011).

As in other sectors of the economy, the observed price and quantity in the farmed salmon industry are produced by interaction between supply and demand as well as government regulations, and hence, it is important to identify and attempt to quantify the impact of the supply side of the market. Existing studies on supply have used panel data approaches with yearly data (Asche, Kumbhakar, and Tveterås 2007; Andersen, Roll, and Tveterås 2008) or have focused on the short-run supply of farmed salmon (Aasheim et al. 2011). The purpose of this study is to estimate regional long- and short-run supply elasticities of Norwegian farmed salmon using a time series model with monthly data for three regions: Northern Norway, Central Norway, and Southern Norway.

Asche, Kumbhakar, and Tveterås (2007) use a panel data set for Norwegian fish farms with annual observations for the period from 1985 to 1995 to estimate a cost function, which is common in productivity studies. They employ the fact that a cost function is a special form of a restricted profit function, and they report a long-run supply elasticity of 1.5.

Andersen, Roll, and Tveterås (2008) also use a panel data set for Norwegian fish farms with annual observations from 1985 to 2004 to estimate a profit function which deviate from earlier productivity studies. They estimate a partial equilibrium model in which capital is fixed over the short run and variable over the long run. The short-run elasticity is barely positive at 0.05, indicating a very limited short-run response. The long-run elasticity is very similar to the aforementioned study and is reported to be 1.4.

Aasheim et al. (2011) use an aggregated data set with monthly observations from January 1995 to December 2007. Using a system of equations, their study shows how biomass development affects short-run supply, and they find a short-run supply elasticity of 0.09, which is in line with the study by Andersen, Roll, and Tveterås (2008). Although their focus is on the short-run supply, they also report a long-run elasticity of 0.13, which differs conceptually from the results of Asche, Kumbhakar, and Tveterås (2007) and Andersen, Roll, and Tveterås (2008)

Framework and Data

Schultz (1956) argued that supply analysis is more complicated to conduct than demand analysis because a function must be stable over time to be useful. If it is not stable, we should be able to predict how it will change. The stability of the demand function is reliant on tastes, while the stability of the supply function is reliant on technology. While tastes are relatively stable over time, technology is not. This is partly because technological change is unpredictable and partly because not all improvements in technology will actually be implemented. Further, Schultz identifies three other factors that are unaccounted for by growth in inputs but contribute to growth in supply: first, the specialization of labor; second, the closely related improvement in labor quality; and third, the concept of diminishing returns (Schultz 1956; Brækkan 2014a).

Other issues that complicate the estimation of agricultural supply responses are due to the gap between seedtime and harvest because the production of animal-based food takes a significant amount of time. For a salmon farmer, the production process begins when juvenile salmon weighing less than 250 g are released into sea pens and until they grow to a marketable size. There is some variation in the grow-out period, and Atlantic salmon are raised for 16-19 months to reach a marketable size of 3 kg (Thyholdt 2014). This presents uncertainty for the producers and complicates their ability to respond immediately to a change in price. Due to this time lag, the producers must make a production decision based on their expectations of the future price of the product produced as well as the prices of their future inputs. This situation has led to a discussion about how producers form their expectations. See Nerlove and Bessler (2001) for a discussion on how expectations are formed and could be estimated. Nerlove (1958a, 1958b) developed adaptive expectations theory, which states that agents' expectations depend on the expected "normal" prices that are based on historical prices as well as current prices. Adaptive expectations is nested within the partial adjustment model developed by Nerlove (1956, 1958b), and this model has since dominated agricultural supply analysis (Askari and Cummings 1977). Thus, agricultural supply analyses have since relied on dynamic supply functions.

As Norway is the only salmon producing country in which data are systematically gathered, virtually all empirical studies have been conducted using Norwegian data. For a long time, it was only possible to obtain annual observations on Norwegian salmon farm production and profitability. However, in 2009, the Norwegian Directorate of Fisheries started to report data they call "Biomass Statistics of Norwegian Farmed Salmon" with monthly observations dating to January 2005. Combining this data set with disaggregated data from the Norwegian Directorate of Fisheries from 2002 to 2004, we have data from January 2002 until August 2011. In this study, aggregated slaughter (*s*), price of salmon (*p*) and price of soybean oil (*f*) are used, and all variables are in log form. Specifically, *p* is the log of a deflated index of the average official export prices of Norwegian salmon gathered by Statistics Norway (2002 = 100), while *f* is the log of a deflated index of soybean oil prices obtained from the IMF (2002 = 100). Finally, *s* is aggregated official slaughter data for each of the nine salmon producing counties in Norway. Here, we have aggregated the three northernmost counties into one region called Northern Norway, the three southernmost counties into Southern Norway and the three middle counties into Central Norway, denoted s^N, s^M and s^S, respectively.

The export prices gathered by Statistics Norway are, as the name alludes, collected at the export level and not at the farm level. A remarkable 96% of all Norwegian salmon production is exported (Kinnucan and Myrland 2002), which indicates that export prices are very important for farmers. Still, export prices reflect a mix of fixed contract and spot prices. Larsen and Asche (2011) investigate this issue using 2006 weekly price data. They are unable to detect any differences between their synthetic spot price and the official export price when they examine an entire year, and they can only detect a difference between the synthetic spot price and the export price in one quarter when they divide the price series into quarters. NOS Clearing ASA, a clearinghouse for the international commodity exchange Fish Pool ASA that trades salmon futures, has collected prices at the farm level since 2007. Before 2007, the Norwegian Seafood Federation collected these price data. However, farm-level prices have not always been collected systematically, and only a subset of farmers has reported their prices. Thus, the export price is more representative.

Because we are using the export price to determine the response at the farm gate, we are essentially using the price at the next stage in the supply chain to explain behavior at the former stage in the supply chain. We expect perfect elasticity of price transmission, which means that a change in the farm price will be completely transmitted through the marketing channel to the export price. Larsen and Kinnucan (2009) argue that the marketing channel from farm to export to wholesaler for Norwegian farmed salmon is purely competitive, and they argue for perfect elasticity of price transmission because the salmon undergo no processing on their way to the Norwegian border. Thus, we consider the export price a good proxy for the price at the farm gate.

Soybean oil prices are used as a proxy for salmon feed prices because gathering statistics for feed prices has always been problematic. There are only a few producers of salmon feed in the world, and in 2005, Ewos and Skretting produced over two-thirds of total global salmon aquafeed (Tacon, 2005). Tacon reports that salmon feed consists of approximately 50% fish meal and fish oil and 50% dietary protein and lipid in non-marine form, mainly soybean concentrate and soybean meal. However, Tacon published his report in 2005, and practices have since changed. Marine Harvest, the largest Norwegian producer of farmed salmon, claims on their website that salmon feed consists of as little as 30% fish oil and fish meal[1]. This reduction in marine commodities has been replaced by vegetable commodities, mainly soybean oil. Further, an industry source has claimed that salmon feed prices are highly correlated with the world soybean oil price index, which serves as a proxy for salmon feed in this model.

The original data for slaughter were seasonally unadjusted. However, there are seasonal patterns in salmon trade due to traditional holiday consumption of salmon, particularly before Christmas (Asche 1997b), and several authors correct for seasonality when using salmon data (Xie, Kinnucan, and Myrland 2009; DeVoretz and Salvanes 1993; Asche, Bremnes, and Wessells 1999). Most authors use seasonal dummies to correct for seasonality, but because that will influence the degrees of freedom, the data were seasonally adjusted through the TRAMO and SEATS programs developed by Gomez and Maravall (1996) using the Demetra+ software developed by Eurostat because seasonality is observed in the three slaughter variables. Because no seasonality was found in the price indices, they were not seasonally adjusted.

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[1] (Marineharvest.com 2011)

Supply model

Hallam and Zanoli (1993) developed an error correction form supply model with a partial adjustment model nested within it. The error correction form has been widely used in several fields of applied economics and has the advantage that it incorporates both short- and long-run effects. Error correction models were first introduced by Sargan (1964) and popularized by Davidson et al. (1978). Engle and Granger (1987) suggest if there is cointegration, then the error correction model is a valid representation. Murray (1994) provides a description of cointegration and the link between cointegration and error correction models. As discussed by Alogoskoufis and Smith (1991), there are several interpretations of error correction models, and Hallam and Zanoli use a general-to-specific modeling strategy developed by Hendry and Ericsson (1991) to estimate the short-run relationship and an error correction vector autoregression (ECVAR) or vector error correction model (VECM) to estimate the long-run relationship. According to Rao (2005), the VECM is undoubtedly the most widely used method in applied work for estimating short- and long-run relationships. The VECM is a restricted vector autoregression (VAR) model designed for use with non-stationary variables that are known to be cointegrated. VECM, like VAR models, treat all variables as endogenous. Consider two variables, y_t and x_t, that are both integrated of order one, $I(1)$. If these two variables are cointegrated, this implies that there must be Granger causality between them in either one or both directions. A general ARDL specification of a small system with these two variables is defined as shown in equations (1) and (2).

$$y_t = \beta_{11} + \beta_{12} x_{t-1} + \beta_{13} y_{t-1} + u_{t1} \qquad (1)$$

$$x_t = \beta_{21} + \beta_{22} x_{t-1} + \beta_{23} y_{t-1} + u_{2t}, \qquad (2)$$

Equations (1) and (2) are essentially an unrestricted VAR. If the variables are $I(1)$ and cointegrated, we should model the data using a VECM. Transforming the VAR system in equations (1) and (2) into their error correction forms, we obtain

$$\Delta y_t = \beta_{11} + \beta_{12} \Delta x_{t-1} + \beta_{13} \Delta y_{t-1} + \alpha_1 (y_{t-1} - \theta x_{t-1}) + u_{1t} \qquad (3)$$

$$\Delta x_t = \beta_{21} + \beta_{22} \Delta x_{t-1} + \beta_{23} \Delta y_{t-1} + \alpha (y_{t-1} - \theta x_{t-1}) + u_{2t}, \qquad (4)$$

where y_{t-1}-θx_{t-1} is the error correction term. The ECM equation states that the ΔY depends on ΔX and on the error equilibrium term. If the latter term is not equal to zero, then the model is out of equilibrium. α_2 is expected to be negative, and the absolute value of α_2 determines how quickly equilibrium is restored. The model can be expanded using predefined exogenous *I*(1) and *I*(0) variables and trend variables, and a general VECM can be defined as

$$\Delta y_t = a_{0y} + a_{1y}t - \Pi_y z_{t-1} + \sum_{i=1}^{p-1} \Gamma_{iy} \Delta z_{t-i} + \Psi_y w_t + u_{ty} \ , \qquad (5)$$

where $z_t = \begin{pmatrix} y_t \\ v_t \end{pmatrix}$ and y_t is an $m_y \times 1$ vector of jointly determined (or endogenous) *I*(1) variables. v_t is an $m_x \times 1$ vector of *I*(1) exogenous variables, w_t is a $q \times 1$ vector of *I*(0) exogenous variables and the intercept and the trend coefficients a_{0y} and a_{1y}, respectively, are $m_y \times 1$ vectors. The implicit VAR model for the *I*(1) exogenous variables, x_t, is given by

$$\Delta v_t = a_{0x} + \sum_{i=1}^{p-1} \Gamma_{ix} \Delta x_{t-i} + \Psi_x w_t + e_t \, . \qquad (6)$$

Combining (5) and (6) we obtain

$$\Delta z_t = a_0 + a_1 t - \Pi z_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta z_{t-i} + \Psi w_t + u_t \ , \qquad (7)$$

where
$$z_t = \begin{pmatrix} y_t \\ v_t \end{pmatrix}, \quad u_t = \begin{pmatrix} u_{ty} \\ e_t \end{pmatrix}, \quad a_0 = \begin{pmatrix} a_{0y} \\ a_{0x} \end{pmatrix}, \quad a_1 = \begin{pmatrix} a_{1y} \\ 0 \end{pmatrix}$$
$$\Pi = \begin{pmatrix} \Pi_{0y} \\ 0 \end{pmatrix}, \quad \Gamma_i = \begin{pmatrix} \Gamma_{iy} \\ \Gamma_{ix} \end{pmatrix}, \quad \Psi = \begin{pmatrix} \Psi_y \\ \Psi_x \end{pmatrix}.$$

Models of this type naturally arise in empirical macroeconomic analyses of small open economies for which variables such as foreign prices, foreign interest rates and foreign income can often be treated as exogenous *I*(1) variables (Pesaran and Pesaran 2010). In our model, $a_1 = 0$ and $a_0 \neq 0$ because we are using an unrestricted intercept and no deterministic trends, and $\Psi = 0$ because we do not have any exogenous *I*(0) variables in the system. This means that we are estimating the model

$$\Delta z_t = a_0 + \Pi z_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta z_{t-i} + u_t \ , \qquad (8)$$

where $z_t = \begin{pmatrix} y_t \\ v_t \end{pmatrix}$ and $y_t = s_t \ and \ p_t$ because slaughter (*s*) and salmon prices (*p*) are endogenous *I*(1) variables in the system, and $v_t = f_t$ because the soybean prices variable (*f*) is exogenous *I*(1) in the system. Here we treat the prices of soybean oil as exogenous under the assumption that the Norwegian salmon industry is not big enough to be able to affect the world prices of soybean. This model is estimated separately for all three regions.

Using the slaughter variable as a dependent variable means that this study, in a theoretical sense, is considered an output response study rather than a supply response study. Supply is not merely what is actually sold. Supply is defined as the quantity of a product that is offered for sale in a particular market during a specific time interval at any specified price, which means that unprocessed products could indicate the amount of product offered (Colman 1983). Many supply response studies should therefore be considered output or production response studies (Colman 1983; Mundlak 2001), depending on the choice of the dependent variable. The use of slaughter, harvest, or herd size data might be a question of preference. Here, we follow the approach of Fabiosa and Qi (1998), who consider slaughter data to be flow data and herd data to be stock data, and their conditions that behavioral specifications should follow the flow variables.

Results

The convenient way to determine whether the variables are integrated of order 1, *I*(1), is to conduct unit root tests. When conducting a unit root test for stationary, it is normal to use the conventional augmented Dickey-Fuller (ADF) test to examine each variable for the presence of a unit root. Two other test statistics are also used. Elliott, Rothenberg, and Stock (1996) use a modification of the ADF test called the ADF-GLS, and Pantula, Gonzalez-Farias, and Fuller (1994) developed a weighted symmetric version called the ADF-WS. The null hypothesis of the test is that y_t is a random walk. Recall that the slaughter variable is seasonally adjusted, which will preclude seasonal unit roots. However, there exists a discussion about the relevance of unit root tests for seasonal adjusted variables. Ghysels and Perron (1993) and Olekalns (1994) suggest that unit root tests will be biased towards non-rejection of the unit root null when seasonally adjusted data are used. However, Lee and Siklos (1991) find that unit roots exist both in raw and adjusted data when testing several different macroeconomic time series; hence, using seasonally unadjusted data does not influence finding a unit root in seasonally adjusted data. Nevertheless, it should be borne in mind that the unit roots tests might have low power when interpreting our results. Table 1 shows the results of the unit root tests, and all variables are *I*(1).

Table 1. Unit Root Tests

Variable	*No. of lagged differences*	*ADF*	*ADF-GLS*	*ADF-WS*
S^N	6	-.57657	.45293	-.50301
		(-2.9313)	(-1.9959)	(-2.5860)
ΔS^N	0	-15.3154	-15.3154	-15.5104
		(-1.8609)	(-1.8609)	(-2.1604)
S^M	5	-.58319	-.91992	.19969
		(-2.9257)	(-2.2254)	(-2.7522)
ΔS^M	3	-7.9831	-7.9831	-8.1642
		(-2.0234)	(-2.0234)	(-2.2631)
S^S	2	-2.4554	-1.3873	-2.2533
		(-2.9375)	(-2.1160)	(-2.6177)
ΔS^S	3	-7.7110	-7.7110	-7.9511
		(-2.0234)	(-2.0234)	(-2.2631)
F	5	-1.6768	-.37276	-1.2165
		(-2.9257)	(-2.2254)	(-2.7522)
ΔF	7	-4.7401	-4.7401	-4.9721
		(-1.7615)	(-1.7615)	(-2.0209)
P	6	-1.7324	-1.4092	-1.9238
		(-2.9313)	(-1.9959)	(-2.5860)
ΔP	5	-5.7707	-5.7707	-6.0338
		(-1.8609)	(-1.8609)	(-2.1388)

The Lütkepohl (2004) approach to testing for unit roots has been followed. If just a constant is needed to test y_t, then no deterministic term is needed to test Δy_t. Lag lengths were determined using the Akaike Information Criterion (AIC). The 5% critical values are shown in parentheses. Microfit 5.01 was used to estimate the test statisticBefore testing for cointegration, the optimal lag length for each variable in the VECM was successively determined by applying the Schwarz Bayesian Criterion (SBC), Hannah-

Quinn Criterion (HQC) and Akaike Information Criterion (AIC). The SBC, HQC and AIC suggest using two lags for all three models; consequently, the optimal lag length is set to two in all models. The cointegration rank is established by Johansen tests.

Table 2. Johansen Cointegration Tests

$\lambda_{\max}$ **rank tests**		**Northern Norway**	**Central Norway**	**Southern Norway**
H_0	H_A	$\lambda_{\max}$ rank value	$\lambda_{\max}$ rank value	$\lambda_{\max}$ rank value
$r = 0$	$r = 1$	21.0622	19.0615	21.6209
$r \leq 1$	$r = 2$	2.0801	2.3446	6.4722
λ_{trace} **rank tests**				
H_0	H_A	λ_{trace} rank value	λ_{trace} rank value	λ_{trace} rank value
$r = 0$	$r \geq 1$	23.1424	21.4061	28.0931
$r \leq 1$	$r \geq 2$	2.0801	2.3446	6.4722
Rank $r = 0$				
Maximized LL		262.8459	245.1472	225.0054
AIC		254.8459	237.1472	217.0054
SBC		243.9012	226.2024	206.0606
HQC		250.4041	232.7058	212.5636
Rank $r = 1$				
Maximized LL		273.3771	254.6780	235.8159
AIC		261.3771	242.6780	223.8159
SBC		244.9599	226.2608	207.3987
HQC		254.7142	236.0152	217.1531
Rank $r = 2$				
Maximized LL		274.4171	255.8503	239.0520
AIC		260.4171	241.8503	225.0520
SBC		241.2637	222.6969	205.8986
HQC		252.6438	234.0770	217.2787

For the λ_{max} rank tests, the 95% and 90% critical values are 18.06 and 15.98, respectively. For the λ_{trace} rank tests, the 95% and 90% critical values are 23.32 and 20.75, respectively.

Table 2 above shows the results of the cointegration tests. Both the maximum eigenvalue test statistic $(\lambda_{\max})$ and the trace test statistic (λ_{trace}) suggest that $r = 1$ for Southern Norway at the 95% level. For Northern and Central Norway, the maximum eigenvalue test statistics reject the hypothesis of no cointegration at the 95% level and indicate the existence of one cointegrating vector ($r = 1$), but the trace test statistics only indicate the existence of one cointegrating vector at a 90% level. However, the AIC, SBC and HQC favor $r = 1$ for Northern and Central Norway. In what follows, we assume $r = 1$ for Northern and Central Norway. When only one cointegrating vector exists, it can be interpreted as an estimate of the long-run cointegrating relationship between the variables concerned (Hallam and Zanoli 1993). Normalizing with respect to the coefficient of *s*, the cointegrating vectors take the following forms for all three models:

$$s^N = \underset{(.33925)}{1.2229p} + \underset{(.13265)}{.39507f}$$

$$s^C = \underset{(.42096)}{1.3992p} + \underset{(.15809)}{.51708f}$$

$$s^S = \underset{(.29511)}{.57653p} + \underset{(.11649)}{.34086f},$$

where the asymptotic standard errors are in parenthesis. All coefficients are statistically significant at a 5% level. The estimated coefficients indicate the long-run elasticities for the three models. Thus, a 1% increase (decrease) in prices for salmon leads to a 1.22% increase (decrease) in slaughter of salmon in Northern Norway, a 1.4% increase (decrease) in slaughter of salmon in Central Norway and a 0.58% increase (decrease) in slaughter of salmon in Southern Norway. On average, over the entire period, Northern Norway has a 33.68% share of the total supply, while Central and Southern Norway have shares of 32.54% and 33.78%, respectively. This indicates that the weighted average of the own price supply elasticities for Norway is 1.06.

The differences in response might be due to different biophysical conditions along the Norwegian coast. High sea temperatures have a negative effect on salmon growth in Southern Norway and a positive effect on salmon growth in Central and Northern Norway, while the opposite pattern occurs when the sea temperature is low (Thyholdt 2014). Sea temperatures that are too high, above a threshold of 17° C, have a significantly negative effect on growth (Lorentzen 2008). Today, high sea temperatures are a problem mainly in Southern Norway, which might explain their inelastic price responses compared to the other two Norwegian regions. High sea temperatures may force the farmers in Southern Norway to slaughter more fish independent of the price in contrast to farmers in Central and Northern Norway.

Lorentzen and Hannesson (2005) claim that production conditions in the Central and Northern regions are more favorable compared to the Southern region, and this might contribute to higher flexibility in supplying salmon to the market.

The feed price elasticity for all regions is positive, which might be somewhat remarkable. Our results conflict with the findings of Andersen, Roll, and Tveterås (2008), who obtain a long-run feed price elasticity of -0.8, and Aasheim et al. (2011), who obtain a negative feed price elasticity over the long-run, although their estimate is not significantly different from zero. Normally, one would assume that when input prices increase, the output decreases due to increased costs. However, Jarvis (1974) shows that feed cost increases may increase the slaughter ratio. Likewise, Bjørndal (1988) shows that increased feed costs make it optimal to slaughter the fish earlier in the production process, which will increase total production. This is because the specific growth rate decreases with increasing body weight; thus, smaller fish convert feed more efficiently than larger fish (Talbot 1993). Several studies show positive feed elasticities (e.g., Jarvis 1974; Marsh 1994) but only over the short run; these studies show negative feed cost elasticities over the longer run. Another explanation for positive feed elasticities may be that salmon farmers focus on efficiently exploiting other input factors, making the production process more feed intensive. Examining the cost shares in the farmed salmon industry from 1985 to 2008, the cost share of feed is the only one that increased. The share of feed costs increased from 34% in 1985 to 54% in 2008. During the same period, the cost share of smolts decreased from 25% to 12%; capital costs decreased from 12% to 8%; labor from 15% to 9%; insurance cost from 4% to 1%; and other operating costs remain steady at 12% (Asche and Bjørndal 2011). Still, we cannot reject the possibility that the feed proxy, the world soybean index, might not be suitable for analytical use. During the period from 2002 to 2011, the ingredients in salmon feed have shifted from mainly marine proteins to vegetable inputs. While a soybean price index might be a good proxy for the end of the period, it might be a poor proxy for the beginning of the period. In addition, before 2005, producers were restricted by a feed quota regime to limit production. This regime was abandoned in 2005, suggesting a structural change. A dummy variable with the value of 1 before 2005 and 0 after did not have a significant effect, indicating that there is no structural change present in our data. The only available feed prices are yearly data based on the financial accounts of salmon farmers, and the correlation between the actual feed cost and yearly averages of soybean index is approximately 0.85.

Table 4. Maximum Likelihood Estimates of the VECM

Δs_t^{N} equation		Δs_t^{M}equation		Δs_t^{S} equation	
Δs_{t-1}^{N}	-0.30947	Δs_{t-1}^{M}	-0.33305	Δs_{t-1}^{S}	-0.076894
	(0.089799)		(0.089019)		(0.094197)
Δp_{t-1}	-0.25374	Δp_{t-1}	-0.35913	Δp_{t-1}	-0.25374
	(0.15270)		(0.17723)		(0.15270)
Δf_{t-1}	-0.10474	Δf_{t-1}	-0.16143	Δf_{t-1}	-0.13615
	(0.14034)		(0.16247)		(0.18760)
EC_{t-1}	-0.28631	EC_{t-1}	-0.32045	EC_{t-1}	-0.51010
	(0.097261)		(0.11278)		(0.11278)
R^2	0.203	R^2	0.224	R^2	0.184

The MLE of the VECM in table 4 can be interpreted as the short-run estimates for the model. The most interesting estimates are the short-run own price supply elasticities, which all are negative, although only the price elasticity for Central Norway is significant at the 5% level. Andersen, Roll, and Tveterås (2008) and Aasheim et al. (2011) are the only studies that have published a short-run elasticity; their own price supply elasticity was barely positive at 0.05 and 0.09, indicating that producers do not respond much to price changes over the short run. Jarvis (1974) shows that it is plausible to have negative own price responses over the short run because farmers retain younger fish, leading to an immediate reduction in output. Another issue is the grow-out period; a salmon spends 16–24 months in the water before it is slaughtered, and this long production time makes it difficult for the farmer to respond immediately to price changes over the short run. Models with lag lengths up to 24 lags were estimated but did not produce any significant results.

The Norwegian government has used different regimes for controlling the production of farmed salmon. Before 2005, capacity regulations limited pen volume to 12 000 m^3 and specified the feed quota for each license. The system changed after 2005, and capacity regulations were changed to a restriction on maximum total biomass (MTB). The restriction sets the maximum allowed biomass per license; when it was introduced, the limit was 65 tons of fish per 1000 m^3, with some exceptions. Figure 1 shows the average sales price per kilogram of salmon for salmon farmers and the average production cost per kilogram of salmon for each year between 2002 and 2011. As shown in the figure, from 2003 onwards, the average sale price has been higher than the average production cost. If salmon farmers expect this pattern to last, the focus will be to maximize production; the short-run output elasticity will be close to zero because the supply curve will approach the vertical line that represents the maximum biomass allowance. This could in turn explain why we observe positive values for feed elasticity; because farmers expect to generate profits, they follow their initial production plan even if the prices of the input factors are increasing.

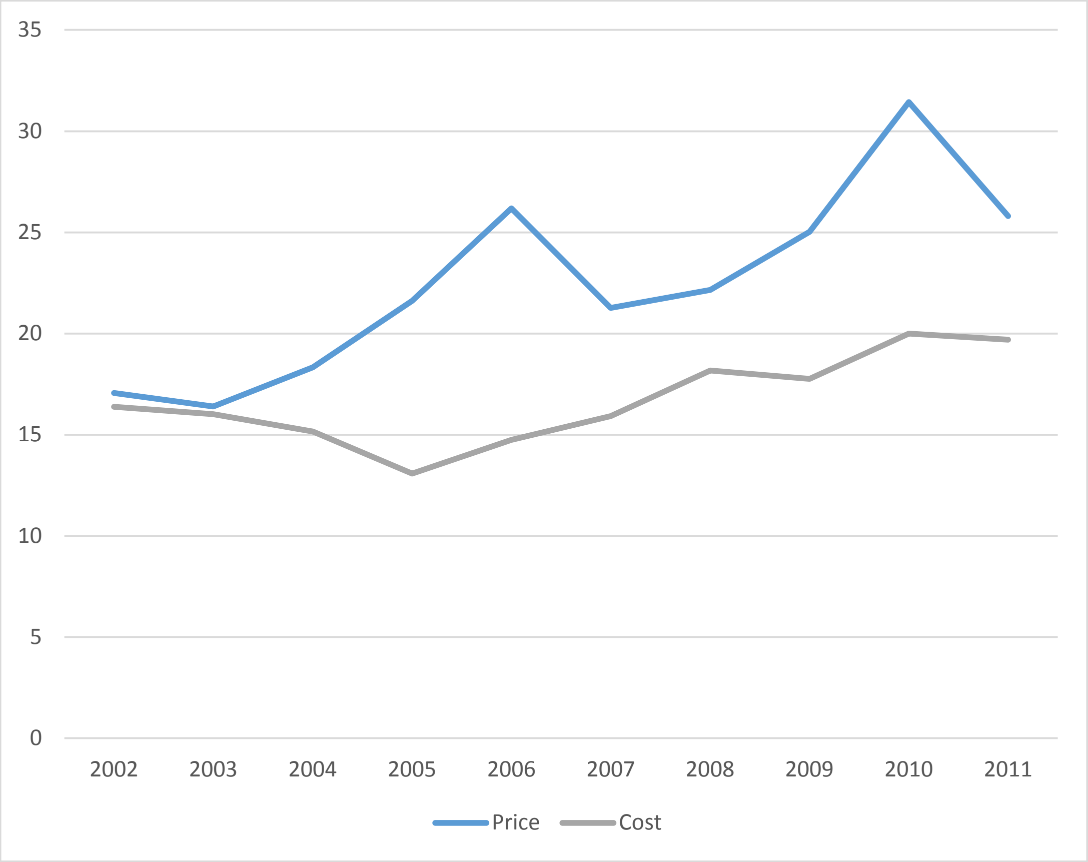

Figure 1. Average sales price and production cost (Source: Norwegian Directorate of Fisheries)

The error correction term, EC_{t-1}, in table 4 shows the adjustment speed toward equilibrium after an exogenous shock occurs, where the larger (absolute value of) the error correction term, the faster the return to equilibrium after a shock. In this case, Southern Norway returns to its equilibrium more quickly than the two other regions. The persistence profile (Figure 2), developed by Lee and Pesaran (1993) and Pesaran and Shin (1996), shows the effects of system-wide shocks on the cointegrating relations and the speed of convergence of the cointegrating relationships towards equilibrium. The effects of shocks diminish relatively quickly; 80% of the adjustment occurs within the three first months in Northern and Central Norway, while 90% occurs within the three first months in Southern Norway.

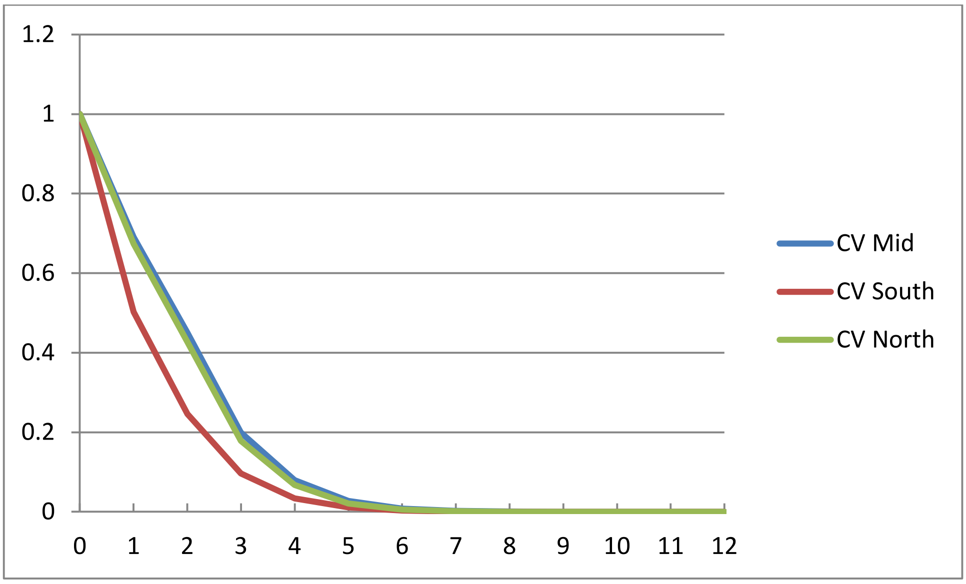

Figure 2. Persistence Profile

Concluding Remarks

In this article, an attempt to measure the short- and long-run output responses in salmon production for three different regions in Norway was conducted. We find that salmon producers respond to price changes over the long run, while there are no or negative responses to price changes over the short run. The long-run response differs by region, and the output response is 1.22 for the Northern region, 1.39 for the Central region, and 0.58 for the Southern region, with a national average of 1.06. This may indicate that production conditions in the Central and Northern regions are more favorable and contribute to higher flexibility in supplying salmon to the market. This article is in line with the findings of Andersen, Roll, and Tveterås (2008) as well as Aasheim et al. (2011); salmon prices have limited influence on supply over the short run. During the period examined here, we have experienced tremendous global growth in demand for farmed salmon (Brækkan and Thyholdt 2014), and it seems that demand growth is now outpacing productivity growth (Asche, Guttormsen, and Nielsen 2013; Vassdal and Sørensen Holst 2011; Brækkan 2014b). If this movement continues, it will be interesting see whether this would lead to further innovations in the farmed salmon industry and to what extent such innovations could affect the output elasticity of farmed salmon.

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