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RECENT TRENDS IN SALMON PRICE VOLATILITY

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□ *The price of farmed Atlantic salmon from Norway has increased in recent years. This new regime follows several years of consistently falling prices. At the same time price volatility has increased substantially. This article models the volatility of salmon prices and establishes empirically that volatility is on an increasing trend. Further empirical analysis suggests that the volatility trend is largely accounted for by the common trend in other food prices relevant to salmon, including meats, cereals, oils and fish meal observed in recent years. Other potentially contributing factors to volatility are also discussed. This includes the role of the 2005 maximum total allowable biomass restriction, the 2006 introduction of the Fish Pool ASA futures market for salmon, the Chilean Salmon crisis and the increasing use of bilateral contracts.*

Keywords aquaculture, markets, salmon, volatility

INTRODUCTION

Since the start of intensive salmon farming, salmon has become an increasingly cheaper source of protein. Salmon has transitioned from a relative luxurious food item to a staple part of everyday diets. For most of the 1980s and 1990s the price of salmon fell consistently both in nominal and real terms. The price decline was caused by steady improvements in productivity, reducing unit production costs (Asche, 1997, Tveteras & Wan, 2000; Guttormsen, 2002; Vassdal, 2006; Asche et al., 2007; Asche, 2008; Asche et al., 2009b). Along with improvements in productivity salmon has enjoyed strong demand growth (Asche et al., 2011). However, since the early part of the last decade prices seem to have leveled out and even increased. In some sense demand growth seems to have caught up with productivity growth. Although productivity still increases it appears to have slowed down relative to demand growth (Vassdal & Holst, 2011).

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This apparent slowdown must also be seen relative to recent developments in demand conditions. The Chilean disease issues, starting in late 2008, shifted demand towards non-Chilean suppliers (Asche et al., 2009a; Hansen & Onozaka, 2011). This provided strong prices for Norwegian salmon farmers. The shock is likely temporary as the Chilean industry seems to be recovering. More importantly overall global growth in demand for food, including protein, has been strong and is likely to remain strong (Trostle et al., 2011). This suggests continued high demand for fish, putting continued upward pressure on prices.

Volatility has also increased along with increasing prices. High volatility is not surprising considering the perishable nature of harvested salmon in addition to a long production time. This effect is demonstrated in Oglend and Sikveland (2009). Recent developments show a steady increase in price volatility. This is different from occasional shocks, or clustering, of volatility associated with temporary seasonal effects such as temperature fluctuations (Asheim et al., 2011). Higher volatility is not necessarily bad as farmers appear to be compensated by higher prices in general. For processors, however, extreme price movements might put undesirable pressure on profit margins. At least it should make hedging instruments more attractive for risk adverse processors.

Higher prices of proteins have increased the production cost of salmon. Cereals, oils and meals (specifically fishmeal) are important input factors in salmon production. Given a strong demand for fish some of these higher production costs can be passed to consumers. Whether strong demand and higher production costs lead to higher price volatility is an important question. There is at least one channel by which this could be the case. The opportunity cost of harvesting, in essence a cost of storing fish by having to keep the fish in pens, increases when feed prices increase. Fish not harvested will have to be fed even with little net growth benefits. It is likely that higher feed prices, in combination with strong current demand for fish, will lead farmers to harvest earlier than they otherwise would. Such behavior will lead to less supply smoothing, reducing the short-run elasticity of supply. As a consequence the volatility of prices will increase.

Volatility is important in terms of biomass management. Biomass management refers to decisions concerning harvesting and restocking to keep a standing stock of fish sufficient to meet demand at lowest possible costs. The biological production process is long, leading to slow adjustments to shocks (Andersen et al., 2008). With more price volatility the value of the biomass becomes more uncertain. This makes managing the biomass more difficult. In addition returns to investments in the industry become more uncertain. In terms of salmon price volatility Oglend and Sikveland (2009) demonstrate that price volatility is itself volatile. Solibakke (2012) uses a stochastic volatility model to demonstrate that front month futures contracts of salmon display significant time varying volatility. In terms of forecasting salmon prices (Guttormsen, 1999), higher price volatility will increase the variance of forecast errors. The price risk comes in addition to a substantial production risk (Asche & Tveteras, 1999; Tveteras, 1999; Kumbhakar & Tveteras, 2003).

The purpose of this article is twofold. First, an empirical measure of salmon price volatility is established. Using a derived measure of volatility from a GARCH model evidence of strong co-movement between price volatility and global food prices is provided. This lends support to a hypothesis that higher price volatility is due to strong demand and higher production costs. Second, other potential factors influencing volatility such as the 2005 maximum allowable biomass (MTB) restriction, the introduction of a futures market for salmon (Fish Pool), the Chilean salmon crisis and the change in use of bilateral contracts are discussed. Next, salmon price volatility is defined and preliminary evidence of higher price volatility is established. Following this some potential factors affecting volatility are discussed and an empirical investigation of food prices and volatility is carried out.

THE VOLATILITY OF SALMON PRICE

The price of salmon used in this article is weekly prices paid by exporters to Norwegian farmers for fresh gutted salmon of superior quality. The data can be found at www.nosclearing.com. Norway is the largest producer of farmed Atlantic salmon with a market share of 50% in 2008[1] (FAO, 2010). Most salmon from Norway is exported, with EU as the primary export market. Our observations cover the first week of 1995 to week 37 in 2012. Figure 1 shows the prices.

Since the early 2000s, prices have been on an increasing trend with a large correction towards the end due to the Chilean recovery. In addition to the price we observe greater week-by-week price fluctuations towards the end of the sample.

Volatility can be defined as variations in prices around its expected value. If expected prices are formed as the expected future intersection

FIGURE 1 The nominal price of fresh Atlantic Salmon.

of supply and demand, volatility is fundamentally related to unexpected movements in supply and/or demand. A commonly used measure of price volatility which avoids the specification of an expected price is the standard deviation of price returns. Volatility is here a measure of the magnitude of price fluctuations from period to period.

Figure 2 shows the annual mean price of salmon and the annual standard deviation of weekly price returns (logarithmic)[2].

Figure 2 establishes the same stylized fact hinted to in Figure 1—volatility and price have increased since the early 2000s. A varying volatility is not surprising. Salmon is a seasonally produced commodity where most fish growth occurs in summer/early fall when sea water temperatures are high (Hermansen & Heen, 2012). As with other seasonally produced commodities, such as corn or wheat, volatility is greatest just prior to the production or harvest period (Peterson & Tomek, 2005) when annual stocks are lowest. For storable commodities volatility is decreasing in available stocks. Larger availability leads to increased supply elasticity as stocks are used to buffer demand movements. In the spring, a convenience yield can arise as expected immediate growth is high and thus immediate production valuable. The cost of storing and producing (keeping the fish in the pens) might be negative leading to higher spot prices and lower expected future prices.

This phenomenon is known as "backwardation" in futures markets. If biomass is lower than expected prior to the production period farmers must be compensated by higher prices in order to give up the valuable high growth period. In such circumstances there is not enough fish to satisfy both consumption and "production" demand. If processors and exporters want fish on the spot they must bid up the price. These occasional seasonal spikes, as in for example the spring/summer of 2006, will lead to variation in volatility between years. Unless such seasonal spikes occur with increasing frequency, these effects should be distinguished from long-run trends in volatility.

Another way to examine volatility is to look at the number of price movements exceeding a specific level. In the full sample the standard deviation of

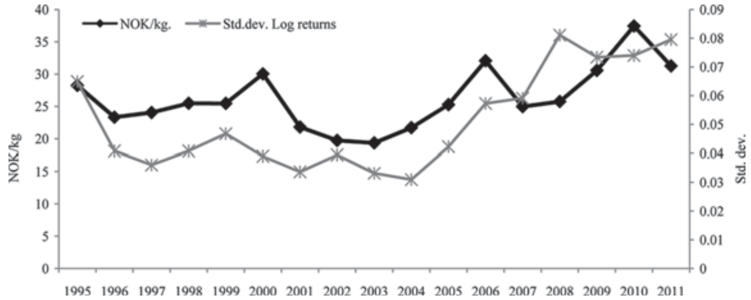

FIGURE 2 Annual mean salmon prices (left axis, black) and the standard deviation of log-returns.

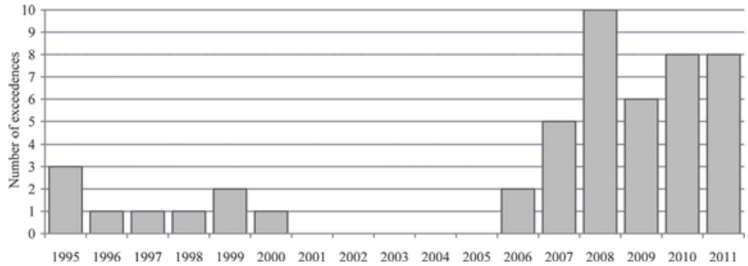

FIGURE 3 Number of weekly percentage price movements exceeding 10.8% (two times the standard deviation over the sample period).

percentage price returns is 5.4%. Assuming an approximate normal distribution the probability of a weekly price movement exceeding 10.8% (two times the standard deviation) should be around 5%. This means that in a given year there should be on average two to three weekly price movements exceeding 10.8%. Figure 3 shows the actual number of exceedences from 1995 to 2011 (2012 is excluded due to not being a full year in the sample).

The number of price movements exceeding 10.8% is not evenly distributed over the sample. The figure highlights how larger week-by-week price movements have become more prevalent, and salmon price volatility has increased in recent years. The next question is why volatility has increased.

POTENTIAL FACTORS CONTRIBUTING TO HIGHER VOLATILITY

Several factors have likely contributed to a more volatile market. It is not our purpose here to give a complete list of such factors, but rather to discuss some possible contributing elements. Potential factors include the 2005 maximum allowable biomass restriction, the 2006 introduction of the Fish Pool ASA futures market for salmon, input-factor market trends, general demand conditions for fish and other foods, the Chilean disease crisis and the increasing use of bilateral contracts. An empirical investigation of volatility and food prices is provided later.

The market for salmon is competitive; there is little evidence of significant market power (Asche & Bjørndal, 2011).In competitive markets for storable commodities there is a predicted positive relationship between price and volatility (Wright & Williams, 1991; Chambers & Bailey, 1996; Deaton & Laroque, 1992, 1996; Pindyck, 2001). When the commodity is scarce both price and volatility will increase. Scarcity means that limited stocks are available to smooth demand fluctuations. This is associated with a speculative stock-out or a large convenience yield on remaining stocks.

Scarcity will reduce the elasticity of supply leading the market to respond to shocks by adjusting prices rather than quantity. It is natural to investigate the change in volatility by looking at the scarcity of salmon. Has salmon become scarcer in recent years?

In terms of salmon from Norway there is little evidence of scarcity if we look at total annual biomass (Figure 4). From the figure we observe a consistent increase in biomass from 1995 and onwards. However, total biomass is not a sufficient measure of scarcity as total biomass includes both fish ready to harvest (speculative stock) and fish used for further production through growth. It is possible that supply/demand conditions are tight even if total biomass has increased. For example, if demand from processors and exporters grows, farmers might still be wary to increase their harvests too much so as not to sacrifice future biomass[3].

One factor deserving of discussion here is the Chilean salmon crisis. Starting in late 2007 the Chilean salmon industry experienced severe disease issues (Asche et al., 2009a). This had a significant effect on production from 2009 until at least early 2011. From 2011 production appears to at least partially recover. To show one effect of the Chilean crisis, Figure 5 shows imports of frozen and fresh filets from Chile and Norway to the United States.

Although imports from Chile decreased substantially, imports from Norway increased. Norway experienced a positive demand shift. The crisis can account for the strong prices in 2009 and 2010. From 2011 the import market appears to be normalizing. The positive demand shift for Norwegian salmon contributed to the relative scarcity of salmon, and has likely contributed to keeping volatility high. However, the general increase in volatility started from around 2005, four years before the Chilean crisis.

The Maximum Total Allowable Biomass Restriction

Prior to 2005 salmon farmers in Norway faced restrictions on both production volume per license, biomass density and feed usage (Asche & Bjørndal, 2011). In an attempt to simplify this system a single maximum

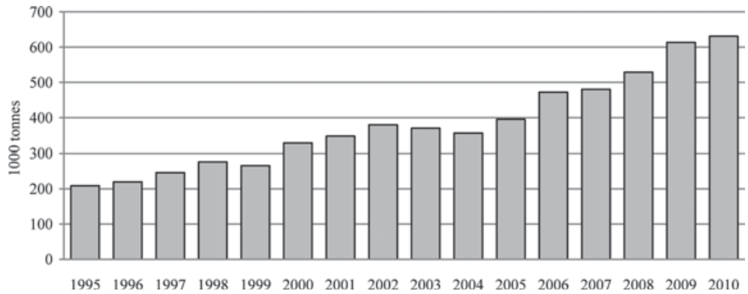

FIGURE 4 Total annual salmon biomass from 1995–2010. *Source*: Norwegian Directorate of Fisheries (2012).

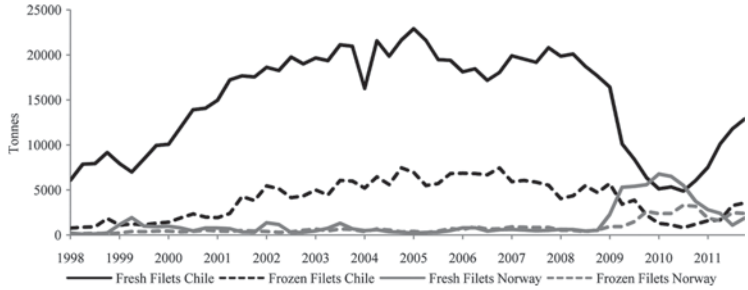

FIGURE 5 U.S. imports of Atlantic salmon from Chile and Norway. *Source*: NOAA (2013).

total allowable biomass restriction (MTB) was introduced in 2005. The MTB restriction states that a farmer can keep no more than 65 tons of fish per 1,000 m^3 license volume. A standard license (12,000 m^3) is then converted to 780 tons MTB. Based on the number of licenses and the standard license size, we can construct a crude measure of capacity utilization in the industry.[4]

Figure 6 shows MTB-implied capacity utilization from 1995 to 2010. According to this measure capacity utilization has increased steadily since the start of the sample. In 2010 capacity utilization was over 81%. This might be an indication that supply/demand conditions have become tighter in recent years. This suggests that higher price volatility is linked to tighter supply/demand conditions for Norwegian farmers and an effective scarcity of fish. Of course this is a simple correlation and not evidence of causality so we should remain skeptical and look for other corroborative evidence.

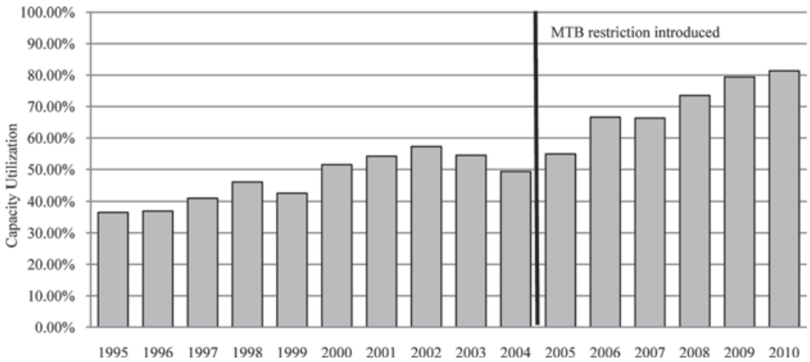

FIGURE 6 MTB implied capacity utilization for Norwegian salmon farms. *Note*: Available capacity is calculated as (number of licenses × average license's MTB). The average license's MTB is 780 tons of salmon. Capacity utilization is then estimated as the average total biomass' share of available capacity. *Source*: Norwegian Directorate of Fisheries (2012).

At least from a theoretical standpoint an MTB-type restriction is likely to affect harvest patterns. If farmers expect capacity to be binding they are likely to harvest earlier than planned and thereby creating larger fluctuations in harvests. The direct consequence of violating MTB restrictions are fines equal to the amount (in kg) exceeding MTB times a relevant sales prices set by the Norwegian Directorate of Fisheries. Violations of MTB are based on self-reported biomass. There is anecdotal evidence that if MTB is likely to be binding a certain month farmers will increase harvest prior to the end of the relevant month. This is because they have to report at the start of each month the prior month biomass. MTB has been binding for farms in recent years as companies have been fined in accordance with regulations due to MTB violations.

It should be noted that effective biomass restrictions were in place prior to the current MTB regime. The stated purpose of the current MTB regime was to simplify reporting and give individual farmers more flexibility. Hence, the changes in regulations can, but need not have contributed to increased volatility.

Hedging Instruments

From May 2006 futures contracts for salmon have been traded on a derivative market facilitated and organized by Fish Pool ASA (www.fishpool.eu) in collaboration with NOS clearing. This market has provided new hedging instruments outside of the traditional bilateral agreements. In addition to hedging and risk sharing, the futures market can provide necessary standardization and price discovery regarding the value of salmon. If markets are liquid and otherwise well-functioning, derivatives could provide stabilizing effects on prices through improved conditions for biomass and marketing decisions. Alternatively, if futures prices are consistently "wrong," and spot prices are affected by futures prices, the introduction of the futures market could add unnecessary price volatility.[5] An additional problem could arise if relatively little volume is traded on the futures market but other market agents use futures prices for biomass and marketing decisions.

If we are to take volume as an indication, it is unlikely that the futures market has had much effect on the spot price of salmon. Although traded volume on the futures market has consistently increased (31,700 tons salmon equivalence in 2007 to 100,630 tons in 2010)[6], it is still relatively small compared to the total size of the market. It is still possible for futures prices to affect spot prices given enough agents make decisions based on futures prices without participating directly in the market. To examine this effect further necessitates a detailed empirical study outside the scope of this article.

Of specific relevance to price volatility is the use of bilateral contracts to hedge cash-flows. With salmon becoming a staple item at retail stores across Europe a steady supply of fish is demanded. As such bilateral agreements have become more prevalent in recent years (Kvaløy & Tveteras, 2008; Larsen & Asche, 2011). Increasing use of bilateral agreements over spot trading is relevant as it affects short-run supply elasticity. If more biomass is tied to binding contracts then less fish is available to respond to short-run demand fluctuations. This effectively means that less "speculative" stock is available. Even if farmers expect higher prices they could not respond by delaying harvests as fish is tied to contracts. This will have the direct effect of increasing short-run price volatility.

General Food Price Trends

Food prices on a global scale have been strong in recent years. Various factors have contributed to this. Increasing energy prices, the bio-fuel revolution, a weak dollar, export restrictions and rapid economic growth, specifically in China and India, combined with low yields are some proposed factors explaining the price run-up (Minot, 2010; Baffes, 2011). Especially relevant to fish is the "westernization of diets" from consumers experiencing rising purchasing power. This has resulted in increasing demand for protein and more varied diets in general (Zhang & Law, 2010).

In addition to increasing prices, the so-called biofuel revolution has created new connections between agriculture and energy markets (Serra et al., 2010; Ciaian & Kancs, 2011; Nazlioglu and Soytas, 2011; Salvo & Huse, 2011). This has directly manifested in a stronger relationship between corn and ethanol prices and, by extension, gasoline (Du & Lu McPhail, 2012). Energy has always been an important factor on the input side of agricultural production but has only recently become a substitute to energy on the demand side. This has caused stronger volatility spill-over effects from energy to agricultural markets in recent years (Trujillo-Barrera et al., 2011).

Salmon is related to other commodities both through food substitution and input factors, because salmon aquaculture feed accounts for the largest share of production costs. The major components of salmon feed are fish-meal, fish-oil and soybean-meal. The markets for these important commodities have not been immune to recent trends in commodity markets. As such salmon has experienced both increasing demand and higher production costs.

Figure 7 illustrates the recent run-up in agricultural prices relevant to salmon. This includes a meat price index, a cereals price index, an oils price index and a capture fish price index[7]. Meat and capture fish are protein substitutes for salmon. Cereals, oils and fish-meal are important

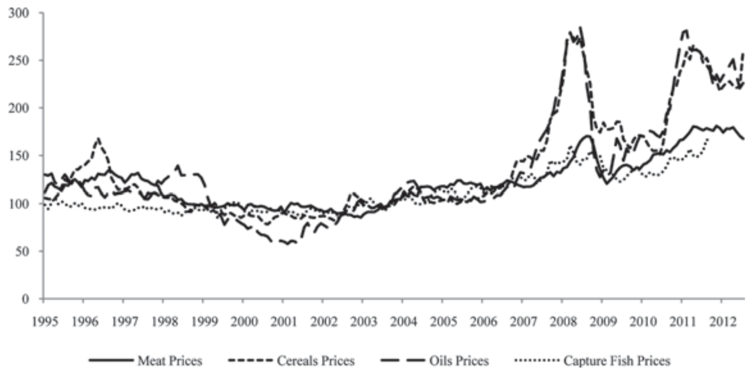

FIGURE 7 FAO food price indices. *Note*: 2002–2004 = 100. The Meat Index contains four types of meats: two poultry products, three bovine meat products, three pig meat products and one ovine meat product. The Cerals Index contains various grains and rice prices, including wheat and corn. The Oils Index consists of 12 different oils including animal and fish oils. The Fish Price Index consist of import prices for major fish species traded.

components in salmon feed. The overall trends for the indices point in the same direction, with oils and cereals being the most volatile. To investigate the co-movement in indices we perform a principal component analysis. Table 1 reports the correlation matrix and the variations in indices accounted for by the principal components.

A majority of the variation in indices (89.54%) can be accounted for by the first factor. Examining this factor it accounts for the major long run swings in indices. We will refer to this factor as the food price trend (fpt). Later this factor will be used to examine how volatility correlates with relevant food prices.

Strong demand for fish and meat in general likely also includes salmon. The 2008 food crisis, which manifested strongly in cereal prices, did not manifest strongly in aquaculture prices. Capture prices on the other hand did increase significantly up to the summer of 2008. This could be explained by the stronger energy component in the 2008 crisis. Fuel price is a larger component of the direct input cost in capture fisheries. Many of the same factors contributing to the 2008 commodity price peak also contributed to the recent 2011 food crisis. Contrary to 2008, the 2011 prices has a stronger meat component (Trostle et al., 2011). Global per capita pork

TABLE 1 Correlation Matrix and Principal Components of Food Indices

	Meats	Cereals	Oils	Fish		Eigenvalues	% variation	% cumulative
Meats	1				PC1	3.582	89.54	89.54
Cereals	0.89	1			PC2	0.192	4.81	94.35
Oils	0.84	0.91	1		PC3	0.157	3.94	98.29
Fish	0.81	0.88	0.82	1	PC4	0.0683	1.71	100.00

and poultry consumption has increased steadily the over last decade. Production decisions (for pork and beef) made when prices were low, following the late 2008 price drop, affected supply in 2011, causing higher prices (Trostle et al., 2011). More intensive feeding systems (especially for cattle) with more use of grain and protein meal in combination with high cereal and meal prices has also contributed to upward pressure on meat prices.

Important feed factors like cereals, oils and meal prices have also been consistently high. It should be noted that dependence on costly marine proteins in aquaculture production has decreased. This decrease is most dramatic for carnivore's species such as salmon. The fish-in fish-out ratio for salmon decreased from 7.5 to 4.9 from 1995 to 2006 (Tacon & Metian, 2008). Relative differences in protein and cereal prices will trigger substitution on the input side of production. However, a common trend in input factor prices will limit substitution benefits such that production costs have likely increased overall.

Judging by the overall developments in food and feed factor prices, salmon has experienced both increasing demand and higher costs of production in recent years. Salmon competes with other protein sources and is dependent on other agricultural commodities as inputs to production. Will strong demand in addition to higher production costs lead to more volatile prices? The largest cost component in salmon production is feed (Guttormsen, 2002). Fish not harvested and sold will have to be fed even with little net growth benefits. The alternative cost of harvesting, in essence a cost of storing, increases when feed prices increase.

Coupled with strong demand and high prices, it is likely that such conditions will lead farmers to harvest earlier than they would otherwise do. Rather than keeping fish in pens and speculating on future price developments, farmers might rather harvest now. Such behavior will lead to less supply smoothing, in effect reducing the elasticity of supply. This will increase the volatility of prices. In the next section, I derive a time-varying measure of volatility and investigates empirically how measurable quantities such as prices directly correlate with salmon price volatility.

Salmon Price Volatility and Food Prices

Here the variance of period-to-period price movements is modeled by a GARCH model (Bollerslev, 1986). In the GARCH model, the current period variance is a function of lagged variances and squared model prediction errors. The GARCH model is applied to allow volatility of prices, measured as the standard deviation of non-predictable price movements, the freedom to change in time. Non-predictable price movements are here defined as the part of prices not accounted for by a predefined parametric model of prices. To model current price we use an error correction model. The information set available to predict prices is lagged prices.

We will also allow deterministic seasonality. The degree to which the model error is non-predictable can be evaluated using conventional tests of the i.i.d. nature of model errors such as the Q-statistics. Non-predictable should here be interpreted relative to the family of univariate linear error correction models and the restricted information set used. The model is not necessarily an optimal forecasting model or a representation of the markets true expectations of prices. We will model both week-by-week and month-by-month volatility of prices, where monthly prices are constructed as average within month weekly prices.

We denote the logarithm of current price as p_t and price return as $\Delta p_t = p_t - p_{t-1}$. Current period price return is modeled as:

$$\Delta p_t = \mu + seas_t + \gamma_0 p_{t-1} + \sum\nolimits_{i=1}^{k} \gamma_i \Delta p_{t-i} + \sigma_t \varepsilon_t, \tag{1a}$$

$$\sigma_t^2 = \sum\nolimits_{l=1}^{m} \alpha_l \varepsilon_{t-l}^2 + \sum\nolimits_{n=1}^{p} \beta_n \sigma_{t-n}^2. \tag{1b}$$

Equation (1a) is an error correction representation of prices where $0 > \gamma_0 > -2$ implies mean reverting prices. If $\gamma_0 = 0$, prices contain a random walk component and do not settle at a stationary distribution. The purpose of Equation (1a) is to decompose price return into a predictable and non-predictable component. The variation in the non-predictable model error, ε_t, can then be interpreted as the volatility of prices. Due to the possibility of deterministic seasonality we introduce a deterministic seasonal component $seas_t$ in Equation (1a). For the weekly prices we model seasonality by Fourier series; that is, sums of trigonometric functions. We allow annual, semi-annual and quarterly cycles in the Fourier representation[8]. For the monthly prices seasonality is modeled by monthly dummy variables. Experimenting with different cycle frequencies in the Fourier representation suggests that the GARCH parameter estimates are robust to the seasonal representation.

The model error ε_t is assumed IID(0,1) such that the implied conditional variance of returns is σ_t^2. The conditional variance is modeled as following a GARCH process (1b). In the GARCH model the persistence of variance shocks are dictated by the magnitude of α_i and β_i in equation (1b). Coefficients equal to zero implies a constant conditional variance. For a GARCH(1,1) model, where both squared residuals and conditional variance are lagged by one period, the half-life of a shock is $ln(0.5)/ln(\alpha_1 + \beta_1)$. The closer $\alpha_1 + \beta_1$ is to unity the longer it takes for a shock to variance to be absorbed.

For the weekly series the lag length of differences is set to three weeks; for the monthly series, two months. These are sufficient to eliminate significant serial correlation when evaluated by the Q-statistics. Experimentation shows that GARCH parameters are robust to changes in different lag combinations. For the variance process one period lags for both the squared error and variance is sufficient to account for ARCH effects and autocorrelation in squared residuals. The model is estimated by maximum likelihood. In addition we use variance targeting in the estimation such that the conditional variance implied by Equation (1b) is consistent with the unconditional variance of the data (Mezrich & Engle, 1996). Estimation results for weekly and monthly prices are shown in Table 2.

To make the table more readable the seasonal estimates are not shown but results are available by request. If we impose a restriction of no deterministic seasonality we get a *P*-value < 0.001 for both the weekly and monthly model. This suggests the presence of deterministic seasonality. The seasonal effects are not pursued in any greater detail here as it would extend beyond the scope of the article. Seasonality in this article is relevant to the degree that it affects volatility. Trying different specifications for seasonality (more or less cycles in the Fourier representation) suggests that the GARCH estimates are robust to the imposed seasonality.

The sign of γ_0 in both models is negative, suggesting mean reversion. Due to the non-standard distribution of γ_0 under the null ($\gamma_0 = 0$) these *P*-values should be evaluated relative to the Dickey Fuller distributions. The t-statistics of γ_0 for the weekly and monthly series is -2.134 and -2.343, respectively. Using Dickey Fuller critical values from the relevant null model ($5\% = -3.43$, $1\% = -4.01$) we cannot reject a unit root in price levels. This is in accordance with what is commonly found in the literature (Asche et al., 2002; Tveterås & Asche, 2008; Nielsen et al., 2009).

Both the weekly and monthly GARCH estimates give strong evidence against constant volatility. The coefficients for the ARCH and GARCH

TABLE 2 GARCH Estimation Results

Weekly Prices			Monthly Prices		
	Estimate	*P*-value		Estimate	*P*-value
μ	0.0541	0.035	μ	0.4174	0.019
γ_0	−0.0171	0.033	γ_0	−0.1183	0.038
γ_1	0.0295	0.484	γ_1	0.2427	0.018
γ_2	−0.1613	<0.001	γ_2	0.0565	0.508
γ_3	−0.1176	0.002	α_1	0.0431	0.038
α_1	0.1444	0.002	β_1	0.9450	<0.001
β_1	0.8231	<0.001			
		P-value			*P*-value
Q(20) – residuals		0.2059	Q(20) – residuals		0.2262
Q(20) – squared res.		0.0797	Q(20) – squared res.		0.0791
ARCH (1–5)		0.5051	ARCH (1-5)		0.5204

Note: The Q-statistic is the Box-Pierce test for the null of no-remaining residual autocorrelation. Lags are given in parenthesis. The Q-statistic is χ^2(nlags) distributed under the null, where. The ARCH statistic is Engle's LM ARCH test for presence of residual ARCH effects. The test regresses squared residuals on own lags and tests for significant coefficients using the *F*(nlags,nobs-nlags) distribution.

terms (α_1 and β_1) are significantly different from zero. The sums of the coefficients are close to unity (0.967 for the weekly estimates and 0.988 for the monthly series) suggesting strong persistence in volatility shocks. This is not surprising considering the previous investigation of volatility. The implied standard deviations (defined as volatility) from the GARCH estimates for the weekly and monthly series are shown in Figure 8.

Volatility for both the weekly and monthly series suggests a trending series consistent with what was established earlier. The weekly series show greater short-run fluctuations since week-by-week fluctuations have been averaged out in the monthly series.

If we look at volatility the long-run trend is similar to the trend in food prices (Figure 7). If we include the implied monthly volatility from the GARCH estimation in the principal component analysis of indices we find that the first principal component still accounts for most of the variation across series (87.15%). The correlation between series and the principal components contribution to variance is shown in Table 3. In the principal component analysis excluding volatility (Table 1) the first principal component accounted for 89.54% of the variation in series. The relatively small decrease in explanation from 89.54% to 87.15% by including volatility suggests strong co-movement in food prices and volatility.

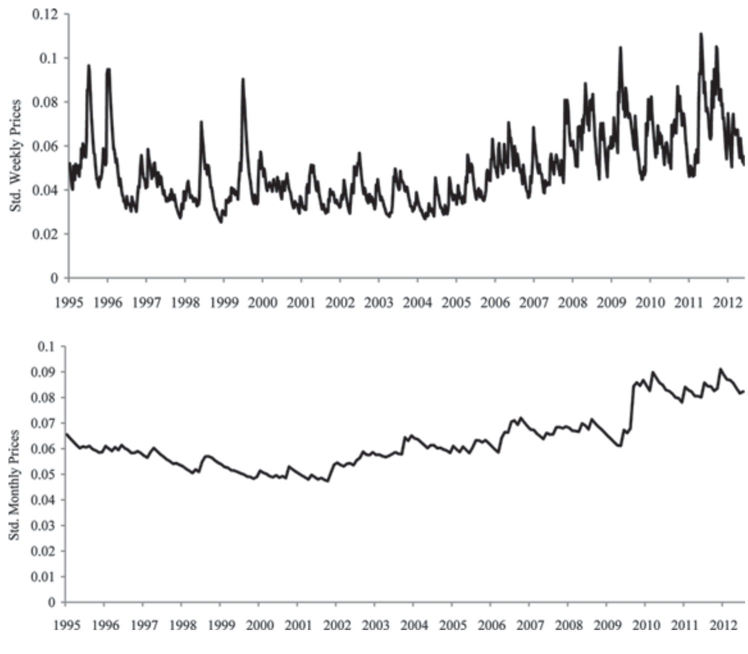

FIGURE 8 Implied volatility (conditional standard deviations) from GARCH model estimates of weekly (top) and monthly (bottom) price returns.

TABLE 3 Correlation Matrix and Principal Components of Food Indices and Volatility of Salmon Prices

	Meats	Cereals	Oils	Fish	Vol.		Eigenvalues	% variation	% cumulative
Meats	1					PC1	4.357	87.15	87.15
Cereals	0.89	1				PC2	0.257	5.15	92.29
Oils	0.84	0.91	1			PC3	0.178	3.58	95.87
Fish	0.81	0.88	0.82	1		PC4	0.147	2.94	98.81
Vol.	0.81	0.79	0.79	0.83	1	PC5	0.059	1.19	100.00

This result indicates that the food price trend (fpt) found in the first principal component analysis (Table 1) accounts for much of the trending in volatility. An OLS regression of the monthly GARCH implied volatility on an intercept and the food price trend ($\sigma_t = \beta_0 + \beta_1 fpt_t$) gives an R^2 of 0.73. The fit of this regression is shown in Figure 9.

Of course we should be careful in equating this high R^2 to a "true" relationship between the variables. Both series are highly trending and the fit could simply be the result of a spurious correlation. To examine this hypothesis further we work under the null hypothesis that the high R^2 is the result of a spurious regression. We generate 50,000 random walk "food price trends". Any high R^2 as a result of running the regression with these artificial food price trends will be the result of regressing two highly trending series against each other. Evaluating the original R^2 of 0.73 relative to the R^2 distribution from the artificial series we get a P-value of 0.022. As such our original result indicates a statistically significant positive relationship between food prices and volatility different from a spurious correlation.

One commodity of special relevance to salmon is fishmeal (Asche et al., 2012). Fish meal is a major component in salmon feed and could potentially have an effect on salmon price volatility outside of the general food price effect established here. The fish-meal price used in this analysis is the monthly CIF price of Peruvian Fish Meal Pellets, 65% protein, from the World Bank. Peru is the largest producer of fishmeal, of which almost

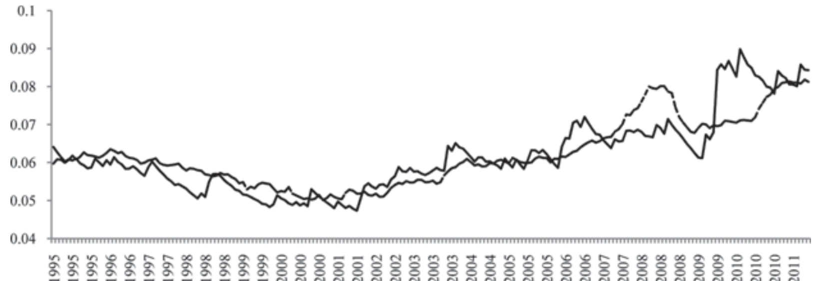

FIGURE 9 OLS fit of monthly volatility from GARCH estimation (solid line) on the food price trend (dotted line).

all is exported. Fish Meal prices depend on several factors including the El Nino weather phenomenon affecting total catches. High demand for fishmeal for various feeds (aquaculture and non-aquaculture production), including demand from new emerging aquaculture producers such as shrimp farmers in Vietnam, is likely keeping prices of fishmeal high.

The food price trend, accounting for the major swings in food prices, accounts for about 61% of the variation in fishmeal prices. The question is if controlling for the food price trend, will fish-meal prices have an additional association with salmon price volatility? We adjust volatility and fish-meal price as $\hat{\sigma}_t = \sigma_t - \beta_0 - \beta_1 fpt_t$ and $\widehat{fm}_t = fm_t - \beta_0 - \beta_1 fpt_t$, where β_0 and β_1 are estimated by OLS. Both the adjusted series reject a unit root using a conventional ADF test at the 1% level. We also include the NOK/EURO exchange rate and the Norwegian Interest Rate (the 1-month Norwegian Inter Bank Offer Rate) to account for other possible macroeconomic effects. Both these variables are defined in growth rates to avoid spurious regression effects. We perform the regression:

$$\hat{\sigma}_t = \beta_0 + \beta_1 \widehat{fm}_t + \beta_2 exchange\ rate_t + \beta_3 interest\ rate_t + u_t,$$

where $u_t = \sum_{i=1}^{k} \alpha_i u_{t-i} + \varepsilon_t$ is an auto-regressive error and ε_t is assumed IID(0,1). We account for serial correlation directly through a *kth* order autoregressive error. Lag length is selected sufficient to eliminate residual autocorrelation. As an alternative to the autoregressive least squares we could perform ordinary OLS and adjust standard errors non-parametrically using the procedure of (Newey & West, 1987). This is the HACSE estimation and the results of both procedures are shown next.

As Table 4 shows, there is some evidence that higher fish-meal prices are associated with higher salmon price volatility although the effect does not appear very strong. Exchange rate and Interest rate effects are even weaker.

The result from this discussion show that a higher volatility of salmon prices is linked to higher food prices in general. This includes both

TABLE 4 Effect of Fish-Meal Price on Salmon Price Volatility

Autoregressive Least Squares Estimation			HACSE Estimation		
Variable	Coefficient	*t*-stat	Variable	Coefficient	*t*-stat
Constant	−0.00029	−0.27	Constant	−0.00037	−0.62
Fish Meal	0.00679	2.36	Fish Meal	0.01077	2.94
Exchange rate growth	0.02406	1.21	Exchange rate growth	0.0165	1.55
Interest rate growth	0.00500	1.74	Interest rate growth	−0.0096	−0.20
Residual AR(1) term	0.8776	11.7			
Residual AR(2) term	−0.0333	−0.34			
Residual AR(3) term	0.2591	2.60			
Residual AR(4) term	−0.2384	−3.13			

demand side substitutes for salmon such as other meats and fish in addition to important input factors such as cereals, oils and fish-meal. This provides support for the hypothesis that higher volatility is due to strong demand for salmon in combination with higher production costs. Fish meal also appears to have an additional weak positive association with volatility.

CONCLUSION

This article focuses on recent trends in salmon price volatility. It is demonstrated empirically that volatility of Atlantic salmon from Norway has been on an increasing trend since the start of the 2000s. This is established parametrically by modeling conditional variance of price returns by a GARCH model.

Having established this stylized fact the question of why volatility has increased is pursued. From commodity price theory the positive association between price and volatility could be explained by tight supply/demand conditions. Such tight conditions means that demand fluctuations, in lack of available biomass, must be adjusted by price movements rather than supply adjustments. Potential factors contributing to tighter supply/demand conditions and lower short-run supply elasticity are: 1) strong demand for salmon from Norway, partially contributed by the Chilean disease issues, 2) increased capacity utilization as a response to favorable demand conditions and the resulting effects of occasionally binding MTB restrictions, 3) the increasing use of bilateral contracts over spot trading and 4) the overall strong prices for relevant commodities globally increasing production costs and contributing to strong demand for salmon. This last factor is given empirical support by investigating the co-movement between volatility and food prices. Evidence is found that the common trend in food prices can also account for a major part of the trend in salmon price volatility. This means that the recent climate of strong demand for fish in combination with higher prices of important input factors has contributed to an environment of higher price volatility. It is also found that higher fish-meal prices are associated with higher salmon price volatility after accounting for the trend in food prices.

NOTES

1. Market shares for 2009 and 2010 were 60% and 65%, respectively; these numbers are naturally inflated by the Chilean disease issues.
2. Logarithmic return of price at time t is defined as $ln(p_t) - ln(p_{t-1})$.
3. For an example of a firm specific harvest model for salmon, see Guttormsen (2008).
4. Please note that due to the seasonal variation in the biological growth pattern (Asche & Bjørndal, 2011), full utilization of the MTB is impossible.
5. It is also of interest to note that the introduction of the futures market is so close in time to the introduction of the MTBs, that it is difficult to separate the potential effects of these two measures on price volatility.

6. Numbers are from the Fish Pool ASA annual rapport. (http://fishpool.eu/uploads/%C3%85rsregnskap_2010_Fish_Pool_ASA.pdf).
7. For details on the FAO fish price index, see Tveterås et al. (2012).
8. The specific seasonal representation for the weekly data is: $seas_t = \sum_{j=1}^{3}\left(\left[\sin\left(2\pi t/k_j\right), \cos\left(2\pi t/k_j\right)\right]\begin{bmatrix}\alpha_{\sin,j}\\ \alpha_{\cos,j}\end{bmatrix}\right)$, where $\alpha_{\sin,\,j}$ and $\alpha_{\cos,\,j}$ are coefficients to be estimated for each seasonal cycle $(k_1 = 52(annual),\ k_2 = 26(semiannual),\ k_3 = 13(quarterly))$.

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