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The risk premium in salmon futures

Risikopremie i laksefutures

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Preface

This thesis represents our final assignment as students in Master of Business Administration at Trondheim Business School (NTNU).

The main objective of the thesis is to determine which factors contribute to variations in the risk premium for salmon futures between 2006 and 2016. The reason why we chose this topic was rooted in the vast growth the salmon industry has experienced in Norway. The existing research on salmon futures is limited, and we therefore found it motivational to provide more insight on the topic.

We would like to thank our supervisor Michael Kisser for valuable guidance and constructive feedback. We would also like to thank Sjur Westgaard for much appreciated information and data on the salmon industry.

The contents of this master thesis reflect our own personal views and are not necessarily endorsed by Trondheim Business School (NTNU).

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Abstract

Futures contracts on fresh Atlantic salmon became available through Fish Pool in 2006. The volumes of traded futures have increased over the years, making Fish Pool a success as the only salmon futures provider in the world. This paper examines the relationship between spot and futures prices at Fish Pool in the period June 2006 through June 2016. Futures contracts with 1-, 2-, 3- and 6-months to delivery are used to identify the historical risk premiums in the salmon market. We analyze if the futures-spot basis significantly explains the variation in the risk premium. Our model incorporates monthly dummy variables, as well as biophysical and economic factors. The regressions are estimated in stages by adding variables to show how the coefficients of the futures-spot basis change. Results show that variation in the risk premium is mostly explained by the basis and seasonality. The risk premium is linked to unexpected shocks in biophysical and economic variables, but with low explanatory power. Shocks in production are significant for all four contracts. We find that the basis significantly explains the variation in the risk premium for contracts with 1-month to delivery. The results for the 2- and 3-month contracts show that the basis significantly explains the variation in the risk premium, especially when controlling for seasonality. For the 6-month contracts, however, we find that the basis in the risk premium regression becomes insignificant. The results indicate that basis primarily contains information about the future spot price changes. This study is of relevance to market participants in the salmon industry, as it provides valuable information on salmon futures as a hedging tool.

Sammendrag

Futureskontrakter på fersk atlantisk laks ble tilgjengelig gjennom Fish Pool i 2006. Volumet av omsatte futures har økt gjennom årene, noe som gjør Fish Pool til en suksess som eneste leverandør av laksefutures i verden. Denne oppgaven undersøker forholdet mellom spot- og futurespriser fra Fish Pool i perioden juni 2006 til og med juni 2016. Futureskontrakter med 1, 2, 3 og 6 måneder til levering brukes til å identifisere de historiske risikopremiene i laksemarkedet. Vi undersøker om futures-spot basis signifikant forklarer variasjonen i risikopremien. Vår modell inneholder månedlige dummyvariabler, samt biofysiske og økonomiske faktorer. Regresjonene estimeres i trinn ved å legge til variabler for å vise hvordan koeffisientene til futures-spot basis endres. Resultatene viser at variasjon i risikopremien hovedsakelig forklares av basis og sesongvariasjoner. Risikopremien er knyttet til uventede sjokk i biofysiske og økonomiske variabler, men med lav forklaringskraft. Sjokk i produksjon er signifikant for alle de fire kontraktene. Vi finner at basis har signifikant forklaringskarft på variasjonen i risikopremien for kontrakter med 1 måned til levering. Resultatene for kontrakter med 2 og 3 måneder til levering viser at basis signifikant forklarer variasjonen i risikopremien, spesielt når vi kontrollerer for sesonger. For kontraktene med 6 måneder til levering finner vi imidlertid at basis i regresjonen for riskikopremie ikke blir signifikant. Resultatene indikerer at basis primært inneholder informasjon om fremtidige endringer i spotpris. Denne oppgaven er relevant for markedsaktørene i lakseindustrien, da den bidrar til verdifull informasjon om laksefutures som et verktøy for hedgning.

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1. Introduction

Farmed salmon production has shown increased growth over the past decade, exceeding 2.2 million tons of harvested salmon in 2015 (Marine Harvest, 2016). Increasing demand for salmon has made this commodity one of the most attractive sources of seafood in the world. Norway currently has more than 50% of the world's salmon production and takes the leading role regarding technology and innovation in the salmon harvest market. Investments regarding research on salmon aquaculture, diseases and sea lice contribute to cost effective production and a sustainable environment. Salmon is marketed as fresh which makes production expensive to adjust when the harvest in one period must be consumed in the same period. Hence, supplied quantity is inelastic in the short term (Marine Harvest, 2016). Producers and buyers have experienced high price volatility which leads to higher risk and uncertainty for market participants. In general, producers and buyers face two main types of risks; price- and production risk. The majority of salmon is sold at spot price, while some producers have bilateral agreements with fixed prices.

In 2006, Fish Pool was introduced as a marketplace for stakeholders in the salmon industry. The Fish Pool exchange is a marketplace with futures and options which could serve as a hedging tool for participants in the salmon industry. Fish Pool does not offer physical trading, which means that all contracts are settled financially. A steady increase in trading, from approximately 4,000 tons in 2006 to 96,000 tons in 2014, shows a significant interest from market participants (Fish Pool, 2014, p.3). A marketplace for derivatives on salmon can provide features which makes it easier for stakeholders to respond to sudden events that affect the salmon price. Since it is less strenuous to trade salmon contracts on a marketplace than physically buying or selling salmon, stakeholders may reduce uncertainty, time and risk in the short-term. Salmon farmers and companies that use fresh salmon in their production, i.e. food processing companies, can fix the price in advance and thereby hedge against price risk.

This study focuses on futures contracts for salmon and the relationship between spot and futures prices. Studies regarding this relationship can mainly be seen from two different perspectives. The first is *the theory of storage*, where the difference between the current spot price and the futures price – i.e. the basis – is explained through the interest foregone in storing the commodity, the convenience yield and storage costs Botterud et al. (2010). The convenience yield is the benefits from holding the physical asset and reflects the expectation of the market regarding the future availability of the commodity. The second perspective is *the risk premium theory*, which originates from the work of Keynes (1930). The difference between the futures price and the future spot price – i.e. the risk premium – is seen as a compensation to speculators for taking on risk from hedgers. As Mork (2006) points out regarding the futures market for electricity; storage costs and convenience yield either become infinite or lose their meaning for non-storable commodities. Hence, the theory of storage will face difficulties when pricing such commodities. Due to the non-storability of fresh Atlantic salmon, we can use the risk premium theory to investigate the spot-forward relationship[1]. To freeze salmon as a mean for storage will degrade the quality of the fish and place it in another price segment compared to the fresh product. In section 3 we discuss the characteristics of salmon in further detail and explain why we consider it to be a non-storable commodity.

The objective of this study is to examine the historical risk premiums in the salmon market and use regression analysis to investigate how the basis, biophysical and economic variables may contribute to explain the variations. We also add monthly dummies to account for seasonality in the risk premium. Examining the spot-forward relationship in the salmon market has been an object of several recent studies; Asche et al. (2016a), Asche et al. (2016b), and Ankamah-Yeboah et al. (2016) being the most important ones. Their research is presented in section 2 of the paper. Our work follows mainly in the footsteps of Asche et al. (2016b), and will include factors that have been studied earlier, as well as factors that have not been considered extensively. The biophysical and economic variables are expected to capture supply and demand changes for fresh Atlantic salmon and provide information about the risk premium and its movements.

This paper contributes to the existing, but scarce, literature on risk premiums in the salmon futures market. We extend recent research by studying futures contracts with 1-, 2-, 3- and 6-months to delivery. Producers, buyers and financial investors may find it useful to address future price risks in the salmon market. The results of the study could provide market participants with valuable information on salmon futures as a hedging tool. There are limited

[1] We use the terms *forward* and *futures* as synonyms. For the distinction between futures and forward contracts, see (Cox, Ingersoll and Ross, 1981).

studies regarding the salmon futures market and we therefore hope that this paper will contribute to further research on the subject and the salmon industry as a whole.

Our study shows that variation in the risk premium is mostly explained by the basis and seasonality. The risk premium is linked to unexpected shocks in biophysical and economic variables, but with low explanatory power. Shocks in production are significant for all four contracts. We find evidence that the basis significantly explains the variation in the risk premium for contracts with 1-month to delivery. The results for the 2- and 3-month contracts show that the basis significantly explains the variation in the risk premium, especially when controlling for seasonality. For the 6-month contracts, however, we find that the basis in the risk premium regression becomes insignificant. The results indicate that basis primarily contains information about the future spot price changes.

The paper is organized as follows. Section 2 presents an overview of the relevant literature on the spot-forward relationship. Section 3 explains some characteristics of salmon as a commodity and the basic concepts of the relation between spot and forward prices. In section 4 we describe the methodology and section 5 gives a description of the data selection. In section 6 we present the empirical results and discuss our findings. Finally, section 7 concludes.

2. Literature review

Previous studies on the salmon farming industry have focused primarily on supply and demand, as well as volatility and the market structures for salmon. See, for example, (Asche, 1996), (Andersen, 2008), (Oglend and Sikveland, 2008), (Oglend, 2013) and (Brækkan, 2014). Some have also tried to forecast salmon prices (Guttormsen, 1999); (Gu and Anderson, 1995). When the latter two papers were written no derivative markets for salmon existed, which made price hedging difficult. The motivation behind predicting salmon prices was therefore to provide producers and buyers of salmon with good forecasting models to minimize future uncertainty. However, since May 2006 a futures market for salmon has existed giving market participants the opportunity to hedge prices. Hedging may be beneficial in terms of both risk and inventory management.

The year after Fish Pool was founded, a paper analyzing the prospects of a potential futures market for salmon was published (Bergfjord, 2007). It finds that the salmon market fits some important characteristics for establishing sustainable futures contracts. Bergfjord (2007) argues that the more risk-averse the hedgers are, the more likely a contract is to succeed. However, a survey of Norwegian fish farmers finds this group of hedgers to be moderately risk-averse (Bergfjord, 2006). The fish farmers report that they use futures as a mean to increase profit rather than to reduce risk. However, Bergfjord (2007) argues that their response may not reflect “true” risk indifference. History shows that banks and governments have bailed out fish-farmers before and that the risk they perceive is substantially smaller than the apparent risk for an outsider.

In a well-functioning futures market the futures price should serve as an unbiased estimator of the spot price (Asche et al., 2016a). Unbiased estimator simply means that the futures prices should on average correspond with the anticipated spot price at expiry. Asche et al. (2016a) find the salmon futures price to be an unbiased estimator. Using monthly observations from 2006 to 2014, the study finds that spot and lagged futures prices are co-integrated up to maturities of 6 months. More interestingly, they find that the causality is one-directional from spot to futures prices. The spot price reacts first to new information, which implies that the futures price does not provide a price discovery function. The results are interesting because they contradict earlier empirical studies on the spot-forward relationship for commodities. According to Asche et al. (2016a), this is not uncommon in new and immature futures markets.

Similar to Asche et al. (2016a), Ankamah-Yeboah et al. (2016) provide an interesting insight to the salmon futures market and explore the relationship between the spot price and futures price of salmon. Ankamah-Yeboah et al. (2016) identify the co-integration relationship between the spot price and 1-6-, 9- and 12-month futures contract prices. They find that the 1-6-, and 9-months futures prices can provide an unbiased forecast of the subsequent spot price. This is a sign of an efficient market with no significant risk premiums. By testing the price discovery function, Ankamah-Yeboah et al. (2016) find that the spot price provides a market leadership role for shorter maturity futures, while the longer futures contracts are found to lead the spot price. As the price discovery function shows to be present for some contracts, Ankamah-Yeboah et al. (2016) conclude that the salmon futures market is near matured. This is in contrast to the empirical findings by Asche (2016a).

Shrimp was the first seafood commodity with a derivatives market. Martínez-Garmendia and Anderson (2001) examine the premiums associated with black tiger shrimp and white shrimp futures. They try to determine whether fixed premiums can eliminate the price differentials between the two shrimp types. They conclude that there may be a long-term price relationship, but that the premiums cannot eliminate opportunities for arbitrage. Misund and Asche (2016) recently find evidence suggesting higher hedging effectiveness of Atlantic salmon futures compared to black tiger shrimp and white shrimp futures. In addition to low hedging efficiency, Martínez-Garmendia and Anderson (2001) find that the shrimp futures cannot provide an unbiased prediction of the spot price. They do not find the results surprising due to low trading volumes. The shrimp futures were later removed from the exchange.

The study by Fama and French (1987) serves as an important foundation for research on futures prices and risk premiums in commodity markets. Their empirical analysis includes 21 different commodities. To test for expected risk premiums and forecasting power in future prices, Fama and French (1987) regress the change in the spot price and the realized risk premium on the basis in two separate equations. They find evidence of forecast power for ten commodities and less support for expected risk premiums. Further details about their methodology will be presented in section 4.

Following the work of Fama and French (1987), Asche et al. (2016b) examine the risk premium for the 1-month futures contracts at Fish Pool. Even though they recently found that futures prices do not provide a price discovery role (Asche et al., 2016a), they believe that the contracts still may be used for transfer of risk (hedging). In addition to the basis, Asche et al. (2016b) include industry-specific risk factors in their model to capture uncertainty about future inventory of salmon. They also add dummy variables to capture seasonality in the risk premium. Demand uncertainty is measured by adding the variance and skewness of spot prices to the regression. The empirical results suggest that the basis and seasonality significantly explain the variation in the risk premium. In addition, they find that shocks in biomass[2] are statistically significant, but do not contribute much to the explanatory power of the model. Their study also shows that the basis is more important for determining the risk premium than the spot price change. This is in contrast to other studies on animal production commodities (Brooks et al., 2013). Hence, Asche et al. (2016b) find that there is a risk premium in the salmon futures prices representing what producers are willing to pay to reduce price uncertainty.

Several studies imply that risk factors affecting the production process of commodities can help explain the variation in the risk premium. Botterud et al. (2010) find a link between the risk premium in electricity futures and variables describing the underlying physical state of the market, such as hydro inflow, reservoir levels and electricity demand. Even though their study examines the electricity market, it should be relevant for other commodities as well. Asche et al. (2015) argue that key elements in the production process of Atlantic salmon, such as biomass and seawater temperature, affect the price development. The risk premium is likely to be driven by the same variables influencing the price (Botterud et al., 2010). Lucia and Torró (2011) find that risk premiums in the Nordic electricity market are affected by seasonality, concluding that premiums are large and positive for contracts with delivery during demand peak periods. We also know from the study of Asche et al. (2016b) that seasonality is the one of the main determinants of the risk premium in salmon futures.

3. The spot-forward relationship in commodity markets

In the following section we present some characteristics of salmon as a commodity and describe the relation between spot and forward prices. Before proceeding it is necessary to make a few clarifications. Salmon is a common name for several species of fish. In this study we only refer to fresh Atlantic salmon from farmed sources. We do not consider frozen salmon, since both the spot price (reflected by the FPI[3]) and the futures price are based on fresh Atlantic salmon. Also, frozen salmon would introduce storage costs and convenience yield considerations.

[2] Biomass is the total amount of fish reported to be in the fish farms.

[3] The Fish Pool Index (FPI) is an index for the salmon spot price. The FPI is a synthetic market price which Fish Pool uses to settle forward and options contracts. FPI is composed of three indexes related to weekly buyers and sellers spot prices of fresh Atlantic salmon (see section 4).

3.1 Characteristics of salmon as a commodity

Before analyzing the spot-forward relationship, we need to understand the characteristics of salmon as a commodity and make some assumptions. The literature distinguishes between storable and non-storable commodities. Fresh salmon is highly perishable and is not directly storable. Live salmon in sea cages, on the other hand, can be stored for an extended period of time. One can therefore argue that the biomass is a suitable measure for the inventory level. Intuitively, if less salmon is harvested, the inventory levels will grow and can be carried from one period to the next. Making this assumption, farmed salmon is considered to be storable and one can apply theories originally used for storable commodities (Asche et al. 2016a).

In this study we consider fresh salmon to be a non-storable commodity for two reasons. First, the fish should be harvested when it reaches a certain marketable size, normally about 4-5 kg (Marine Harvest, 2016). Hence, it is limited how long the fish can be stored in cages before it goes at the expense of quality and optimal size. However, in some situations fish farmers can intentionally delay harvest (i.e. store live fish in sea cages) to affect the supply of salmon. An example is when Russia in 2014 banned food products from Norway, and fish farmers delayed harvest to offset the impact of the ban. This required the Government to raise the maximum amount of fish allowed in one concession. Even though fish as a live product in sea cages is storable, the amount of fish allowed is determined by the concessions given by the government. Hence, storability is highly restricted and this serves as the second argument for treating salmon as a non-storable commodity.

3.2 The pricing of futures contracts on commodities

Futures prices depend highly on the price of the underlying asset. However, the pricing of futures contracts can be understood from different perspectives. *The cost of carry model* is derived from today's spot price of the underlying commodity, while *the expectations theory* depends on the expectations of what the spot price will be in the future. The cost of carry model explains the futures price trough storage costs, financing costs (interest rate) and a convenience yield. The convenience yield is the benefit from holding the physical asset and reflects the market's expectations regarding the future availability of the commodity. If there is a high probability of shortages, the convenience yield will also be high (Hull, 2014). The cost of carry model describes the spot-forward relationship by the following equation:

$$F_{t,T} = S_t e^{(c-y)T} \tag{1}$$

where $F_{t,T}$ is the price of a futures contract at time t with maturity at time T, S_t is the spot price of the underlying commodity at time t, c is the cost of carry and y is the convenience yield. *Cost of carry* refers to the cost of storing the asset for a period of time, plus the interest rate paid to finance the asset, minus the income earned on the asset (Hull, 2014).

The cost of carry model is derived from the no-arbitrage argument. If equation (1) does not hold, then arbitrageurs will execute arbitrage strategies, i.e. strategies with no risk, no initial investment, and positive profits. Eventually the market will reach equilibrium and equation (1) will again hold. The essence of the theory is that futures prices must be high enough to offset the carrying costs incurred until time of delivery. If the futures price is too low, the equilibrium in (1) will not hold. The arbitrageur could sell the commodity in the spot market today and buy a futures contract, avoiding carrying costs until the contract reaches maturity.

The expectations (unbiasedness) theory, on the other hand, does not explain futures prices through storability. The theory implies that the current futures price $F_{t,T}$ is fully representative of the expected future spot price $E_t(S_T)$. This can be shown trough the following equation:

$$F_{t,T} = E_t(S_T | I_t) \tag{2}$$

where I_t is the information set at time *t* and $E(\cdot \mid I_t)$ is the conditional expectations operator at time *t*. The expectations theory builds on the assumption of rational expectations and assumes that investors are risk-neutral (Chen and Zheng, 2008). The question of futures prices being unbiased estimates of future spot prices has been studied extensively. Several tests lead to reject the theory, mainly because most investors are not risk-neutral (Geman 2005; Chen and Zheng, 2008).

Indeed, Keynes (1930) argued that “the spot price must exceed the forward price by the amount which the producer is ready to sacrifice in order to hedge himself, i.e., to avoid the risk of price fluctuations during his production period. Thus, in normal conditions the spot price exceeds the forward price, i.e., there is a backwardation.” In other words; the difference between the futures price and the expected spot price at maturity – i.e. the risk premium – is seen as compensation to speculators for taking on risk from hedgers. Hedgers can both be producers and consumers of the underlying commodity. Producers hold the commodity with intentions of selling it in the future. To hedge price risk, they need to hold short positions in the futures market. The opposite situation occurs for consumers.

The theory of normal backwardation proposed by Keynes (1930) assumes that hedgers are net short. This assumption implies that there are more producers than consumers trading in the futures market. The producers in the salmon market (i.e. salmon farmers) sell futures to fix the prices of their coming harvest. If they are more risk-averse than their counterparts, they may be willing to sell futures at a price below the expected spot price of salmon, essentially paying an insurance premium to reduce their risk. Speculators, on the other hand, are willing to buy the futures in order to earn the premium. Therefore, according to Keynes (1930), speculators normally hold long positions in futures and risk premiums are assumed to be negative.

The risk premium theory, also called *the hedging pressure theory*, originates from the work of Keynes (1930). The futures price of a commodity equals the expected spot price plus a risk premium:

$$F_{t,T} = E_t(S_T) + E_t(P_{t,T}) \tag{3}$$

where $E_t(P_{t,T})$ is the expected risk premium time *t*. As we can see from equation (3), the *risk premium* is defined as the difference between the futures price at time *t* and the expected spot price at maturity. Some researchers use the term *risk premium* as equivalent for *futures premium* (Gjølberg and Brattested, 2011); (Bessembinder and Lemmon, 2002). Others define the risk premium to be $E_t(S_T) - F_{t,T}$ and the futures premium to be $F_{t,T} - E_t(S_T)$ (Botterud et al., 2010); (Weron and Zator, 2014). We use the same definition as Fama and French (1987) and name the difference $F_{t,T} - E_t(S_T)$ a risk premium.

Deviations of futures prices from expected spot prices imply that there exists a risk premium. The sign of the risk premium depends on whether the relative demand for hedging is higher for the buyers or the sellers of a given commodity. Fig. 1 illustrates the relationship between the futures price and the expected spot price at maturity. As described through the theory of normal backwardation, Keynes (1930) assumed that the demand for hedging was higher for sellers than for buyers, resulting in negative risk premiums.

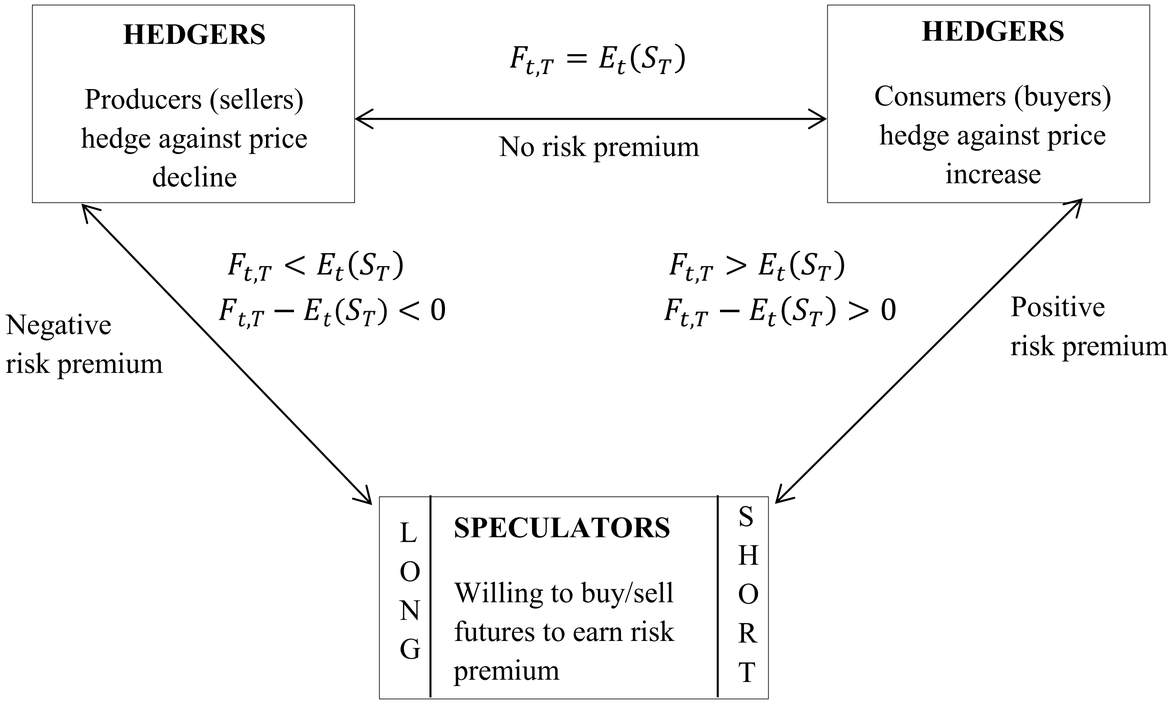

Fig. 1 The relationship between the futures price and the expected spot price at maturity

As the futures contract approaches maturity, the futures price converges towards the spot price of the underlying commodity. This is in line with the no-arbitrage principle. The *basis* is defined in equation (4) and should normally be zero at expiration of the futures contract, but may vary prior to expiration (Hull, 2014).

$$Basis_t = F_{t,T} - S_t \tag{4}$$

If futures prices and spot prices do not converge at maturity *T*, we refer to this as *basis risk* (Geman, 2005). Basis risk can occur if, for example, the asset to be hedged is not exactly the same as the asset underlying the futures contract (Hull, 2014). We further emphasize the need to distinguish between the basis and the risk premium. The basis is calculated using the current spot price at time *t*. The risk premium, on the other hand, is calculated using the spot price at maturity *T*.

The risk premium as defined in equation (3) is the *ex-ante risk premium*, since it depends on a forecast made at time t regarding the spot price at a future date T. However, modelling price expectations is not in the scope of this paper. We use the actual spot price at expiration as a proxy for the previously expected spot price, analyzing the *ex-post* (or *realized*) risk premium. The expected spot price is substituted with the realized spot price at time T.

Ex-post risk premium: $$P_{t,T} = F_{t,T} - S_T \quad (5)$$

A negative (positive) risk premium implies negative (positive) realized returns by holding a short position in the futures market. Under the assumption that market participants form their forecasts of the future spot price under rational expectations, then $E_t(S_T) = S_T$ and the ex-post risk premium will equal the ex-ante risk premium plus a random noise term:

$$F_{t,T} - S_T = E_t(P_{t,T}) + \varepsilon_t \quad (6)$$

A strong assumption often made in the literature is that the noise term (forecasting error) has an expectation value of zero since market participants make their forecasts based on rationality (Pietz, 2009). Fama and French (1987) also assume no market inefficiencies, i.e. market forecasts of future spot prices are rational.

There are some challenges with concluding that the difference between the futures price and the spot price at maturity is indeed a risk premium. See, for example, Frank and Garcia (2009) and Gjolberg and Brattested (2011). As they point out, the difference may also reflect non-rational expectations due to the markets inability to use existing information to make predictions about subsequent spot prices at maturity.

4. Methodology

To examine the historical risk premiums in the salmon futures contracts we follow in the footsteps of Asche et al. (2016b) and extend the empirical model proposed by Fama and French (1987). We incorporate supplementary control variables in addition to the basis. This allows us to test the sensitivity of the risk premium to biophysical and economic factors.

The method that Fama and French (1987) apply to study the spot-forward relationship is based on the risk premium theory as given by equation (3):

$$F_{t,T} = E_t(S_T) + E_t(P_{t,T})$$

Fama and French (1987) proceed with subtracting the current spot price from both sides of the equation and they replace the expected spot price at maturity with the realized spot price:

$$S_T - S_t + F_{t,T} - S_T = F_{t,T} - S_t \tag{7}$$

where $S_T - S_t$ is the change in the spot price, $F_{t,T} - S_T$ is the realized risk premium and $F_{t,T} - S_t$ is the basis. Fama and French (1987) then propose to test the relationship in equation (7) by regressing the risk premium and the spot price change on the basis in two separate equations:

$$F_{t,T} - S_T = \alpha_1 + \beta_1\left(F_{t,T} - S_t\right) + u_{t,T} \tag{8}$$

$$S_T - S_t = \alpha_2 + \beta_2\left(F_{t,T} - S_t\right) + z_{t,T} \tag{9}$$

where $u_{t,T}$ and $z_{t,T}$ are the error terms of the regressions. Equation (8) is a regression of the *ex-post (realized)* risk premium and equation (9) is a regression of the change in the spot price. When β_1 is significantly different from zero then the basis observed at time *t* possesses information about the risk premium to be realized at time *T*. When β_2 is significantly different from zero then the basis observed at time *t* incorporates information about the future spot price change. It is worth noticing that the sum of the risk premium and the spot price change equals the basis, which means that the coefficients β_1 and β_2 add up to one and that the intercepts add up to zero ($\alpha_1 = -\alpha_2$). This means that variation in the basis either reflects variability in spot price expectations, variability in the expected risk premium, or a combination of both.

Asche et al. (2016b) argue that including industry-specific production factors, monthly dummies to capture seasonality in the risk premium and price risk measures will improve the fit of the model proposed by Fama and French (1987). In our analysis we include the same biophysical variables as Asche et al. (2016b), as well as variables that have not been studied earlier. In section 5 we motivate and explain these factors in further detail.

Asche et al. (2016b) suggest the following augmentation of equations (8) and (9)[4]:

$$F_{t,T} - S_T = \alpha_1 + \beta_1(F_{t,T} - S_t) + \sum_{i=2}^{12} \theta_i MONTH_{i,T} + \sum_{i=1}^{6} \gamma_i \Delta CV_{i,T} + u_{t,T} \qquad (10)$$

$$S_T - S_t = \alpha_2 + \beta_2(F_{t,T} - S_t) + \sum_{i=2}^{12} -\theta_i MONTH_{i,T} + \sum_{i=1}^{6} -\gamma_i \Delta CV_{i,T} + z_{t,T} \qquad (11)$$

where $MONTH_{i,T}$ are monthly dummy variables and $\Delta CV_{i,T}$ are the additional control variables expressed as the log changes from time t to T (shocks). The coefficients θ_i and γ_i should be equal in magnitude in equation (10) and (11), but with opposite signs. This is due to the basis being equal to the sum of the risk premium and the spot price change. The models in equation (10) and (11) are estimated for futures contracts with 1-, 2-, 3- and 6-month(s) to delivery.

To avoid confusion, fig. 1 illustrates the terms related to the futures contracts in our study. All contacts at Fish Pool have a delivery period of 1 month. We refer to the month when the futures contract is signed as *t.* The month of delivery, i.e. when the futures contract is settled, is referred to as *T*.

We illustrate with two examples. A futures contract signed in June 2006 for delivery in July 2006 has one month left until delivery, also referred to as *time to maturity.* Number of months left to delivery is defined as $n = T\text{-}t$. In this example, $n = 1$. The futures price for June 2006 is calculated as an average of the daily futures prices in that month, representing the monthly futures price $F_{t,T}$ for June 2006 with delivery period in July 2006.

A futures contract signed in June 2006 for delivery in August 2006 has two months left until delivery. In this example, $n = 2$. The futures price for June 2006 is calculated as an average of

[4] For simplicity we continue to use the previously introduced notation.

the daily futures prices in that month, representing the monthly futures price $F_{t,T}$ for June 2006 with delivery period in August 2006.

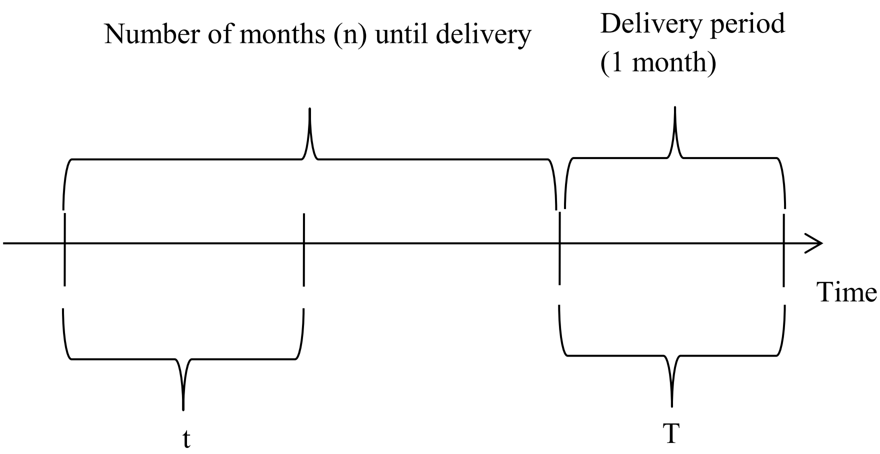

Fig. 2 Definition of the terms related to the futures contracts

The models are estimated using ordinary least squares (OLS) with Newey-West and pre-whitening correction of the standard errors. The Newey-West estimator is commonly used to compute heteroscedasticity and autocorrelation consistent (HAC) standard errors. Pre-whitening is recommended for HAC estimators to reduce bias and over-rejection of the t-statistics.

5. Data

The dataset ranges from June 2006 through June 2016, which gives us a total of 121 monthly futures price observations. We collect additional spot price observations until December 2016, since we need the realized spot prices to calculate the risk premium and spot price changes. We also collect observations from June 2006 through December 2016 for the additional control variables (introduced below) to calculate the deviations from time t to time T.

5.1 The Fish Pool Index

The Fish Pool Index is a synthetic spot price for salmon measured in Norwegian krone (NOK). Fish Pool uses the FPI to settle forward and options contracts. The index has seen a sharp rise the last two years, showing high price volatility (Fig. 2).

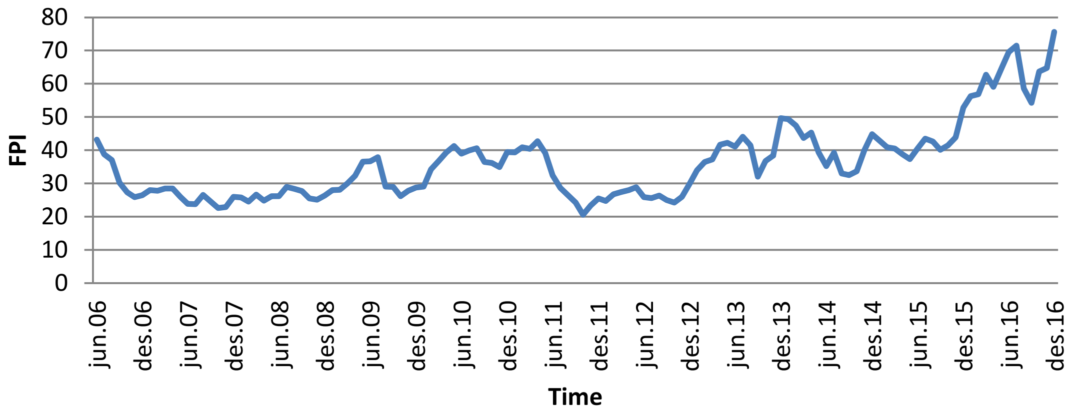

Fig. 3 Monthly FPI June 2006 to December 2016. Note: The price is measured in NOK.

The FPI is composed of three indexes related to weekly buyers and sellers spot prices of fresh Atlantic salmon. The included indexes are; Nasdaq Salmon Index (exporters sales price), Fish Pool European Buyers Index (large purchasers purchase price) and Statistics Norway Customs Statistics (Norwegian export statistics). Fish Pool also accounts for the different weight classes with three main size categories; 3-4 kg, 4-5 kg and 5-6 kg. These are assigned weightings 30%, 40% and 30%, respectively. The aim of the FPI is to serve as a reference price and thereby provide a correct reflection of the market price. The index should also be possible to verify and not be able to manipulate (Fish Pool, 2016, p.4). In our analysis we calculate monthly averages from the weekly FPI which represents the monthly settlement price for salmon futures. The weekly FPI is collected from Fish Pools website[5].

5.2 The futures price

The futures contracts at Fish Pool start trading the first Monday in every month and are settled the 15th in the following month after the delivery period.[6] The settlement price is based on a

[5] http://www.fishpool.eu

[6] The futures can be traded after the delivery period until the 15th (Fish Pool, 2015, p. 4). Market participants will already know the historical prices during the delivery month and thus have information about the realized spot prices. To avoid this information bias, we only use the pre-delivery futures price observations in our study.

simple average of the FPI in the delivery month (4-5 weeks). Since the settlement price is an average of the realized weekly spot prices in the delivery month, we calculate an average of the daily futures prices in each month to represent our monthly futures price. The futures price history is collected from Fish Pools website.

The descriptive statistics for the FPI and the futures prices are presented in table 1 and 2. The average FPI for the period is NOK 36.19 and has a maximum of NOK 75.62 and a minimum of NOK 20.64. The FPI has a higher average price compared to the four futures contracts (table 2). Furthermore, we see that the futures price decreases as time to maturity increases. The futures prices have a higher minimum and a smaller maximum compared to the FPI. This is expected as the spot price is more volatile due to seasonality and unexpected events. Seasonal variation in salmon prices also contributes to mean reversion, i.e. a decline in salmon prices is most likely followed by an upward price movement (Ankamah-Yeboah et al., 2016). The volatility of the futures prices is declining as time to delivery increases. This is in line with the empirical findings by Ankamah-Yeboah et al. (2016). They show that volatility is higher for futures contracts with shorter time to delivery.

Table 1 Descriptive statistics: Fish Pool Index (FPI)

	Average	**SD**	**Min**	**25%**	**Median**	**75%**	**Max**
FPI	36.188	11.401	20.638	26.730	34.965	41.008	75.615

Note: Monthly average of the FPI (spot price) based on weekly observations. The total number of observations is 127.

Table 2 Descriptive statistics: Futures prices

$\boldsymbol{F_{t,T}}$	**Average**	**SD**	**Min**	**25%**	**Median**	**75%**	**Max**
1M	34.311	8.793	23.679	26.467	34.178	39.062	59.589
2M	34.040	8.352	23.736	26.736	33.580	38.926	57.018
3M	33.847	7.969	23.852	26.761	33.059	38.865	54.623
6M	33.430	7.804	23.638	26.669	31.476	38.470	56.681

Note: Monthly average of futures prices $(F_{t,T})$ based on daily observations. n = *T-t* is the number of months to maturity. 1M, 2M, 3M and 6M denotes the futures prices for contracts with (n) number of months to maturity. The total number of observations is 121.

Table 3 presents the descriptive statistics for the risk premium, spot price change and basis. Keep in mind that we define the risk premium in equation (3) and (10) to be the futures price minus the spot price. A *decrease* in the risk premium implies that the sellers of futures contracts pay a *higher* premium to speculators. The risk premiums are on average negative and statistically different from zero for all maturities. This indicates that the futures market is in normal backwardation as proposed by Keynes (1930). For the analysis period from June 2006 through June 2016, we observe a higher number of negative than positive risk premiums (% negative). As time to maturity increases, the risk premium decreases. The basis is on average negative as well, and decreases with time to maturity which indicates backwardation.

Table 3 Descriptive statistics: Risk premium, spot price change and basis

	Average	SD	Min	25%	Median	75%	Max	%negative	%positive
Risk premium									
$F_{t,T} - S_T$									
1M	-0.013**	0.088	-0.228	-0.074	-0.025	0.050	0.242	60%	40%
2M	-0.023**	0.123	-0.302	-0.111	-0.041	0.069	0.256	64%	36%
3M	-0.030**	0.151	-0.365	-0.121	-0.046	0.067	0.384	63%	37%
6M	-0.063***	0.184	-0.465	-0.189	-0.081	0.054	0.555	69%	31%
$S_T - S_t$									
1M	0.004	0.089	-0.267	-0.049	0.008	0.067	0.256	47%	53%
2M	0.008	0.136	-0.320	-0.080	0.027	0.102	0.301	44%	56%
3M	0.010	0.175	-0.399	-0.097	0.025	0.130	0.438	45%	55%
6M	0.033	0.232	-0.727	-0.103	0.033	0.210	0.540	39%	61%
$F_{t,T} - S_t$									
1M	-0.009	0.065	-0.157	-0.055	-0.007	0.034	0.152	56%	44%
2M	-0.015	0.088	-0.233	-0.075	-0.012	0.038	0.213	56%	44%
3M	-0.019	0.104	-0.288	-0.094	-0.010	0.047	0.263	58%	42%
6M	-0.030	0.130	-0.336	-0.127	-0.021	0.058	0.305	56%	44%

Note: Risk premium ($F_{t,T} - S_T$) = difference between log monthly futures price at time t and log monthly spot price at time T. Spot price change ($S_T - S_t$) = difference between log monthly spot price at time T and log monthly spot price at time t. Basis ($F_{t,T} - S_t$) = difference between log monthly futures price at time t and log monthly spot price at time t. 1M, 2M, 3M and 6M denotes number of months (n) until the delivery period. The statistical significance of the negative risk premium is denoted by asterisks. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The number of observations is 121.

5.3 Additional control variables

The additional control variables in this study are selected based on supply and demand driving factors. Impacts on demand are the most challenging to estimate. Trends, such as sushi and health campaigns which can boost demand and prices, are difficult to quantify and anticipate. Hence, we choose to include only one demand driving factor in our study, namely, the EUR/NOK exchange rate. This variable should capture changes in demand due to relative change in purchasing power. The supply driving factors are linked to production of farmed salmon. Marine Harvest (2016) has published a handbook of salmon harvesting that provides a good overview of the industry structure and the sensitive production factors. Our model will include several of these as control variables for the risk premium. We also include dummy variables to capture seasonality in the risk premium.

5.3.1 EUR/NOK

Considering that most of the harvested salmon is not consumed in the producing country but exported abroad, we find it reasonable to include exchange rates between the producing and importing countries. According to Marine Harvest (2016), farmed salmon from Norway is most widely traded in Euro (EUR), which accounts for 64 % of the total salmon trade. Thus, it is expected that a depreciation of the NOK against the EUR will increase demand and prices. Xie et al. (2008) find the prices received by producers in the major exporting countries to be at least as sensitive to changes in domestic currency as to changes in salmon export volumes. Chile is the second largest exporter of salmon and should also have a significant impact on the salmon price. 40% of total salmon sales from Chile are traded in US Dollars (USD) (Marine Harvest, 2016). In the event of an appreciation of the Chilean Peso (CLP) against the USD, imports of salmon may shift from Chile to Norway. Hence, an increase in demand from the US may increase salmon prices in Norway. Historically, the US has accounted for a small share of Norwegian salmon exports. This, in addition to the long distance between Norway and the US, argues against a significant impact of the CLP/USD on the Norwegian salmon price. The only exchange rate we consider is the EUR/NOK, which is retrieved from Bank of Norway[7].

5.3.2 Smolt release

Smolt is young fish which are fed in fresh water tanks before they are transferred to sea cages. The growing process in fresh water takes approximately 10-16 months before the smolt is released and needs another 14-24 months in the sea cages before harvesting. Smolt is released approximately twice a year and this naturally contributes to seasonality due to the fish reaching an optimal harvesting size at the same time (Marine Harvest, 2016). We therefore expect smolt release to be a suitable parameter to indicate future inventory of salmon and thus

[7] http://www.norges-bank.no/

have an effect on the salmon price and the risk premium. A deviation from normal release of smolt may increase uncertainty and lead to changes in the risk premium of salmon futures. Statistics on smolt release are measured in number of smolt and collected from the Norwegian Directorate of Fisheries' website[8].

5.3.3 Biomass

Standing biomass is defined as the total weight of live fish, where the number of fish is multiplied with an average weight (Marine Harvest, 2016). Standing biomass serves as an indicator for inventory levels and may be an important parameter for predicting the expected future production volume. Events such as an outbreak of diseases and environmental disasters can take out large shares of the biomass and set back production for a considerable time. Thus, it is expected that a change in biomass levels will impact the salmon price and the risk premium for salmon futures. It is also worth mentioning that each license allows a maximum biomass which puts a roof on production. The biomass also inhabits seasonality due to temperature fluctuations and the life cycle of salmon. Statistics for the standing biomass are collected Norwegian Directorate of Fisheries' website.

5.3.4 Production

When the salmon has reached the desirable size, it is taken to the production plant to be slaughtered and gutted. Salmon harvesting inhabits seasonality due to factors such as smolt release and seawater temperature levels. These factors may impact the timing for harvest, which may affect the amount of salmon on the market. Extended licenses, natural disasters and other unpredicted incidents are sensitive to the biomass and may in turn influence production quantities. We therefore expect deviations in production to impact the salmon price and the risk premium for salmon futures. Production is measured in tons of harvested salmon (slaughtered and sold) and we use this as our production variable. The statistics are collected from the Norwegian Directorate of Fisheries' website.

5.4.5 Temperature

The seawater temperature is important for the production length of salmon. Salmon has a bigger appetite when the water is warmer and less when the water turns colder. This affects

[8] http://www.fiskeridir.no

the growth rate of the fish. The optimal growth rate is between 8°C and 14°C. The seawater temperature has large variations through the year, with low temperatures in the beginning of the year for farms in the Northern hemisphere (Marine Harvest, 2016). Increased temperature contributes to higher risk for diseases while low temperatures below zero may lead to mass mortality. We expect a sudden increase in seawater temperature to cause a buildup of biomass. In the opposite case, a significant decrease in temperature should reduce the inventory levels. The temperature measurements in this study are from three fixed hydrographic stations[9] distributed along the Norwegian coast. Daily seawater temperatures are retrieved from the Institute of Marine Research[10] and averaged per month.

5.4.6 Feed sales

Feed sales are the total amount of purchased feed measured in tons, and should be suitable as an indicator for future inventory levels of salmon. We expect a relationship between feed sales, biomass and production. Increased feed sales should indicate increased future inventory and higher salmon prices. The increase may be due to an excessive amount of biomass or superior growth conditions. Feed is storable up to a year and suppliers may have different policies with respect to the amount of feed in stock. This could affect the validity of the indicator. We have also considered whether the price of feed may have an effect on the salmon price and, thus on the risk premium. Like other commodity producing industries, salmon farmers have to sell the fish to a market price and act as price takers. This means that the producers have to accept a market price regardless of the associated costs. Hence, we do not include feed costs as a variable in our study. The data on feed sales are retrieved from Sjømat Norge[11].

Table 4 presents the expected signs on the coefficients for the control variables in equation (10). Keep in mind that S_T has the opposite sign in equation (10) and (11), and that we

[9] The stations included in our study are Eggum, Skrova and Sognesjøen. Data from the other five stations had missing values and we did not find it suitable to use them in our analysis.

[10] http://www.imr.no

[11] The original data on feed sales is the total amount of feed sold for both salmon and trout. An estimated share of salmon feed sales was given to us by Sjømat Norge (http://www.sjomatnorge.no).

estimate both equations. This means that the signs on the coefficients will cancel out over the two regressions.

Table 4 The expected signs on the coefficients in the regression model (10)

Variable	**Impact**
Biomass	-
Production	+
Feed sales	-
Smolt release	-
Temperature	-
EUR/NOK	-

Since we do not know what type of information the market participants had at the time when the futures contract was agreed (time t), we cannot precisely know whether the effect of the control variables goes through the futures price $F_{t,T}$ or the spot price S_T. Our hypotheses are therefore based on the assumption that the deviations calculated for the control variables are unexpected shocks. In general, we expect any shock that increases the supply of salmon to decrease salmon price. The opposite holds for any shock that increases demand for salmon.

We expect a positive shock in production to increase the supply and decrease the spot price, resulting in a positive coefficient in equation (10). An unexpected buildup of biomass should limit the supply of salmon in the respective periods, resulting in higher spot prices. We have the same expectations for feed sales, smolt release and temperature as these factors are expected to increase biomass in the event of a positive shock. A depreciation of the NOK, i.e. a positive shock in EUR/NOK, is expected to increase the spot price due to higher demand for salmon. Hence, the coefficient on EUR/NOK is expected to be negative.

All the variables, except the basis, are standardized by subtracting the mean and dividing by the standard deviation. Standardizing the variables enables us to compare the effect of the variables on an equal scale.

The variables will have the following abbreviation:

1) ΔBIO: Shocks in log biomass, calculated as the standardized, deseasonalized and detrended deviation in quantity of live Atlantic salmon in Norway from time *t to T*.
2) ΔPRO: shocks in log production, calculated as the standardized, deseasonalized and detrended deviation in quantity of harvested Atlantic salmon in Norway from time *t to T*.
3) $\Delta TEMP$: Shocks in log sea temperature, calculated as the standardized, deseasonalized and detrended deviation in seawater temperature at 10-meter depth from time *t to T*.

As an extension of the study by Asche et al. (2016b) we include three additional control variables.

4) $\Delta FEED$: Shocks in log feed sales, calculated as the standardized, deseasonalized and detrended deviation in tons of feed from time *t to T*.
5) $\Delta SMOLT$: Shocks in log release of smolt, calculated as the standardized, deseasonalized and detrended deviation in number of smolt released in Norway from time *t to T*.
6) $\Delta EUR/NOK$: Change in the log exchange rate, calculated as the standardized deviation in EUR/NOK from time *t to T*.

Descriptive statistics for the standardized control variables are found in appendix B. Table 5 shows low correlations between the explanatory variables for the 1-month time period. Feed sales correlates positively with production, biomass and temperature ranging from 0.242 to 0.349, which are the highest correlations in the table. When sea temperatures rise, the salmon increases its appetite which in turn leads to growth in biomass and higher production volumes. The correlations between the explanatory variables for the 2-, 3- and 6-month time period are found in appendix C. Particularly, the basis and the EUR/NOK changes from being negative for the 1-month time period to positive for the 6-month time period. Feed sales and temperature have the biggest correlation of 0.626. VIF-test indicates no multicollinearity (not reported).

Table 5 Correlations 1M-variables

	Basis	ΔBIO	ΔPRO	$\Delta TEMP$	$\Delta FEED$	$\Delta SMOLT$	$\Delta EUR/NOK$
Basis	1.000						
ΔBIO	0.043	1.000					
ΔPRO	-0.105	-0.126	1.000				
$\Delta TEMP$	-0.016	0.057	0.079	1.000			
$\Delta FEED$	-0.006	0.242	0.349	0.226	1.000		
$\Delta SMOLT$	0.083	0.018	0.102	0.061	0.129	1.000	
$\Delta EUR/NOK$	-0.122	-0.067	-0.136	-0.118	-0.029	-0.007	1.000

Augmented Dickey-Fuller tests show that all the variables used in our analysis are stationary. The test results are summarized in appendix D. Diagnostics tests of the regression residuals reveal the presence of autocorrelation, but not heteroscedasticity (appendix F). The Newey-West estimator computes autocorrelation and heteroscedasticity consistent standard errors.

5.4 Detrending and deseasonalizing

The production cycle of salmon is in some sense predetermined. For example, market participants should know when harvesting is or when the smolt is being released. Asche et al., (2016b) argues that shocks from (deterministic) seasonal and trend components in the control variables may cause too much noise for the model to capture pure and robust relationships. We can think of the biophysical variables without trend and seasonal effects as unexpected shocks, e.g. that the fish had to be harvested before it reaches the optimal size.

The paper examines whether detrending and deseasonalizing the biophysical variables will impact the magnitude of the coefficients β_1 and β_2 from equation (10) and (11). We account for trend and seasonal effects by applying a seasonal and trend decomposition using Loess (STL). The method was developed by Cleveland et al. (1990) and is a filtering procedure that decomposes a time series into three components; seasonal, trend and remainder. Fig. 3 illustrates how STL decomposition transforms a time series into three sub-time series. The seasonal component is periodic, which means it is calculated to be identical across the months. For our data, this means that the average seasonality is removed, but still leaves the excess change in the remainder component. The *remainder* represents the shocks without trend and seasonality. Note that we do not use the STL method for the EUR/NOK variable.

This is due to the exchange not having any natural trend or seasonality like the biophysical variables do (see Fig. 11 in appendix A).

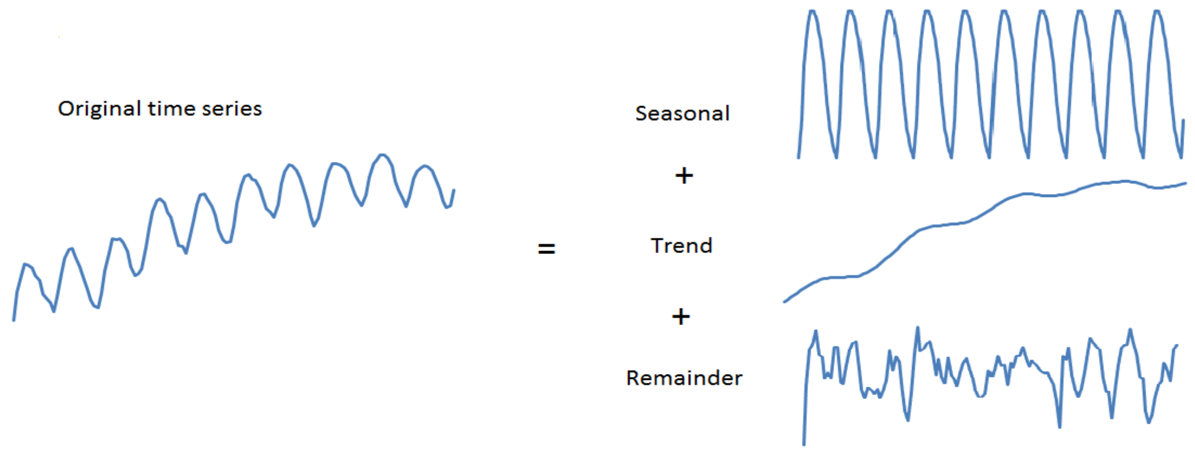

Fig. 4 Example of how STL decomposition transforms a time series into three sub-time series; seasonal, trend and reminder

6. Empirical results and discussion

The estimation results for the 1-, 2- and 6-month futures contracts are presented in table 6, 7 and 8, respectively. The results for the 3-month futures are found in appendix E and are similar to those of the 2-month contracts. The coefficients on the basis (β_1,β_2) in the risk premium regression (10) and the spot price change regression (11) are reported in the tables. The coefficients on the monthly dummy variables and the additional control variables are equal in magnitude in equation (10) and (11), but have opposite signs. Hence, we only report the coefficients for the risk premium regression (10).

6.1 One-month futures contracts

In section 6.1.1 we present the empirical results after detrending and deseasonalizing the biophysical variables. In section 6.1.2 we discuss whether removing seasonality and trend has an impact on the magnitude of the coefficients β_1 and β_2 in equation (10) and (11).

6.1.1 Biophysical variables adjusted for seasonality and trend

The first column in table 6 includes only the basis as an independent variable. The results show that the basis explains the variation in both the risk premium and the spot price change.

The coefficients β_1 (0.476) and β_2 (0.524) are close to equal in magnitude and both are significantly different from zero at the 1 % level. The adjusted R^2 is low at 11.7% and 14.0% for the risk premium and spot price change, respectively. The results are similar to those found by Asche et al. (2016b). Including the biophysical and economic variables in the regressions does not seem to have a substantial impact on the magnitude of β_1 and β_2, nor on the adjusted R^2 (column 2, 4 and 6).

Table 6: Results from the regression of the risk premium and spot price change for futures contracts with one month to maturity

1M	1	2	3	4	5	6	7
Intercept (α_1)	-0.009	-0.009	-0.025	-0.009	-0.034**	-0.009	-0.034
$\boldsymbol{F_{t,T} - S_t}$							
β_1	0.476***	0.493***	0.723***	0.482***	0.636***	0.509***	0.676***
β_2	0.524***	0.507***	0.277*	0.518***	0.364**	0.491***	0.324*
$\boldsymbol{MONTH_{i,T}}$							
Feb			-0.001		-0.012		-0.013
Mar			-0.006		-0.001		-0.000
Apr			-0.002		-0.003		-0.002
May			0.014		0.013		0.014
Jun			0.056*		0.070**		0.073*
Jul			0.004		0.017		0.018
Aug			0.060*		0.056*		0.058*
Sep			0.105***		0.113***		0.115***
Oct			0.067**		0.085**		0.086***
Nov			-0.000		0.021		0.019
Dec			-0.069**		-0.041		-0.042
$\boldsymbol{\Delta CV_{i,T}}$							
ΔBIO		-0.005	-0.005			0.002	0.003
ΔPRO		0.009*	0.011**			0.017***	0.019***
ΔTEMP		-0.003	-0.003			0.001	0.001
ΔFEED				-0.006	-0.005	-0.013**	-0.013**
ΔSMOLT				-0.004	-0.004	-0.005	-0.005
ΔEUR/NOK				-0.015	-0.020**	-0.017*	-0.022***
R^2-adj ($F_{t,T} - S_T$)	0.117	0.111	0.268	0.140	0.308	0.150	0.334
R^2-adj ($S_T - S_t$)	0.140	0.134	0.287	0.162	0.326	0.173	0.351

Note: The models are estimated with Newey-West correction of the standard errors. The statistical significance of the coefficients is denoted by asterisks. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Risk premium ($F_{t,T} - S_T$) = difference between log monthly futures price at time t and log monthly spot price at time T. Basis ($F_{t,T} - S_t$) = difference between log monthly futures price at time t and log monthly spot price at time t. Spot price change ($S_T - S_t$) = difference between log monthly spot price at time T and log monthly spot price at time t. ΔBIO = monthly changes in log biomass from time t to T. ΔPRO = monthly changes in log quantity of harvested salmon from time t to T. ΔTEMP = monthly changes in log temperature from time t to T. ΔFEED = monthly changes in log feed sales from time t to T. ΔSMOLT = monthly changes in log smolt release from time t to T. ΔEUR/NOK = monthly changes in log EUR/NOK from time t to T. 1M denotes that the futures contracts with one month to maturity. The number of observations is 121.

We find a positive and significant coefficient on ΔPRO, indicating that an increase in quantity of harvested salmon has a positive effect on the risk premium. The result is in line with our expectations. Compared to deviations in the other biophysical variables, shocks in harvesting volumes are likely to have a more immediate effect on the spot price. An increase in supply of salmon that results in a realized spot price lower than the original expectations suggests a positive effect on the risk premium. Keep in mind that the deviations in the control variables are assumed to be unexpected shocks. The positive effect of ΔPRO on the difference between the futures price and the spot price at maturity may therefore reflect non-rational expectations about subsequent spot prices.

The coefficient on ΔBIO is negative (column 2 and 3), which is in line with our expectations. However, when all the additional control variables are included in the model, the coefficient turns positive. Asche et al. (2016b) also find the sign of biomass shocks to be positive. They argue that a possible explanation could be that the market does not fully incorporate all the information into futures prices. Since our hypotheses are based on the assumption that the shocks in the control variables are unexpected, we argue that the positive coefficient on ΔBIO could indicate that this information is already incorporated into futures prices at the time of trading. Expectations ex-ante may have resulted in less hedging pressure from producers. This should drive the futures price up and increase the risk premium, causing a positive sign on the coefficient. In unreported results, we find that the switch in sign on ΔBIO is caused by including feed sales to the model. This raises the question if feed sales may be a more suitable factor than biomass to capture uncertainty related to inventory. We find the coefficient on $\Delta FEED$ to be negative and statistically significant (column 6 and 7). The results indicate that an increase in quantity of feed sold to Norwegian fish farmers has a negative effect on the risk premium. A positive and unexpected shock in feed sales increases the probability of realized spot prices higher than the original expectations.

We find that the relationship between $\Delta TEMP$ and the risk premium is positive, opposite of our expectations. A possible explanation could be that a sudden movement in the temperature beyond the expected seasonal variation hasn't had a substantial impact on salmon growth and inventory levels during the sample period. Another explanation could be that precise temperature forecasts have enabled market participants to make good predictions about subsequent spot prices, resulting in lower hedging pressure. However, the variable is not significant. By only including temperature measurements from three out of eight hydrographic stations, the validity of the $\Delta TEMP$ variable could be affected.

We find $\Delta EUR/NOK$ to have a significant and negative effect on the risk premium (column 6 and 7). The result is in line with our expectations. When comparing the additional control variables, we find $\Delta EUR/NOK$ to have the highest explanatory power, indicating that this demand factor has a considerable impact on prices. The coefficient on $\Delta SMOLT$ is negative as expected, but not significant. Due to the long production cycle of salmon, the $\Delta SMOLT$ variable may not be suitable to capture uncertainty about short-term inventory levels.

The monthly dummy variables are included in the regressions to identify if the risk premium varies through the months. Adding the monthly dummy variables (column 3, 5 and 7) changes the magnitude of β_1 and β_2. Column 7 presents the regression results when all of the additional control variables are included. Compared to column 6, we observe that β_1 increases from 0.509 to 0.676 and β_2 decreases from 0.491 to 0.324. Controlling for seasonal effects, the results show stronger evidence for risk premiums than for spot price changes. This is in contrast to Brooks et al. (2013), who find supportive results for forecast power on animal commodity futures (live cattle, pork bellies and feeder cattle), and less support for risk premiums. An explanation could be that these commodities have been trading on the futures market for an extensive period compared to salmon futures. Nevertheless, research on whether salmon futures prices provide a price discovery function have been somewhat inconclusive (Asche et al., 2016a; Ankamah-Yeboah et al. 2016).

We observe that the coefficients on the dummy variables are positive and significant for futures contracts maturing in June, August, September and October. The results indicate that the risk premium is higher in these summer/autumn months compared to January (the base month). Fig. 14 (appendix A) shows that the risk premium varies through time and the positive and negative peaks can be confirmed by the dummy variables. Uncertainty may be higher during those months when harvest increases and the next generation of fish are released into the sea cages. Our results are in line with the empirical findings of Lucia and Torró (2011) regarding electricity futures prices. The risk premium is large and positive for contracts with delivery during demand peak periods. The decrease of β_2 when the monthly dummy variables are included in the regression shows that the price discovery role of futures prices seems to be weaker in periods with high uncertainty.

6.1.2 Biophysical variables with seasonality and trend

Appendix G presents the estimation results for the 1-month futures contracts when seasonality and trend are *not* removed from the biophysical variables. We find that the coefficients β_1 and β_2 from equation (10) and (11) stay roughly the same as when seasonality and trend are removed. The main difference we observe is that the VIF-index for several of the variables increases (not reported). Biomass, feed sales and temperature are highly correlated and follow the same seasonal pattern (see Fig. 1, 5 and 7 in appendix A). The correlations between the variables are significantly higher before seasonality and trend are removed with STL (appendix G). This is due to the seasonal pattern in the life cycle of salmon.

When the dummy variables are not included in the regressions, ΔBIO and $\Delta TEMP$ become significant. This is in contrast to the results found in table 6. From column 7 in appendix G we observe that $\Delta SMOLT$ turns significant with a negative coefficient as expected. We observe that the dummy variables are insignificant (except December) which suggests that the control variables already incorporate the seasonality in the risk premium. Removing seasonality and trend from the biophysical variables gives us the opportunity to capture the seasonality in the risk premium as well as the unexpected shocks in the control variables. The further analysis of the 2- and 6-month contracts therefore uses STL decomposition before estimating the regressions.

6.2 Two- and six-month futures contracts

Table 7 presents the estimation results for futures contracts with 2 months to delivery. Including the basis as the only independent variable does not show the same 50/50 relationship between the beta coefficients as for the 1-month contracts (column 1). We observe that β_1 equals 0.283 and that β_2 equals 0.717, both coefficients being statistically significant. Hence, we find stronger evidence for spot price changes than for risk premiums.

Similar to the 1-month contracts, including the biophysical and economic variables in the model does not seem to have a substantial impact on the magnitude of the coefficients β_1 and β_2 (column 2, 4 and 6). Interestingly, the coefficients are close to equal when we control for

$\Delta FEED$, $\Delta SMOLT$, $\Delta EUR/NOK$ and seasonal effects (column 5). Controlling for ΔBIO, ΔPRO, $\Delta TEMP$ and seasonal dummies on the other hand, results in a significant β_1 equal to 0.708 and an insignificant β_2 equal to 0.292 (column 3). While β_2 is insignificant for the regressions in column 7, we still find that the basis explains more of the variation in the risk premium than in the spot price change.

Table 7: Results from the regression of the risk premium and spot price change for futures with two months to maturity

2M	1	2	3	4	5	6	7
Intercept (α_1)	-0.018	-0.018	-0.115***	-0.019	-0.098***	-0.018	-0.106***
$F_{t,T} - S_t$							
β_1	0.283*	0.330**	0.708***	0.274	0.545**	0.332**	0.659***
β_2	0.717***	0.670***	0.292	0.726***	0.455*	0.668***	0.341
$MONTH_{i,T}$							
Feb			0.067*		0.025		0.034
Mar			0.060		0.022		0.031
Apr			0.060		0.030		0.041
May			0.084*		0.049		0.061
Jun			0.137**		0.112		0.129**
Jul			0.110		0.096		0.111
Aug			0.145**		0.116**		0.131**
Sep			0.234***		0.201***		0.218***
Oct			0.229***		0.216***		0.229***
Nov			0.122***		0.126***		0.129***
Dec			-0.015		0.003		0.000
$\Delta CV_{i,T}$							
ΔBIO		-0.002	-0.003			0.007	0.008
ΔPRO		0.026***	0.031**			0.030***	0.036***
ΔTEMP		-0.004	-0.003			0.004	0.006
ΔFEED				-0.008	-0.007	-0.017	-0.018**
ΔSMOLT				0.003	0.002	-0.001	-0.003
ΔEUR/NOK				-0.021	-0.029**	-0.022	-0.029**
R^2-adj ($F_{t,T} - S_T$)	0.033	0.052	0.286	0.046	0.274	0.080	0.343
R^2-adj ($S_T - S_t$)	0.209	0.225	0.416	0.220	0.406	0.247	0.463

Note: The models are estimated with Newey-West correction of the standard errors. The statistical significance of the coefficients is denoted by asterisks. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Risk premium ($F_{t,T} - S_T$) = difference between log monthly futures price at time t and log monthly spot price at time T. Basis ($F_{t,T} - S_t$) = difference between log monthly futures price at time t and log monthly spot price at time T. Spot price change ($S_T - S_t$) = difference between log monthly spot price at time T and log monthly spot price at time t. ΔBIO = monthly changes in log biomass from time t to t. ΔPRO = monthly changes in log quantity of harvested salmon from time t to T. ΔTEMP = monthly changes in log temperature from time t to T. ΔFEED = monthly changes in log feed sales from time t to T. ΔSMOLT = monthly changes in log smolt release from time t to T. ΔEUR/NOK = monthly changes in log EUR/NOK from time t to T. 2M denotes that the futures contracts with two month to maturity. The number of observations is 121.

We observe some interesting differences for the futures contracts with 6 months to delivery (table 8). Contrary to the 1- and 2-month futures contracts, both $\Delta EUR/NOK$ and $\Delta FEED$ become insignificant. The coefficients β_1 and and β_2 fall outside the range of 0.0 and 1.0, and only β_2 is statistically significant. The basis seems to explain more of the variation in the risk premium when we control for the respective months, but not enough for β_1 to be significant (column 3, 5 and 7). The results indicate that basis primarily contains information about the future spot price changes, suggesting that time-varying risk premiums do not exist. We observe that the coefficients on the dummy variables are negative and significant for futures contracts maturing in March, April, May and July. For contracts maturing in October and November we find positive and significant coefficients. The seasonal dummy variables decrease the magnitude of β_2 (column 3, 5 and 7), implying that the price discovery role of futures prices vary across delivery months.

This paper is the first to our knowledge to examine the risk premium and spot price change for futures contracts with 1-, 2-, 3- and 6-months to delivery. The empirical results suggest that the forecast power of futures prices increases with extended time to delivery. When we only include the basis to the regression (column 1), we observe that β_2 increases steadily form the 1-month contract to the 6-month contract. The evident forecast power of futures prices could be due to this mean-reverting-tendency in salmon prices as found by Ankamah-Yeboah et al., (2016).

Table 8: Results from the regression of the risk premium and spot price change for futures contracts with six months to maturity

6M	1	2	3	4	5	6	7
Intercept (α_1)	-0.066	-0.065	-0.036	-0.067	-0.025	-0.065	-0.020
$\boldsymbol{F_{t,T} - S_t}$							
β_1	-0.084	-0.046	0.291	-0.107	0.198	-0.064	0.293
β_2	1.084***	1.046***	0.709***	1.107***	0.802***	1.064***	0.707***
$\boldsymbol{MONTH_{i,T}}$							
Feb			-0.038		-0.043		-0.047
Mar			-0.100**		-0.101*		-0.113**
Apr			-0.131***		-0.141**		-0.156***
May			-0.113**		-0.137**		-0.148***
Jun			-0.025		-0.061		-0.064
Jul			-0.070		-0.101*		-0.099*
Aug			-0.006		-0.032		-0.027
Sep			0.076		0.047		0.055
Oct			0.097*		0.077		0.085*
Nov			0.084**		0.082**		0.085**
Dec			0.005		0.011		0.009
$\boldsymbol{\Delta CV_{i,T}}$							
ΔBIO		0.019	0.016			0.020	0.018
ΔPRO		0.029	0.038**			0.027	0.036**
ΔTEMP		-0.000	-0.003			0.003	0.005
ΔFEED				0.012	0.011	0.000	-0.004
ΔSMOLT				0.015	0.013	0.014	0.011
ΔEUR/NOK				-0.031	-0.044	-0.029	-0.043
R^2-adj ($F_{t,T} - S_T$)	-0.005	0.012	0.031	0.005	0.030	0.017	0.060
R^2-adj ($S_T - S_t$)	0.365	0.376	0.388	0.371	0.387	0.379	0.406

Note: The models are estimated with Newey-West correction of the standard errors. The statistical significance of the coefficients is denoted by asterisks. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Risk premium ($F_{t,T} - S_T$) = difference between log monthly futures price at time t and log monthly spot price at time T. Basis ($F_{t,T} - S_t$) = difference between log monthly futures price at time t and log monthly spot price at time t. Spot price change ($S_T - S_t$) = difference between log monthly spot price at time T and log monthly spot price at time t. ΔBIO = monthly changes in log biomass from time t to T. ΔPRO = monthly changes in log quantity of harvested salmon from time t to T. ΔTEMP = monthly changes in log temperature from time t to T. ΔFEED = monthly changes in log feed sales from time t to T. ΔSMOLT = monthly changes in log smolt release from time t to T. ΔEUR/NOK = monthly changes in log EUR/NOK from time t to T. 6M denotes that the futures contracts with six month to maturity. The number of observations is 121.

7. Conclusion

This study contributes to the research on risk premiums in the salmon futures market by examining historical risk premiums on futures contracts with 1-, 2-, 3- and 6-months to delivery. Variation in the risk premium is highly explained by seasonality, confirming that the price formation for salmon depends on the production cycle. Our results suggest that the risk premium is linked to unexpected shocks in biophysical and economic variables, but with low explanatory power. However, finding $\Delta EUR/NOK$ to be statistically significant is interesting as this shows the risk premium is affected by other factors than supply driving determinants. Assuming that market participants are not aware of these shocks when they enter the futures contracts, our findings suggest that the difference between the futures price and the spot price could be a result of the inability to make predictions about subsequent spot prices. We find evidence that the basis significantly explains the variation in the risk premium for contracts with 1 month to delivery. The results for the 2- and 3-month contracts show that the basis becomes more important for explaining the spot price change than the risk premium. However, this relationship changes when controlling for seasonality. For the 6-month contracts we observe some interesting differences. The coefficient on the basis in the risk premium regression becomes insignificant. The results indicate that basis primarily contains information about the future spot price changes. This implies that the forecast power of futures prices increases with extended time to delivery.

The futures market for salmon is still relative young compared to other derivative markets on animal commodities. The underlying formation of spot and futures prices is complex and highly dependent on the information available to market participants. The information includes temperature forecasts, diseases and sea lice problems, forecasts of smolt release and the demand for salmon. Market participants' intentions with trading futures could also affect the formation of spot and futures prices. If Norwegian fish farmers indeed are moderately risk-averse (Bergfjord, 2006), this should affect the presence of risk premiums in salmon futures. The risk preferences and the ability to make precise forecasts about subsequent spot prices largely determine how futures prices are set for non-storable commodities.

We believe the salmon price is highly influenced by changes in demand. Further research on risk premiums in the salmon futures market can incorporate other demand driving factors in addition to the EUR/NOK. As for the choice of methodology, estimating an econometric

VAR model to capture the dynamics and time variation of risk premiums would be an interesting extension of the study (Lucia and Torró, 2011).

Negative realized risk premiums are found for most of the futures contracts we examine. However, it is not clear whether these negative risk premiums are due to the sharp rise in the salmon price over the last few years, high demand for futures contracts, or a combination of both. A thorough analysis on the pricing of futures, hedging efficiency and the associated returns would contribute to a deeper understanding of the salmon futures market and the risk preferences of market participants.

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Appendix

Appendix A: Graphic illustrations of the control variables, futures prices and risk premiums

Fig. A1: Monthly biomass level from June 2006 to June 2016 measured in tons.

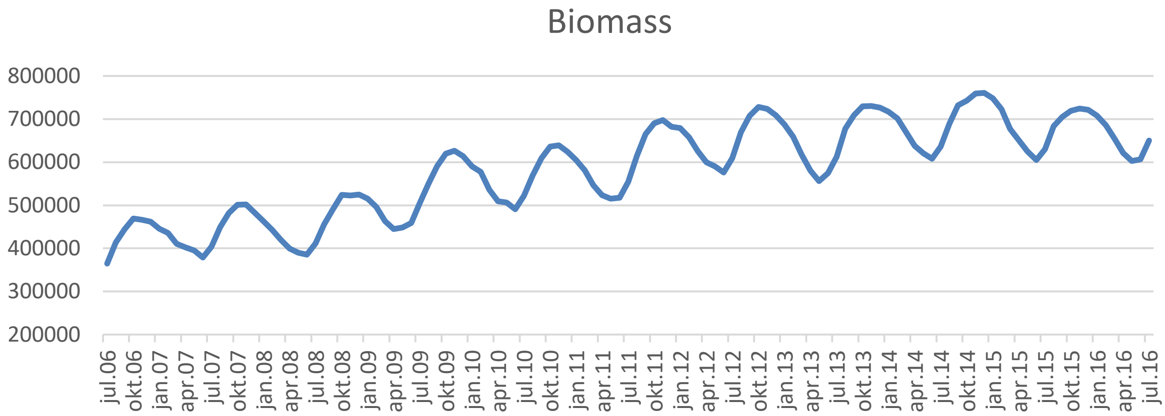


Fig. A2: Monthly log change in biomass, standardized and decomposed with STL

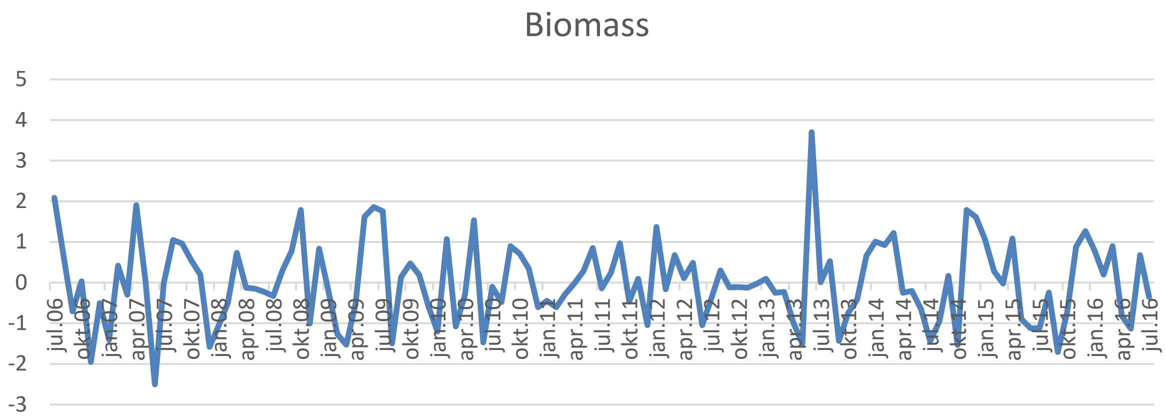


Fig. A3: Montly level of extracted salmon for production from June 2006 to June 2016 measured in tons

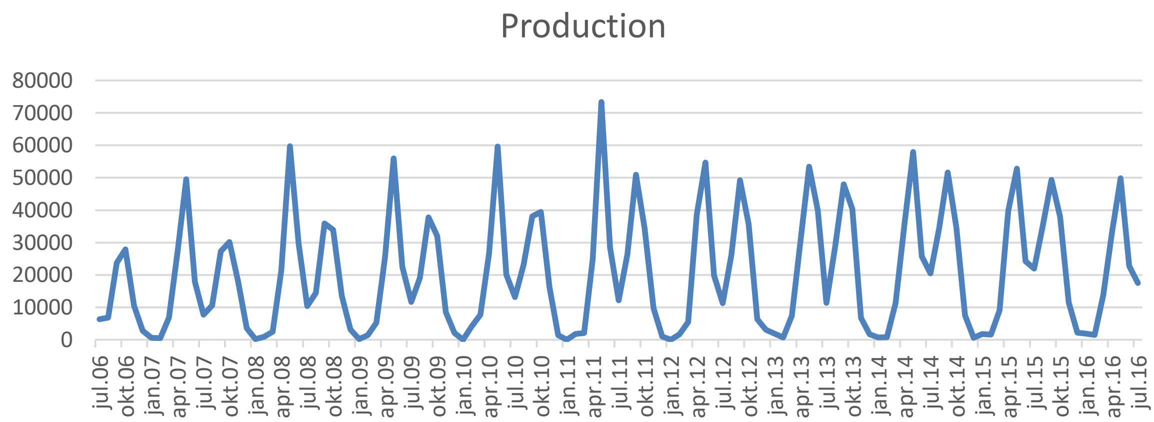


Fig. A4: Monthly log change of extracted salmon for production, standardized and decomposed with STL

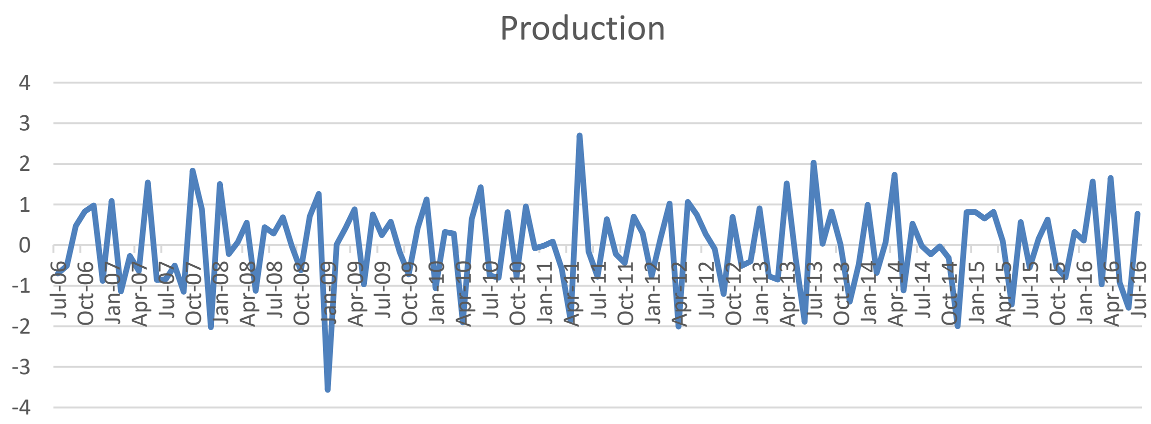


Fig. A5: Monthly level of feed sales from June 2006 to June 2016 measured in tons of feed

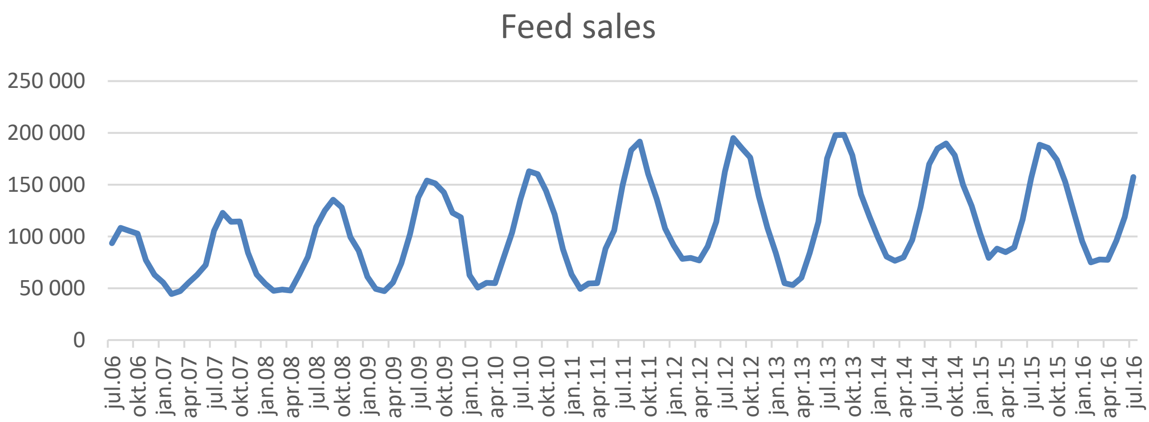


Fig. A6: Monthly log change in feed sales, standardized and decomposed with STL.

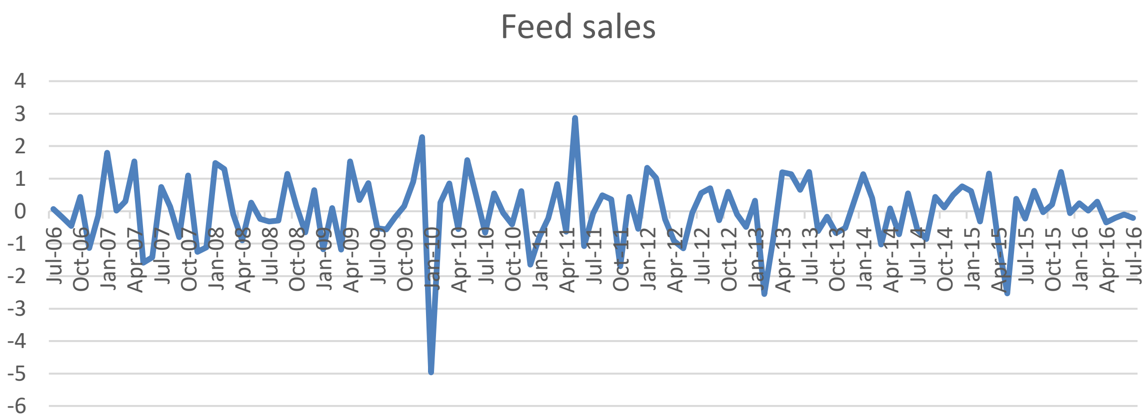


Fig. A7: Montly temperature level from June 2006 to June 2016 measured in celsius

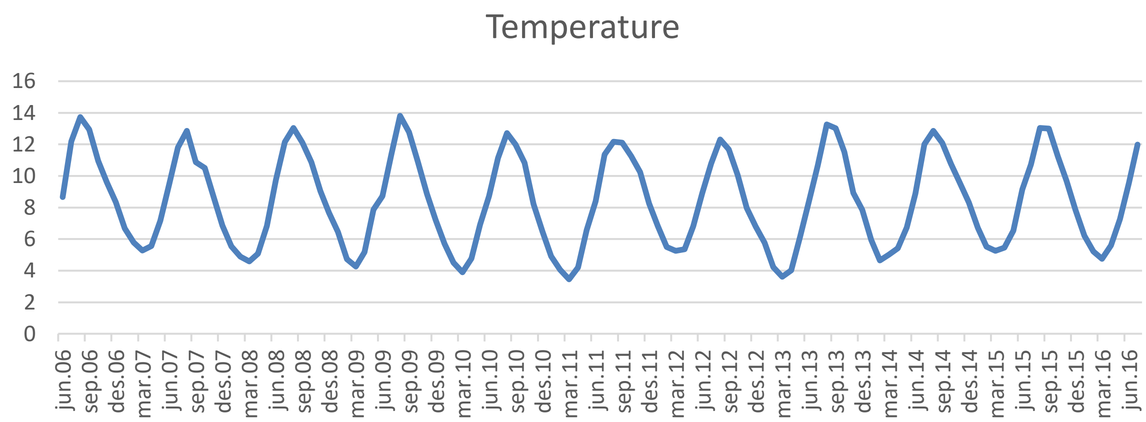


Fig. A8: Monthly log change in temeprature, standardized and decomposed with STL

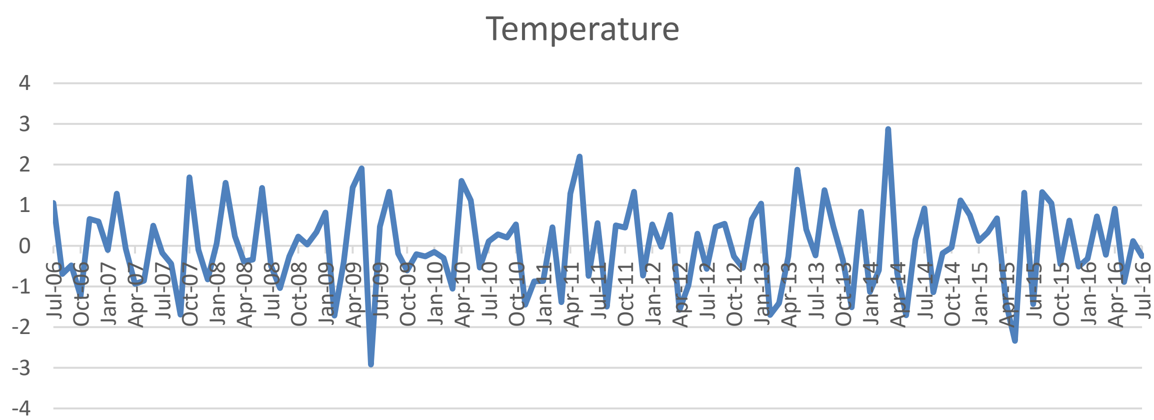


Fig. A9: Monthly level of released smolt from June 2006 to June 2016 measured in number of smolt

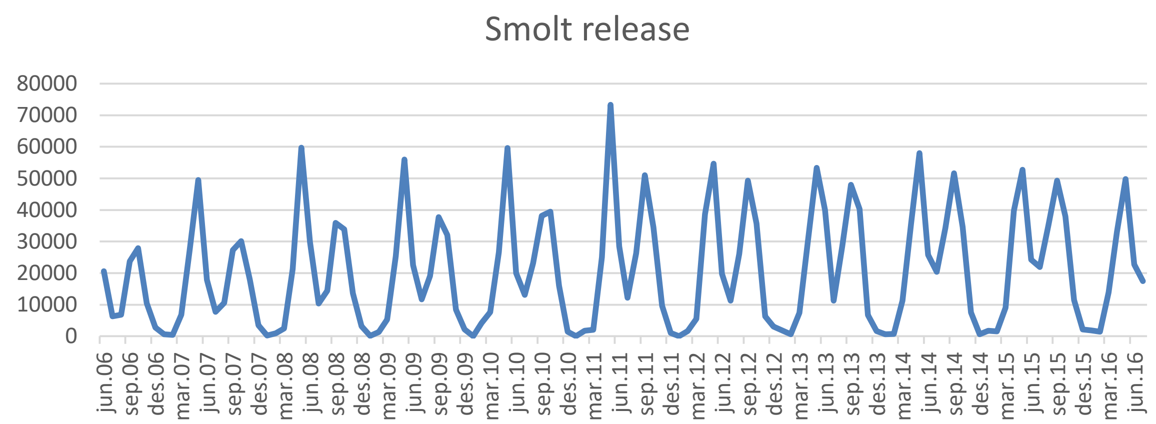


Fig. A10: Montly log change of released smolt, standardized and decomposed with STL

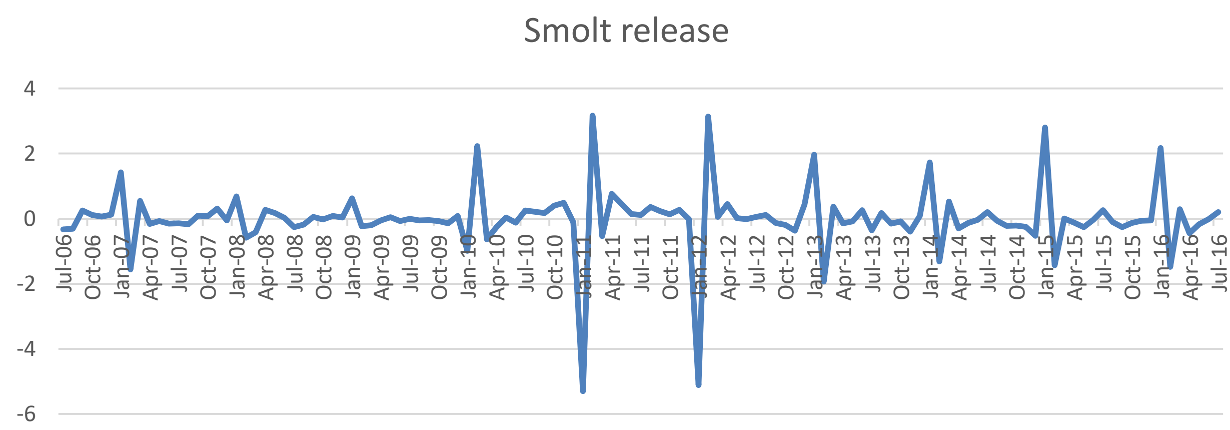


Fig. A11: Monthly exchange rate from June 2006 to June 2016 measured in EUR/NOK

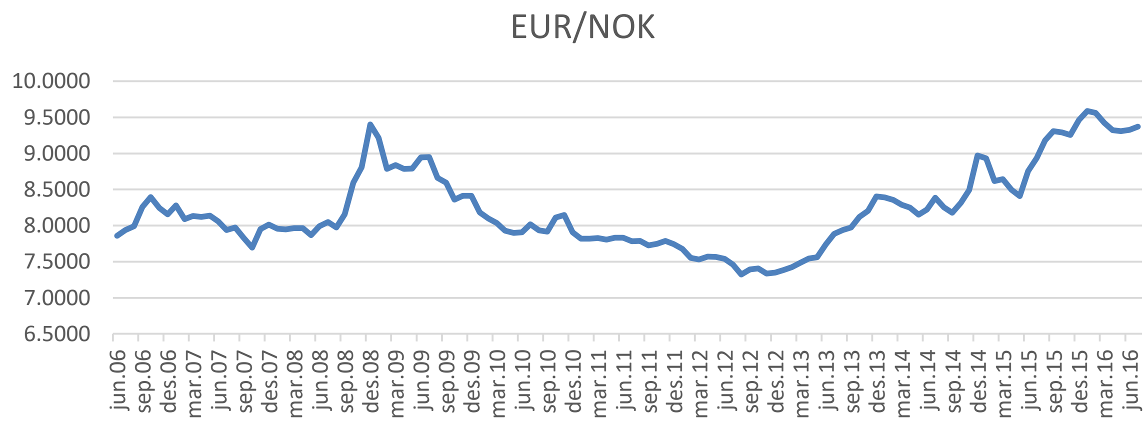


Fig. A12: Standardized monthly log change in exchange rate

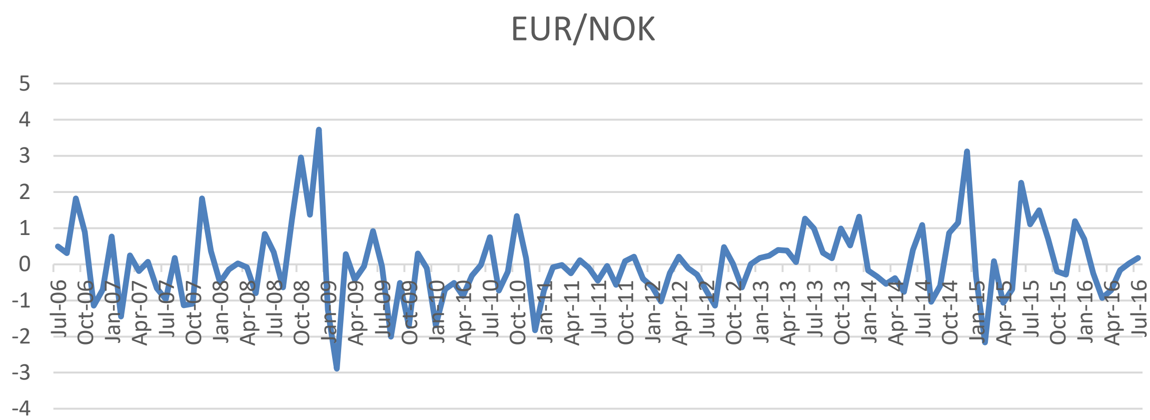


Fig. A13: 1-, 2-, 3- and 6-month futures price in NOK from June 2006 to June 2016

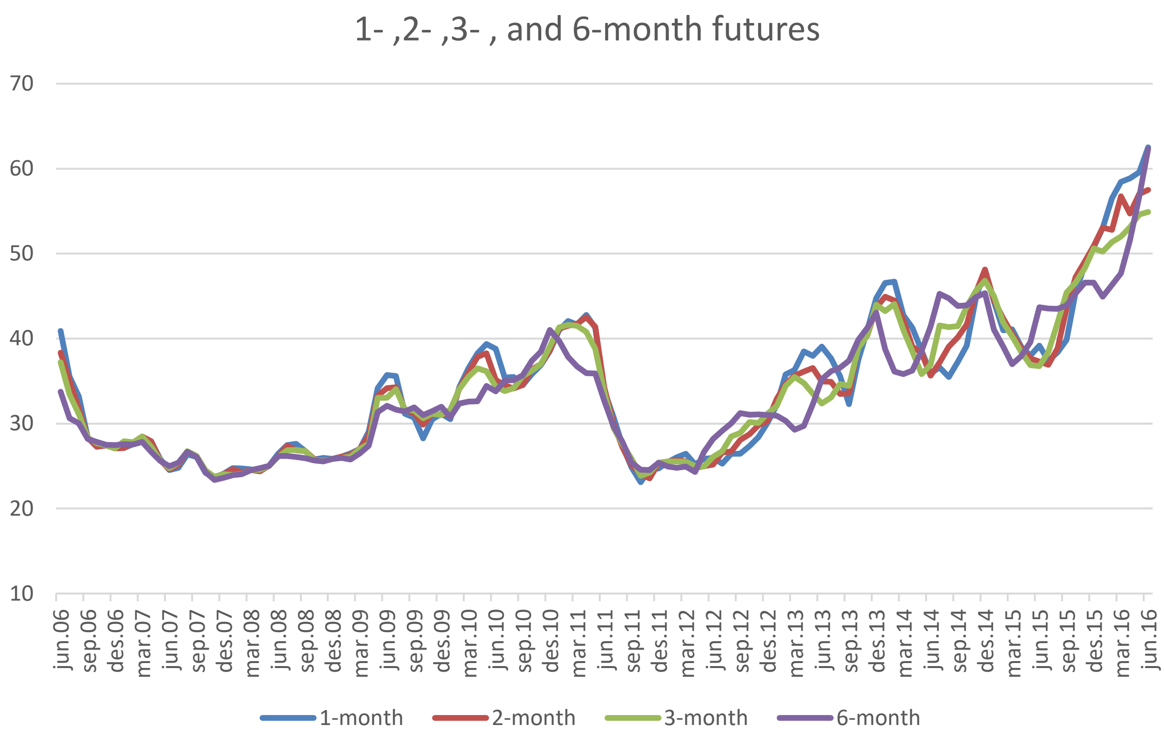
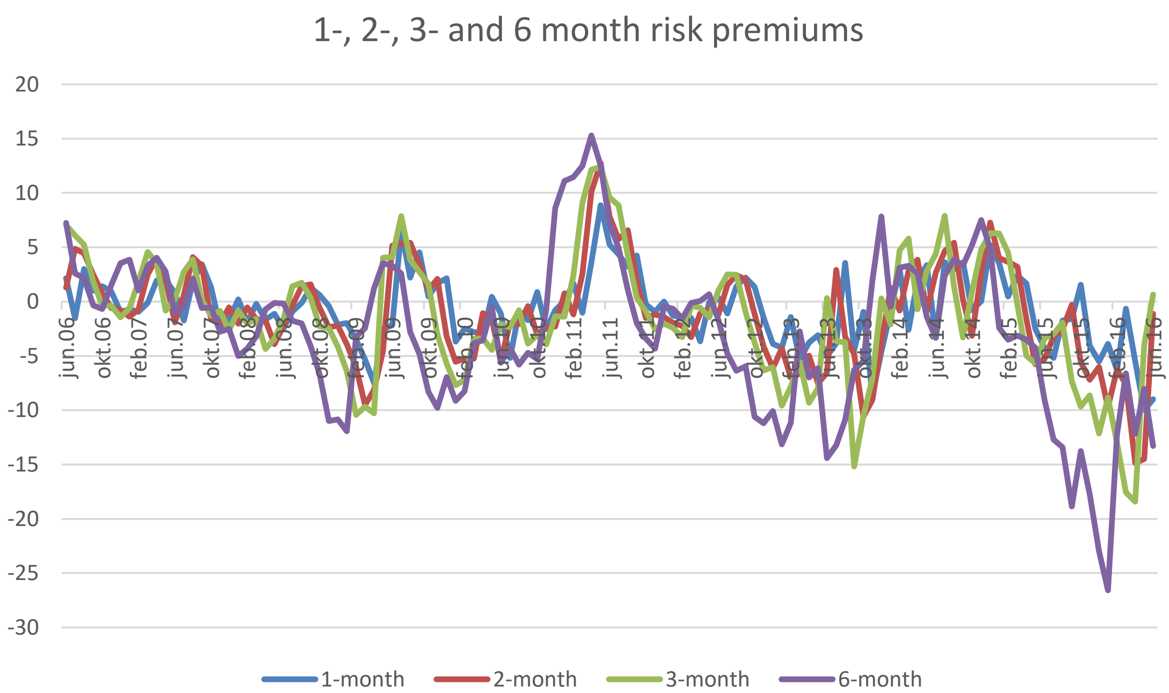


Fig. A14: 1-, 2-, 3- and 6 months risk premium from June 2006 to June 2016



Appendix B: Descriptive statistics of the control variables

	Average	SD	Min	25%	Median	75%	Max
ΔBIO							
1M	0.000	1.000	-2.508	-0.606	-0.102	0.695	3.702
2M	0.000	1.000	-2.159	-0.733	0.071	0.660	2.535
3M	0.000	1.000	-2.274	-0.639	-0.024	0.681	2.847
6M	0.000	1.000	-2.622	-0.798	-0.021	0.724	2.668
ΔPRO							
1M	0.000	1.000	-3.567	-0.723	0.030	0.709	2.701
2M	0.000	1.000	-2.944	-0.594	0.072	0.640	2.544
3M	0.000	1.000	-2.706	-0.512	0.031	0.578	2.456
6M	0.000	1.000	-2.529	-0.656	0.047	0.684	2.121
ΔTEMP							
1M	0.000	1.000	-2.920	-0.607	-0.071	0.654	2.877
2M	0.000	1.000	-2.867	-0.639	-0.037	0.698	2.646
3M	0.000	1.000	-2.494	-0.660	0.002	0.832	2.161
6M	0.000	1.000	-2.424	-0.702	0.054	0.648	2.397
ΔFEED							
1M	0.000	1.000	-4.960	-0.550	0.013	0.592	2.874
2M	0.000	1.000	-3.593	-0.521	0.082	0.601	2.439
3M	0.000	1.000	-2.647	-0.651	0.006	0.697	2.302
6M	0.000	1.000	-2.107	-0.809	0.050	0.725	2.371
ΔSMOLT							
1M	0.000	1.000	-3.480	-0.225	-0.018	0.218	3.991
2M	0.000	1.000	-2.353	-0.496	-0.023	0.494	2.550
3M	0.000	1.000	-5.516	-0.425	0.108	0.457	2.978
6M	0.000	1.000	-2.424	-0.702	0.054	0.648	2.397
ΔEUR/NOK							
1M	0.000	1.000	-2.889	-0.606	-0.071	0.386	3.745
2M	0.000	1.000	-2.587	-0.615	-0.066	0.508	3.221
3M	0.000	1.000	-2.117	-0.677	-0.122	0.443	4.110
6M	0.000	1.000	-2.049	-0.659	-0.251	0.540	3.398

Note: ΔBIO = monthly changes in log biomass from time t to t. ΔPRO = monthly changes in log quantity of harvested salmon from time t to T. ΔTEMP = monthly changes in log temperature from time t to T. ΔFEED = monthly changes in log feed sales from time t to T. ΔSMOLT = monthly changes in log smolt release from time t to T. ΔEUR/NOK = monthly changes in log EUR/NOK from time t to T. 1M, 2M, 3M and 6M denotes number of months (n) until the delivery period. The number of observations is 121

Appendix C: Correlations between the explanatory variables for the 2-, 3- and 6-month time period

Table 1C: Correlations 2M-variables

	Basis $(F_{t,T} - S_t)$	ΔBIO	ΔPRO	$\Delta TEMP$	$\Delta FEED$	$\Delta SMOLT$	$\Delta EUR/NOK$
Basis $(F_{t,T} - S_t)$	1.000						
ΔBIO	0.059	1.000					
ΔPRO	-0.164	-0.100	1.000				
$\Delta TEMP$	-0.047	0.048	0.122	1.000			
$\Delta FEED$	0.010	0.274	0.211	0.369	1.000		
$\Delta SMOLT$	0.099	0.069	0.134	0.084	0.177	1.000	
$\Delta EUR/NOK$	-0.030	0.196	0.046	0.099	0.165	0.181	1.000

Note: Basis $(F_{t,T} - S_t)$ = difference between log monthly futures price at time t and log monthly spot price at time T. Spot price change $(S_T - S_t)$ = difference between log monthly spot price at time T and log monthly spot price at time t. ΔBIO = monthly changes in log biomass from time t to t. ΔPRO = monthly changes in log quantity of harvested salmon from time t to T. ΔTEMP = monthly changes in log temperature from time t to T. ΔFEED = monthly changes in log feed sales from time t to T. ΔSMOLT = monthly changes in log smolt release from time t to T. ΔEUR/NOK = monthly changes in log EUR/NOK from time t to T. 1M, 2M, 3M and 6M denotes number of months (n) until the delivery period. The number of observations is 121

Table 2C: Correlations 3M-variables

	Basis $(F_{t,T} - S_t)$	ΔBIO	ΔPRO	$\Delta TEMP$	$\Delta FEED$	$\Delta SMOLT$	$\Delta EUR/NOK$
Basis $(F_{t,T} - S_t)$	1.000						
ΔBIO	0.062	1.000					
ΔPRO	-0.245	0.024	1.000				
$\Delta TEMP$	-0.052	0.119	0.150	1.000			
$\Delta FEED$	0.036	0.306	0.109	0.527	1.000		
$\Delta SMOLT$	0.085	0.063	-0.123	0.091	0.056	1.000	
$\Delta EUR/NOK$	-0.048	0.191	-0.022	0.127	0.140	0.155	1.000

Table 3C: Correlations 6M-variables

	Basis $(F_{t,T} - S_t)$	ΔBIO	ΔPRO	$\Delta TEMP$	$\Delta FEED$	$\Delta SMOLT$	$\Delta EUR/NOK$
Basis $(F_{t,T} - S_t)$	1.000						
ΔBIO	0.037	1.000					
ΔPRO	-0.193	0.190	1.000				
$\Delta TEMP$	0.037	0.109	0.154	1.000			
$\Delta FEED$	0.092	0.257	0.177	0.626	1.000		
$\Delta SMOLT$	0.086	0.035	0.067	0.115	0.159	1.000	
$\Delta EUR/NOK$	-0.016	0.039	-0.015	0.153	0.147	0.084	1.000

Appendix D: Augmented Dickey-Fuller (ADF) tests

	1M	2M	3M	6M
Risk premium $(F_{t,T} - S_T)$	-4.399***	-5.105***	-4.349***	-2.980***
Spot price change $(S_T - S_t)$	-6.530***	-7.594***	-5.917***	-4.531***
Basis $(F_{t,T} - S_t)$	-5.329***	-4.834***	-4.583***	-5.022***
ΔBIO	-7.765***	-8.857***	-7.317***	-5.368***
ΔPRO	-13.165***	-12.480***	-8.173***	-7.253***
$\Delta TEMP$	-11.428***	-11.629***	-7.775***	-6.743***
$\Delta FEED$	-13.164***	-9.907***	-7.870***	-6.066***
$\Delta SMOLT$	-11.617***	-12.980***	-7.653***	-8.013***
$\Delta EUR/NOK$	-7.734***	-7.807***	-7.543***	-3.609***
Critical values				
1 % ***	-2.58	-2.58	-2.58	-2.58
5 % **	-1.95	-1.95	-1.95	-1.95
10 % *	-1.62	-1.62	-1.62	-1.62

Note: Augmented Dickey Fuller tests with maximum lag =1 and no constant or drift. The number of lags used is calculated according to the Akaike information criterion. Significance level is denoted by asterisk: *<0,1 significance level, **<0,05 significance level, ***<0,01 significance level. Risk premium $(F_{t,T} - S_T)$ = difference between log monthly futures price at time t and log monthly spot price at time T. Basis $(F_{t,T} - S_t)$ = difference between log monthly futures price at time t and log monthly spot price at time T. Spot price change $(S_T - S_t)$ = difference between log monthly spot price at time T and log monthly spot price at time t. ΔBIO = monthly changes in log biomass from time t to t. ΔPRO = monthly changes in log quantity of harvested salmon from time t to T. ΔTEMP = monthly changes in log temperature from time t to T. ΔFEED = monthly changes in log feed sales from time t to T. ΔSMOLT = monthly changes in log smolt release from time t to T. ΔEUR/NOK = monthly changes in log EUR/NOK from time t to T. 1M, 2M, 3M and 6M denotes number of months (n) until the delivery period. The number of observations is 121

Appendix E: Results from the regression of the risk premium and spot price change for futures contracts with 3 months to maturity

3M	1	2	3	4	5	6	7
Intercept (α_1)	-0.027	-0.025	-0.148***	-0.027	-0.110***	-0.026	-0.131***
$\boldsymbol{F_{t,T} - S_t}$							
β_1	0.138	0.230*	0.703***	0.128	0.451**	0.219	0.649***
β_2	0.862***	0.770***	0.297	0.872***	0.549**	0.781***	0.351
$\boldsymbol{MONTH_{i,T}}$							
Feb			0.012		-0.018		-0.011
Mar			0.072		0.007		0.032
Apr			0.071		0.003		0.030
May			0.091		0.031		0.060
Jun			0.154**		0.099		0.131**
Jul			0.134		0.081		0.119
Aug			0.198**		0.141*		0.181**
Sep			0.261***		0.204***		0.240***
Oct			0.303***		0.251***		0.287***
Nov			0.225***		0.199***		0.223***
Dec			0.047**		0.051**		0.058***
$\boldsymbol{\Delta CV_{i,T}}$							
ΔBIO		0.002	-0.001			0.008	0.008
ΔPRO		0.042***	0.054***			0.042***	0.052***
ΔTEMP		-0.010	-0.008			-0.003	0.001
ΔFEED				-0.004	-0.003	-0.010	-0.013
ΔSMOLT				0.002	0.001	0.006	0.005
ΔEUR/NOK				-0.021	-0.035	-0.021	-0.033*
R^2-adj ($F_{t,T} - S_T$)	0.001	0.050	0.292	-0.004	0.213	0.046	0.318
R^2-adj ($S_T - S_t$)	0.255	0.291	0.472	0.252	0.413	0.290	0.492

Note: The models are estimated with Newey-West correction of the standard errors. The statistical significance of the coefficients is denoted by asterisks. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Risk premium ($F_{t,T} - S_T$) = difference between log monthly futures price at time t and log monthly spot price at time T. Basis ($F_{t,T} - S_t$) = difference between log monthly futures price at time t and log monthly spot price at time t. Spot price change ($S_T - S_t$) = difference between log monthly spot price at time T and log monthly spot price at time t. ΔBIO = monthly changes in log biomass from time t to T. ΔPRO = monthly changes in log quantity of harvested salmon from time t to T. ΔTEMP = monthly changes in log temperature from time t to T. ΔFEED = monthly changes in log feed sales from time t to T. ΔSMOLT = monthly changes in log smolt release from time t to T. ΔEUR/NOK = monthly changes in log EUR/NOK exchange rate from time t to T. 3M denotes that the futures contracts with three month to maturity. The number of observations is 121.

Appendix F: Autocorrelation and heteroscedasticity tests

Table 1F: From the regression of the risk premium and spot price change for futures contracts with 1 months to maturity

	1	2	3	4	5	6	7
Ljung-Box	11.196***	10.603***	11.487***	12.556***	4.151**	11.184***	2.441
Breusch-Godfrey	15.304***	14.713***	15.977***	17.124***	5.168**	15.283***	3.033*
Breusch-Pagan	0.001	1.326	2.229	3.261	12.244	4.922	13.094

Note: The null hypotheses for the tests for serial correlation (Ljung-Box and Breusch-Godfrey) are that of no serial correlation. Both tests use 1 lag. The null hypothesis for heteroskedasticity test (Breusch-Pagan) is that the error term is homoscedastic. The column numbers 1, 2, 3, 4, 5, 6 and 7 correspond to the associated regression results in table 6.

Table 2F: From the regression of the risk premium and spot price change for futures contracts with 2 months to maturity

	1	2	3	4	5	6	7
Ljung-Box	59.641***	55.591***	61.114***	62.761***	54.763***	59.831***	46.398 ***
Breusch-Godfrey	63.885***	61.401***	67.633***	69.250***	58.303***	66.829***	49.648 ***
Breusch-Pagan	0.132	2.056	1.012	0.893	13.252	5.151	15.608

Note: The column numbers 1, 2, 3, 4, 5, 6 and 7 correspond to the associated regression results in table 7.

Table 3F: From the regression of the risk premium and spot price change for futures contracts with 3 months to maturity

	1	2	3	4	5	6	7
Ljung-Box	73.421***	74.600***	73.391***	74.407***	69.550***	76.237***	69.962 ***
Breusch-Godfrey	74.693***	78.293***	77.133***	77.791***	72.485***	80.760***	73.376 ***
Breusch-Pagan	0.263	6.904	0.361	0.736	11.590	9.161	14.784

Note: The column numbers 1, 2, 3, 4, 5, 6 and 7 correspond to the associated regression results in appendix G.

Table 4F: From the regression of the risk premium and spot price change for futures contracts with 6 months to maturity

	1	2	3	4	5	6	7
Ljung-Box	92.141***	92.920***	89.630***	88.788***	89.986***	90.967***	91.784 ***
Breusch-Godfrey	90.604***	92.957***	89.023***	88.313***	89.924***	91.618***	91.231 ***
Breusch-Pagan	2.006	16.371	5.150	4.568	13.748	19.413***	28.474 *

Note: The column numbers 1, 2, 3, 4, 5, 6 and 7 correspond to the associated regression results in table 8.

Appendix G: Results from the regression of the risk premium and spot price change (seasonality and trend is *not* removed from the biophysical variables)

1M	1	2	3	4	5	6	7
Intercept (α_1)	-0.009	-0.008	0.007	-0.009	-0.053**	-0.008	-0.013
$\boldsymbol{F_{t,T} - S_t}$							
β_1	0.476***	0.571***	0.736***	0.524***	0.638***	0.592***	0.704***
β_2	0.524***	0.429***	0.264*	0.476***	0.362**	0.408***	0.296*
$\boldsymbol{MONTH_{i,T}}$							
Feb			-0.009		0.006		0.004
Mar			-0.077*		0.023		-0.037
Apr			-0.004		0.021		0.042
May			-0.025		0.043		0.011
Jun			0.026		0.097***		0.078
Jul			-0.012		0.047		0.028
Aug			0.008		0.082**		-0.013
Sep			0.040		0.133***		0.028
Oct			0.013		0.101***		0.016
Nov			-0.039		0.029		-0.037
Dec			-0.082***		-0.033		-0.050*
$\boldsymbol{\Delta CV_{i,T}}$							
ΔBIO		0.020***	0.004			0.026***	0.027
ΔPRO		0.024***	0.028***			0.034***	0.042***
ΔTEMP		-0.001	-0.004			0.027**	0.013
ΔFEED				0.009	-0.008	-0.033***	-0.039**
ΔSMOLT				-0.005	-0.006	-0.006	-0.008*
ΔEUR/NOK				-0.018*	-0.021**	-0.024***	-0.023***
R^2-adj ($F_{t,T} - S_T$)	0.117	0.234	0.281	0.143	0.305	0.323	0.362
R^2-adj ($S_T - S_t$)	0.140	0.254	0.299	0.166	0.324	0.340	0.379

Note: The models are estimated with Newey-West correction of the standard errors. The statistical significance of the coefficients is denoted by asterisks. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Risk premium ($F_{t,T} - S_T$) = difference between log monthly futures price at time t and log monthly spot price at time T. Basis ($F_{t,T} - S_t$) = difference between log monthly futures price at time t and log monthly spot price at time t. Spot price change ($S_T - S_t$) = difference between log monthly spot price at time T and log monthly spot price at time t. ΔBIO = monthly changes in log biomass from time t to T. ΔPRO = monthly changes in log quantity of harvested salmon from time t to T. ΔTEMP = monthly changes in log temperature from time t to T. ΔFEED = monthly changes in log feed sales from time t to T. ΔSMOLT = monthly changes in log smolt release from time t to T. ΔEUR/NOK = monthly changes in log EUR/NOK from time t to T. 1M denotes that the futures contracts with one month to maturity. The number of observations is 121.