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Efficiency in the Salmon Futures Market

An empirical study based on Fish Pool 2006-2016

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Working on this thesis for the past months has been very rewarding. We feel fortunate to be able to study a topic of our own choice; one which is also meaningful for the Norwegian economy, as salmon farming is an important element of the Norwegian industry. Conducting this research has given us valuable insight into the field of finance and has contributed to our development of analytical skills. We hope that it is as interesting to read as it was for us to write.

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ABSTRACT

This thesis assesses efficiency in the salmon futures market by testing for cointegration between spot and futures prices, and tests whether futures prices are the best forecast of subsequent spot prices, which is referred to as the unbiasedness hypothesis. Since spot and futures prices on salmon are found to be non-stationary processes, cointegration procedures are employed to test the unbiasedness hypothesis. In addition to efficiency, this thesis investigates the salmon futures market´s ability to function as a risk management tool by examining whether the futures prices provide a price discovery function for future spot prices.

Using weekly observations of spot and futures prices with 1- to 12-months to maturity in the period from June 2006 – June 2016, we find evidence that supports market efficiency. Spot and futures prices are cointegrated and the unbiasedness hypothesis holds for most contract lengths. Furthermore, we find that the futures market for salmon provides a price discovery function and conclude that this futures market is mature and satisfies as a risk management tool.

Our findings are consistent with the previous literature on efficiency in salmon futures markets, although our tests show stronger evidence on the salmon futures market´s ability to provide a price discovery function. Differences may be due to alternative methodological approaches and a different data set. Since the futures prices are shown to be unbiased and provide a price discovery function, this thesis suggest that hedgers and commercial participants in the salmon farming industry can use Fish Pool for risk management purposes.

Acronyms

ADF	Augmented Dickey Fuller
AIC	Akaike Information Criteria
ASA	Corporation listed on the Oslo Stock Exchange
BIC	Bayesian Information Criterion
ECM	Error Correction Model
EMH	Efficient Market Hypothesis
FAO	Food and Agriculture Organization of the United Nations
FPI	Fish Pool Index
GDP	Gross Domestic Product
LR	Likelihood Ratio
MVHR	Minimum Variance Hedge Ratio
NOS	Norwegian Futures and Options Clearing House
OLS	Ordinary Least Squares
SSB	Statistics Norway
VECM	Vector Error Correction Model

TABLE OF CONTENTS

1. Introduction

The production of farmed salmon has expanded rapidly over the last three decades. This growth has led farmed salmon to become an internationally traded commodity and highly important for the Norwegian economy as it is currently the country´s second largest export after oil and gas. One of the biggest drivers behind this expansion is arguably the increasing growth in the world's population. Farmed salmon has a huge potential to become a cheap and sustainable source of protein that can feed the growing population. However, salmon farmers are exposed to a high degree of risk because the price of salmon is volatile (Oglend, 2013). In 2005, Fish Pool ASA was established as an international exchange for salmon futures contracts in order to provide predictability and reduce uncertainty for commercial participants. Based on the rapid growth of the salmon farming industry and the young age of Fish Pool, this thesis aims to investigate the following research question: Is the futures market for salmon efficient?

Efficiency in the salmon futures market is investigated by testing whether futures prices are unbiased predictors of subsequent spot prices. On the basis of Fama´s (1970) efficient market hypothesis, all relevant information about the expected future spot price is incorporated in the current futures prices, and thus make futures prices the best forecast of future spot prices. In futures markets literature, this argument is expressed as the "unbiasedness hypothesis" and represents joint tests of efficiency and the absence of a risk premium (Brenner and Kroner, 1995). Unbiasedness is necessary for risk management purposes (Benninga et al. 1984), and implies that there are no excess returns to be made from speculating in the futures market. However, a rejection of the unbiasedness hypothesis can reflect the presence of a risk premium. In an efficient market where the short hedging demand is equal to the long hedging demand, futures prices should equal expected spot prices. However, if the hedging demand is unbalanced, then futures prices would deviate from the expected spot price by the risk premium (Gjolberg and Brattestad, 2011). This is referred to as contango or backwardation, depending on whether the risk premium is net paid by the buyer or the seller of the contract.

Since the spot and futures prices on salmon are found to be non-stationary (Asche et al, 2016), standard statistical procedures are no longer appropriate and can incorrectly reject market efficiency (Elam and Dixon, 1988). As a result, Hakkio and Rush (1989) and Lai and Lai (1991) suggest cointegration techniques when testing for market efficiency. Two non-stationary series are cointegrated if they are tied together in a long-run equilibrium. In addition to futures prices being unbiased predictors of subsequent spot prices, an efficient futures market require that spot and futures prices are cointegrated. This is because the factors that determine future spot prices also are reflected in current futures prices (Beck, 1994).

Unbiasedness seems to hold for some futures markets such as for crude oil (Switzer and El-Khoury, 2007), but not for others such as for currency (Lai and Lai, 1991). While there are many studies that test efficiency in commodities like crude oil, only a few studies have been conducted on the relatively young futures market for salmon, such as Asche et al. (2016) and Yeboah et al. (2016). By using cointegration techniques, previous studies on the salmon futures market support the unbiasedness hypothesis, but provide contradicting findings on this futures market´s ability to provide a price discovery function. Price discovery refers to the use of futures prices in determining expected spot prices (Schroeder and Godwin, 1991), and is investigated by testing whether the futures prices are exogenous in the systems of spot and futures prices. If a futures market is able to provide a price discovery function, it is said to be mature in the sense of functioning as a risk management tool (Yeboah et al., 2016).

Our data is publicly available and consists of weekly spot prices and daily futures prices in the period from June 2006 – June 2016. We consider futures with contract lengths of 1- to 12-months. In this paper, we find evidence that support market efficiency. Spot and futures prices are cointegrated for all contract lengths and the unbiasedness hypothesis holds for most of the contract lengths. Furthermore, we find that the futures market for salmon is able to provide a price discovery function and we conclude that the futures market for salmon is mature in the sense of functioning as a risk management tool. Thus, commercial participants in the salmon farming industry can use the futures contracts at Fish Pool as a tool to reduce their risk exposure.

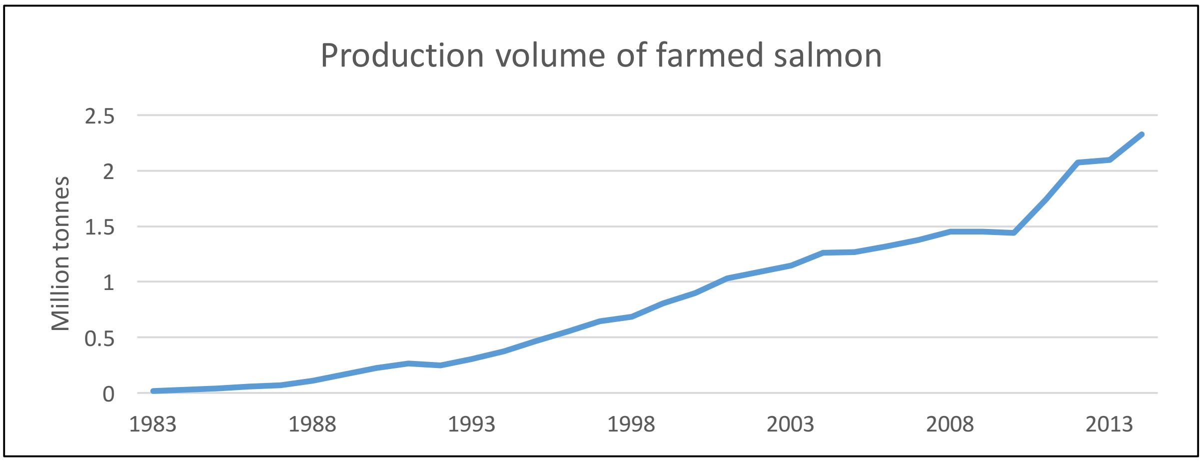
In order to substantiate the cointegration results, we apply a test for short-run causality known as the Granger causality test. We find short-run causality in at least one direction for all contract lengths, which is consistent with the cointegration results (Granger, 1988). In addition, we conduct analyses of both the cointegration and unbiasedness result's sensitivity to the number of lags selected in the models. While the sensitivity analyses show that the cointegration results are not sensitive to lag lengths, the unbiasedness results seem to be somewhat sensitive. The sensitivity analyses support the cointegration results, but they indicate that we should be somewhat critical of the results from the unbiasedness hypothesis.

2. The Salmon Market

In order to understand the background of our research question, we provide an overview of the salmon farming industry and futures exchange. Subsection 2.1 provide a brief overview of the production volume and the biggest farmers in the industry. Further, market efficiency imply that spot and futures prices are cointegrated because the same factors that drive the spot price are also reflected in futures prices. Some of the most important factors are discussed in subsection 2.2. In subsection 2.3, we take a look at Fish Pool and briefly elaborate on the motivation behind our research question. The main sources in this section are Marine Harvest, the Food and Agriculture Organization of the United Nations (FAO), and Fish Pool.

2.1 Overview

Figure 1: Farmed salmon production volume in the period, 1983 – 2014 (FAO, 2016)

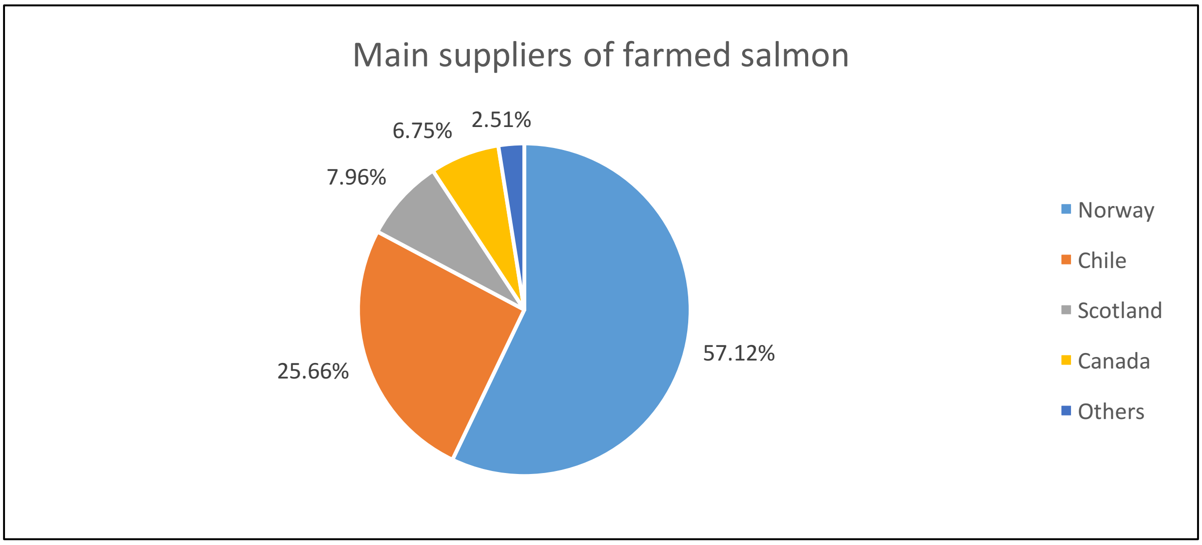


Salmon farming started in the 1960´s and has since then surpassed wild salmon in terms of production volume. Over the last three decades, farmed salmon have become a highly traded commodity, and the production has been rapidly growing and exceeded two million tonnes in 2011[1]. Increase in global fish consumption is the main driver of the rapid growth in salmon farming. Further, salmon has many characteristics that make it more sustainable than other sources of protein such as chicken, pork, and beef. For instance, salmon yields more edible meat, consume less water per kilo, and leave a smaller carbon footprint that any of these substitutes (Marine Harvest, 2016).

[1] The data is collected at FAO and can be accessed at http://www.fao.org/fishery/culturedspecies/Salmo_salar/en

Norway has the leading position in the salmon industry and is the biggest supplier of farmed salmon, responsible for more than 50 percent of the world´s production. Salmon farming is an important part of the Norwegian economy and is the second largest export after oil and gas. Export of farmed salmon yields more than 40 billion NOK, which corresponds to 2-3% of the Norwegian GDP[2] (SSB, 2015). Other big salmon farming countries includes Chile, Scotland, and Canada. In terms of production volume, Marine Harvest is the largest salmon farmer. While based in Norway, Marine Harvest also have production facilities in Chile, Scotland, and Canada. Other large salmon producing companies includes Salmar, Lerøy Seafood, Mitsubishi (Cermaq), and Emperas Aquachile.

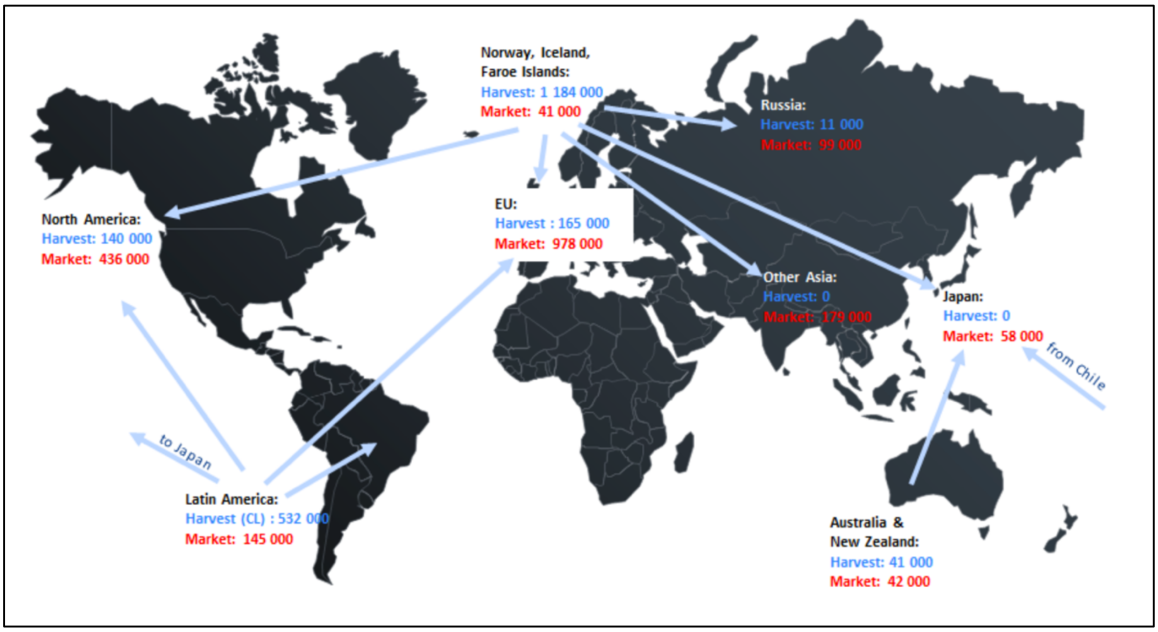
Figure 2: Distribution of farmed salmon production across countries, 2015 (Marine Harvest, 2016)



Salmon has become an internationally traded commodity and is consumed all around the world, but to a smaller degree in Africa and Australia. As salmon is a fresh product, each producing country primarily focus on delivery to nearby regions. Norway primarily export to the European Union (EU), Russia, and Asia. Chile focuses on USA, Latin America, and Asia. Canada export to USA, and Scotland focus on the domestic area.

[2] The data can be accessed at https://www.ssb.no/en/utenriksokonomi/statistikker/muh/aar-endelige/2016-05-19

Figure 3: Salmon production (harvest), consumption (market) and trade flows in 2015. Source: Marine Harvest 2016



2.2 Supply and Demand

The volatility of the salmon price has increased substantially during the recent years (Oglend, 2013) and is affected by the size of the salmon when harvested, degree of processing, and other factors on both the supply and the demand side. The supply of farmed salmon is inelastic in the short-run while the demand fluctuates through the year, and thus increases the volatility. In this subsection, we present the most important factors that affect the price of farmed salmon.

Due to different weight classes, a long production cycle, and a short shelf life, the "spot" price is based on the overall price/quantity preference of consumers. The most normal market size is 4-5 kg, but the farmers offer both smaller and larger sizes. Smaller sizes are cheaper, but are offered when there is a need for cash or early harvest to realize ongoing capacity. Larger sizes are sold at a premium and may be offered when there are lower production costs or an increase in demand for larger fish in niche markets. Salmon is a fresh product and has a shelf life of only three weeks, but the total production cycle can take up to 24 – 40 months. The production cycle is separated into six sections. Fertilized eggs start off in freshwater incubation tanks and are moved over into larger fresh water tanks when they are able to feed themselves. After some time, the fish will have gone through physical changes that enables them to live in seawater.

The fish are then moved from the freshwater tanks into the sea. By the time the fish have reached the desired weight, the fish are harvested and processed.

The market for farmed salmon is inelastic on the supply side. This is because the supply of farmed salmon is affected by several long-term factors. First, the supply is affected by the salmon price. Producers can react by changing the limits of grown up fish for slaughter. Next is the availability of production sites and industry regulations. There are only a few coastlines feasible for farming since salmon farming requires a certain temperature range and certain water currents. As a result, farmed salmon are currently only produced in Norway, Chile, United Kingdom, Farao Islands, Ireland, North America, and New Zealand[3]. In the salmon farming countries, a license is required which put constraints on production. Also, there are some medium term factors that affect the supply of farmed salmon. This includes the amount of young fish farmers put in their tanks and the growth pace of the salmon. How fast the fish grow depends on factors such as the sea surface temperature, and feeding schedules. Producers are only able to influence the speed of growth with their feeding schedule. Finally, the supply of farmed salmon is exposed to several risk factors. The main risk factors includes outbreak of infectious diseases, unexpected developments in the sea surface temperature[4], and winter storms that can disrupt supply and damage farming facilities.

The demand for farmed salmon is more elastic than the supply. The world´s population have increased exponentially over the last decades and is one of the main drivers of the increased demand for farmed salmon. As the world´s population is constantly expanding, it is expected that the demand for farmed salmon will increase in the future as well (Marine Harvest, 2016). In addition to population growth, health benefits of salmon may work as a demand booster. The demand for farmed salmon depends on factors such as the salmon price, price of substitutes, and politics. The closest substitute for farmed salmon is wild salmon, but it might also be substituted by other fish such as trout, cod, and tuna or other sources of proteins such as chicken, pork, and beef. Politics also play an important role in the demand for farmed

[3] However, the Food and Drug Administration (FDA) have recently approved genetically engineered Atlantic salmon for food use. This will facilitate production in regions that have previously been unsuited for salmon farming (FDA, 2016).

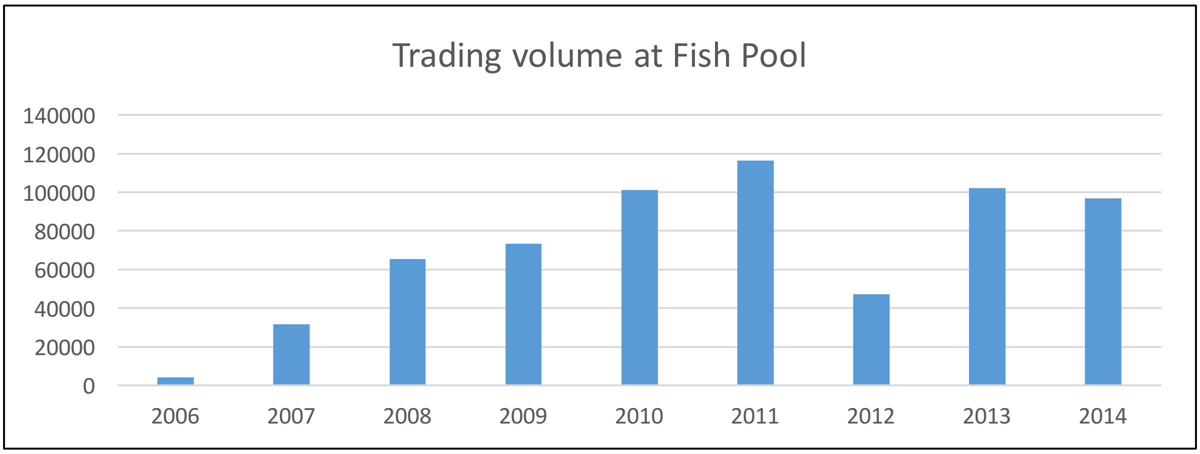
[4] Over the last couple of years, the southern oscillation of a band of warm ocean water known as El Niño has greatly disturbed the Chilean production of farmed salmon.

salmon. Consuming countries can place restrictions on import and thus reduce the demand. Examples of political interferences include China´s effective ban of Norwegian salmon after the Nobel Peace Prize was awarded to Chinese dissident Liu Xiaobo, and Russia´s ban of Norwegian salmon in 2014 as a retaliation against economic sanctions.

2.3 Fish Pool ASA

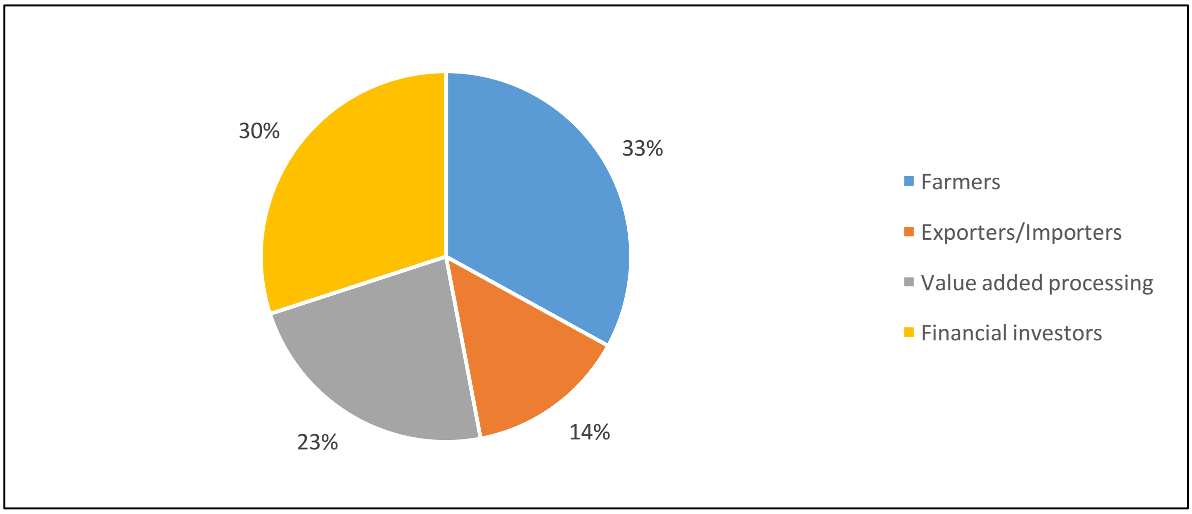
Fish Pool ASA operates as an international marketplace for buying and selling financial contracts on salmon. The exchange is located in Bergen, Norway and was established in 2005 in order to provide predictability in the market for farmed salmon. Oslo Stock Exchange owns more than 90 percent of the shares at Fish Pool and their mission is to offer predictability and reduce risk for participants in the salmon market. Fish Pool allow traders to be anonymous, and provide security of settlement with its clearing central, NOS Clearing ASA. This subsection provides an overview of Fish Pool, which is the market place we investigate in this paper. Information and data are collected at the Fish Pool website.

Figure 4: Yearly trading volume at Fish Pool, 2006-2014 (Fish Pool, 2015)



Fish Pool´s goal is to offer predictability for its trade members by offering financial derivatives on the salmon price. Fish Pool has over 200 trade members, and offer two products; futures and options. Futures are financial contracts that obligate the buyer/seller to buy/sell salmon, at a predetermined date and price. These contracts currently constitute about 98.5 percent of the total trading volume at Fish Pool. Options are financial contracts that give the buyer/seller the right, but not the obligation to buy/sell salmon at a fixed price over a specified time period. In this paper, we focus on the futures contracts at Fish Pool. All financial contracts at Fish Pool are settled in cash against the Fish Pool Index (FPI). The FPI is a synthetic market price that aim to reflect the most correct spot price of fresh Atlantic salmon. FPI is constructed as weekly averages of three index elements; Nasdaq Salmon Index, Fish Pool European Buyers Index and Norwegian export statistics (SSB), which constitutes 85%, 10% and 5% of the FPI respectively[5] (weights from 2016). Moreover, the price index is based on weekly weighted averages of the most traded weight classes. These weight classes are 3-4 kg, 4-5 kg, 5-6 kg, and constitute 30%, 40%, and 30%, respectively.

Figure 5: Trade volume divided by segment, 2010-2013 (Fish Pool, 2015)



Fish Pool was established to offer hedging products for market participants that worked directly with salmon. Even though, these contracts were marketed towards farmers, importers, exporters and value adding processors, financial traders were responsible for almost one third of the trading volume at Fish Pool during the period 2010-2013. Financial traders consist of speculators and arbitrageurs, and may also include cross-hedgers. Cross-hedgers may be using financial derivatives on salmon in order to hedge other assets or commodities that are correlated with the salmon price. Speculators try to obtain returns by betting on the direction of future spot prices. Arbitrageurs try to obtain risk free profits by exploiting inefficiencies in the market. If the market is efficient, then there would be no reason to try to profit from arbitrage.

[5] A detailed description of FPI can be accessed at http://fishpool.eu/price-information/spot-prices/fish-pool-index/

3. Efficiency in Futures Markets

The efficient market hypothesis (EMH) was developed by Fama (1970) and states that financial markets are efficient if prices reflect all available information at any given time. In futures markets, efficiency implies that the current futures price should equal the expected spot price and thus make futures prices the best forecast of future spot prices (Beck, 1994). In futures markets literature, this is referred to as the unbiasedness hypothesis and represents joint tests of market efficiency and the absence of a risk premium. This section describes the unbiasedness hypothesis and earlier findings in the futures markets literature.

3.1 The Unbiasedness Hypothesis

Pricing of commodity futures are based on two theoretical frameworks; the theory of storage and the risk premium model. Both frameworks have been widely discussed in studies such as Fama and French (1987) and Deaves and Krinsky (1992). The following subsection discuss these frameworks in the light of our assessment of efficiency in the salmon futures market. Under the theory of storage, also called cost-of-carry or convenience yield, the relationship between spot and future prices are based on arbitrage theory. Storage costs include interest rates and insurance premiums, and convenience yield is the benefit of holding an underlying product rather than the contract. The theory of storage is described by Kaldor (1939) and Working (1948), where they suggest the following relationship:

$$F_t - S_t = r_t + W_t - \delta_t \tag{1}$$

F_t is the futures price at time *t*, S_t is the spot price at time *t*, r_t is the interest rate between time *t* and delivery, W_t is the storage cost between time *t* and delivery, and δ_t is the convenience yield over the same time span. Storage is an important component in this relationship because without storage, arbitrage pricing theory may not work effectively (Yang et al., 2001).

The risk premium model, also called the unbiasedness expectation model, link the futures prices to expected risk premiums and a forecast of future spot prices. Examples of studies that are based on this model are Keynes (1930), Cootner (1960), and Dusaak (1973). The risk premium model describes the following relationship:

$$F_t - S_t = E_t[RP] + E_t[S_T - S_t] \tag{2}$$

where $F_t - S_t$ is the difference between current futures and spot prices that can be expressed as the expected risk premium $E_t[RP]$ plus the expected change in the spot price $E_t[S_T - S_t]$ at time *T*. The expected risk premium is defined as the bias of the futures price as a predictor of the future spot price:

$$E_t[RP] = F_t - E_t[S_T] \tag{3}$$

The expected risk premium can be positive, negative or zero depending on the net hedging position. Long speculators are needed to supply price insurance, which implies that long positions are typically rewarded by increases in the futures price. If hedgers are net short, the risk premiums are positive. This pattern of futures price changes is often referred to as "normal backwardation", where the futures price is below the expected future spot price. If hedgers are net long, the risk premium would be negative in order to motivate short speculators into taking offsetting positions, and as a reward for the risk, futures prices should decline over time. This pattern is referred to as "contango" where the futures price is above the expected future spot price. In a balanced and efficient market, i.e. the short hedging demand is exactly matched by the long hedging demand, the risk premium would be zero and the futures price should equal the expected spot price (Gjolberg and Brattestad, 2011). This relationship is expressed in equation (4), where I_t is the information set at time *t* and $E_t[\cdot\,|I_t]$ is the conditional expectations operator in time *t*:

$$F_t = E_t[S_T|I_t] \tag{4}$$

In this paper, we base our discussion on the risk premium framework. First of all, for a non-storable commodity such as fresh salmon, the risk premium theory is a more suitable tool for assessing market efficiency (Yeboah et al., 2016). Secondly, the theory of storage is not controversial while there is little agreement on whether futures prices contain expected premium and a forecast of future spot prices (Fama and French, 1987). Lastly, the theory of storage is not overly useful for the purpose of investigating market efficiency, because it is no way of knowing what would constitute an appropriate convenience yield (Deaves and Krinsky, 1992).

Roberts (1967) and Fama (1970) classified market efficiency into three levels: weak form efficiency, semi-strong form efficiency, and strong form efficiency. The market is weak-form efficient when all historical price information is incorporated into today´s price. The semi-strong form efficiency indicates that all publicly available information is incorporated into the price. Strong form efficiency implies that all information, including publically unavailable information is incorporated into the price. In this paper, we analyze weak-form efficiency in the salmon futures market, and thus the word “efficiency” refer to efficiency of the weak form.

Under the unbiasedness expectations model, given a balanced hedging demand, efficiency implies that the current futures price is equal to the expected spot price. Whenever the futures prices differ from the expected spot price, investors will profit from trading futures contracts until equality is re-established. Hence, efficiency implies that futures prices are the best forecast of subsequent spot prices (Beck, 1994). Since the expected future spot price is unobserved, we use the traditional approach of comparing the spot price with futures prices at maturity. Whether futures prices are the best forecasts of subsequent spot prices represents a joint hypothesis of market efficiency and the absence of a risk premium. This has been referred to as “simple efficiency” (Hansen and Hodrick, 1980), “speculative efficiency” (Bilson, 1981), and the “unbiasedness hypothesis” (Brenner and Kroner, 1995). We use the phrase “unbiasedness hypothesis” to refer to the joint hypothesis of market efficiency and no risk premium. Following Hakkio and Rush (1989) and Lai and Lai (1991), efficiency in the salmon futures market is examined based on the following model:

$$S_t = a + \beta F_{t-T} + u_t \tag{5}$$

where S_t is the spot price at time t, and F_{t-T} is the price for the futures contract at time *t* with expiration at time *T*. The error term u_t has a mean of zero and finite variance. Efficiency in the absence of a risk premium imply that $a = 0$ and $\beta = 1$. Since salmon spot and futures are found to be non-stationary processes (Asche et al., 2016), standard statistical procedures are not appropriate, and simple F-tests on the restrictions may incorrectly reject market efficiency (Elam and Dixon, 1988). First-differencing the data impose too many unit roots, invalidating standard inference (Brenner and Kroner, 1995) and examining their first differences would not be sufficient since it would not provide evidence on the underlying equilibrium (Hakkio and Rush, 1989). As a result, Lai and Lai (1991) and Beck (1994) suggests cointegration techniques developed by Engle and Granger (1987) and Johansen (1991) when testing for market efficiency. In addition to futures prices being unbiased predictors of future spot prices, efficiency implies that spot and futures prices are cointegrated. This is because factors that determine future spot prices are reflected in current futures prices (Beck, 1994).

Given that the unbiasedness hypothesis holds, empirical hedging models such as the *minimum variance hedge ratio* (MVHR) is also the optimal hedge ratio in terms of risk and return (Benninga et al., 1984). MVHR is an important risk management model that aims to minimize the risk exposure in the spot market by using the futures market. The MVHR represents the number of contracts needed to hedge a position and is obtained by regressing changes in the spot price on the changes in the futures prices (Ederington, 1979). Next, unbiasedness indicates that there are no excess returns to be made from speculating in the futures market (Brenner and Kroner, 1995). Since the unbiasedness hypothesis represents joint tests of risk neutrality and market efficiency, rejection of this hypothesis can imply either the presence of a risk premium or that the market is inefficient.

3.2 Evidence in Futures Markets Literature

After Engle and Granger (1987) and Johansen (1991) introduced their cointegration procedures, these have been widely applied by researchers in terms of dealing with non-stationary processes when testing for efficiency in futures markets. Even though the unbiasedness hypothesis is expected to be rejected because the assumption of risk neutral market participants is not theoretically defensible (Beck, 1994), studies assessing unbiasedness relationships have so far provided mixed findings (Brenner and Kroner, 1995). This subsection provides a review of popular studies that test efficiency in futures markets by applying cointegration techniques. A review of studies on the salmon futures market is also included.

The Engle-Granger procedure have been used in several studies of efficiency in futures markets because of its straight-forward implementation. Hakkio and Rush (1989) used this method in the futures market for exchange rates and found that spot and futures are cointegrated, but the unbiasedness hypothesis does not hold for German Mark and British pound. Beck (1994) showed that the Engle-Granger method can be applied to test for efficiency while permitting the presence of a risk premium. She analyzed spot and futures prices in the futures markets for; cattle, orange juice, corn, copper and cocoa, and states that that all five commodity markets were sometimes inefficient, but not always. Moreover, she concludes that rejection of unbiasedness is caused by inefficiencies rather than a presence of a risk premium. Several studies have been done on the futures market for crude oil. The futures market for crude oil is shown to be efficient where futures provide unbiased estimates of subsequent spot prices (Peroni and MacNown, 1998 and Gulen, 1998).

The Johansen cointegration methodology is also commonly used for assessing efficiency and the unbiasedness hypothesis in futures markets. There also exist several studies that applies the Johansen methodology when testing for unbiasedness in the futures market for crude oil. Like the studies where the Engle-Granger methodology is applied, the futures market for crude oil is found to be efficient (Crowder and Hamed, 1993 and Switzer and El-Khoury, 2007). Lai and Lai (1991) examined efficiency between spot and forward rates for five currencies against the US dollar and rejected unbiasedness which violates market efficiency. The unbiasedness hypothesis in the futures market for interest rates was tested by Krehbiel and Adkins (1994). They included spot and futures rates for treasury bills and Eurodollars. By applying Johansen methods, they found that efficiency holds for the futures market for treasury bills, but not for the Eurodollar market.

Although Fish Pool is a relatively new futures exchange, there have been done some studies on the relationship between the spot and the futures prices, assessing the unbiasedness hypothesis. Among these studies are the paper by Asche et al. (2016) and a more recent paper by Yeboah et al. (2016). In addition to the unbiasedness hypothesis, these papers also investigate the salmon futures market´s ability to provide a price discovery function. Price discovery refers to the use of futures prices in determining expected spot prices (Schroeder and Godwin, 1991), and futures markets ability to provide a price discovery function is tested by examining whether or not futures prices are leading the price discovery relationship. This test is referred to as the weak exogeneity test and tests whether futures prices are exogenous in the systems of spot and futures prices. A futures market´s ability to provide a price discovery function is necessary for functioning as a risk management tool (Asche et al., 2016). Further, futures markets are said to be mature in the sense of functioning as a risk management tool if it provides a price discovery function (Yeboah et al., 2016).

Asche et al. (2016) investigate the relationship between spot and future prices and test the unbiasedness hypothesis, by using the Johansen cointegration procedure on monthly data between 2006 - 2014. They investigate futures contracts with 1- to 6-months to maturity and find that the spot is cointegrated with all contract lengths. Based on the convenience yield theory, they find that futures prices are unbiased predictors of subsequent spot prices. However, regarding price discovery, they find that spot prices leads the futures prices in the price discovery relationship. Based on the leadership role, they conclude that the salmon futures market is still immature.

A similar study on the salmon futures market, has been conducted by Yeboah et al. (2016). While also applying the Johansen cointegration procedure, they use monthly data between 2006 - 2015, and their findings both support and contradict the findings of Asche et al. (2016). Yeboah et al. (2016) investigate futures contracts with 1- to 12-months to maturity, and find that spot prices are cointegrated with futures prices for all contract lengths, except for the 9-, 10-, and 11-month contracts. For the unbiasedness hypothesis and price discovery, they do not consider contract lengths that are not cointegrated with the spot. Based on the risk premium theory, they find that unbiasedness holds for all remaining contract lengths, except for the 12-month contract. Regarding the price discovery leadership, they find some mixed results. The futures prices with 3-, 4-, 9-, and 12-month contract length is leading the price discovery relationship, while the futures prices with 1-, 2-, and 6-months to maturity are led by the spot. Based on the mixed findings in the price discovery relationship, they conclude that the salmon futures market is near matured.

Previous studies done by Asche et al. (2016) and Yeboah et al. (2016) have both similarities and differences in methodology and findings. They both apply Johansen cointegration techniques and show that for most contract lengths, the spot and futures prices are cointegrated and that the unbiasedness hypothesis holds. On the other hand, Asche et al. (2016) finds that the spot leads the price discovery relationship while the findings of Yeboah et al. (2016) are mixed. Moreover, Asche et al. (2016) base their work on the convenience yield theory while Yeboah et al. (2016) base their work on the risk premium theory. Based on weak exogeneity testing, Asche et al. (2016) conclude that this future market is still immature while Yeboah et al. (2016) states that it is mature or near matured. Like Yeboah et al. (2016), we consider contract lengths up to 12-months to maturity and base our study on the risk premium theory. However, we assess efficiency in the salmon futures market by analyzing weekly data form June 2006 – June 2016. In addition to the Johansen procedure, we apply the Engle-Granger approach to test for cointegration, unbiasedness and weak exogeneity. We find that spot and futures prices are cointegrated for all contract lengths. Unbiasedness holds for all contract lengths when using the Engle-Granger approach, but is rejected for the 5-, 7-, 8-, and 11-month contracts when the Johansen procedure is applied. Moreover, we find that the futures prices are leading the price discovery function and conclude that this futures market is mature.

4. Data

In order to test efficiency in the salmon futures market, we construct a data set based on spot prices and 1- to 12-month futures prices on salmon, that we collect from the Fish Pool website. The sample consists of weekly data spanning from June 2006 to June 2016 for a total number of 522 observations. This section provides an overview of the data material as well as necessary adjustments of the futures price series. Then, we discuss descriptive statistics before results from unit root testing are provided.

4.1 Spot Prices

The data material on the FPI are collected from the Fish Pool website[6], and are provided in weekly frequencies. Below, we provide an overview of the historical prices, as well as a discussion on whether to apply seasonality adjustment on the price series.

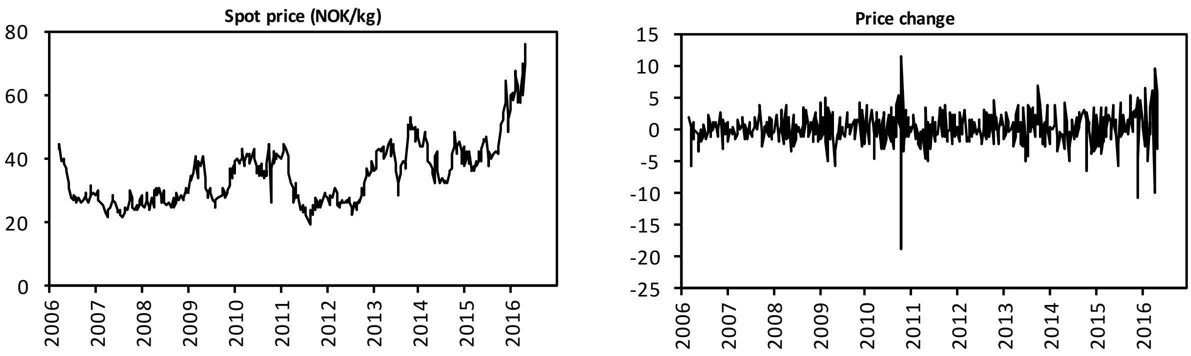
Figure 6 show the development of the salmon price and the price change over the sample period. In the period from mid 2015 to the end of the sample period, the salmon price has had a substantial increase. This is mostly due to a supply shock caused by high sea surface temperatures in the southeast pacific due to an abnormally powerful el Niño effect.

Seasonality is an essential characteristic of salmon aquaculture. Increased consumption of salmon in holidays such as Christmas and Easter create a disequilibrium in the supply-demand relationship. As salmon is a perishable commodity, it cannot be stored to offset spikes in demand around these periods. The disequilibrium is manifested as seasonal patterns in the salmon price.

We face several impediments in assessing whether the data material should be seasonally adjusted or not. First, seasonal adjustment of weekly data is proven to be difficult. As an example, the number of observations in the year varies between 52 and 53 weeks, and thus seasonality cannot be modeled by a set of dummy variables (Harvey et al., 1997). Secondly, if we were to use monthly data rather than weekly, the 10-year period of the data set would still be on the border of what could cause instability problems in the seasonal component

[6] The data can be accessed at http://fishpool.eu/price-information/spot-prices/history/

Figure 6: Weekly salmon spot price and price changes from June 2006 – June 2016



(Mazzi, 2009). Moreover, the volatility of the salmon price seems to be more heavily driven by supply shocks such as lice outbreaks than spikes in demand around Christmas and Easter. Too much tampering with the data material could then potentially dilute the reliability of the results. On the other hand, not adjusting for seasonality also has its disadvantages. The seasonal nature of the salmon price will to some degree induce predictability in the price movements that would not necessarily be caused by market inefficiency. Based on these arguments, we proceed to testing for market efficiency without adjusting for seasonality in the spot and futures prices.

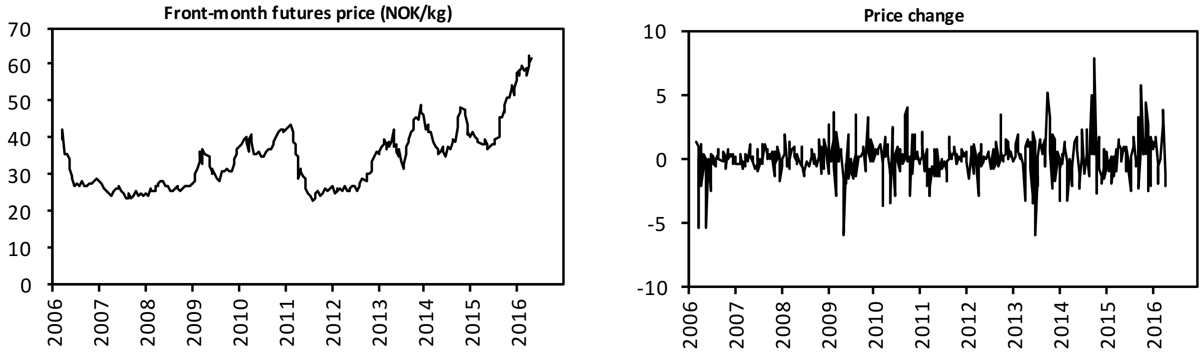
4.2 Futures Prices

The price data on the salmon futures contracts represent daily closing prices and is collected from the Fish Pool website[7]. The salmon futures contracts are settled based on the average spot price during the month of delivery. We sort the data on a rolling basis with contracts maturing from 1- through 12-months forward.

At Fish Pool, the maturity date of the futures contracts is set to the second Friday in the following month, e.g. the contract for July 2016 expired on Friday August 12th 2016. This creates overlapping observations in the time-series as observations from both the July and August contracts will exist in this period.

[7] The data can be accessed at http://fishpool.eu/price-information/forward-prices-3/forward-closing-prices-history/b

Figure 7: Weekly front-month futures prices and price changes from June 2006 – June 2016



At the end of July, the average price of the underlying is known for sure. After this point, the futures price of the July contract will not exhibit any large movements due to illiquidity and the fact that the value of the underlying is known. However, just before the end of the month, the holder of a futures contract will normally rollover the contract to a later month of delivery. This creates a disequilibrium in supply and demand and is known as the rollover effect.

In testing for market efficiency, both overlapping observations and the rollover effect need to be adjusted for. We adjust for overlapping observations by defining the expiration date of the contracts as the start of the delivery period e.g. the last business day of the month, as suggested by Asche et al. (2016). Further, the rollover effect is adjusted for by replacing the rollover dates by the new underlying months, as suggested by Bloznelis (2016). We then proceed to sort the data on futures prices on a rolling basis with 1- to 12-months to maturity.

As the spot prices are provided on a weekly basis, the daily futures prices need to be transformed into weekly. We transform the data to weekly frequencies by taking weekly averages. Although taking the last daily observation would provide the most up-to-date information, the weekly average is more directly comparable to the spot price as the spot price is also a weekly average, and is thus more relevant in testing for market efficiency.

Figure 7 show the development of the price of the front-month contracts, as well as the price change over the sample period. As with the development of the spot price, the front-month futures price has had a substantial increase over the last year of the sample period. However, the increase is not as steep as with the spot price. This could indicate that the market is uncertain about the persistence of the supply shock caused by the heightened sea surface temperatures.

4.3 Descriptive Statistics

The development of the salmon spot price and the front-month futures price is represented in figure 6 and figure 7. The difference between the futures and the spot price, known as the *basis* is shown in figure 8, for the 1-, 2-, 3-, 6-, 9-, and 12-month futures contracts. Descriptive statistics of the spot price and the 1- to 12-month futures contracts are provided in table 1. We apply a Chi-Squared goodness-of-fit test to test the hypothesis that the data comes from a normal distribution. As depicted in table 1, we reject the null hypothesis of normality for all the data at the 1% level. Descriptive statistics of price changes are provided in table A1 in the appendix and show that spot price changes are normally distributed. Price changes on the 1- to 12-month futures, on the other hand, are not normally distributed.

All of the price series lie in the interval between 18.99 NOK/kg and 75.62 NOK/kg, and both the highest and the lowest observation belong to the spot price. The average spot price is higher than the average of all the 1- to 12-month futures prices. This suggest that the salmon futures market generally is in normal backwardation. The spot price and all the futures prices are positively skewed, which could indicate upward price spikes (Bloznelis, 2016).

Table 1: Descriptive statistics of weekly spot and 1-12 month futures prices

	Mean	Median	Min.	Max.	St. dev.	Coef. of variation	Skewness	Excess kurtosis	Normality (Chi-squared)
Spot price	34.73	33.18	18.99	75.62	9.68	0.28	1.13	1.60	166.07***
Futures prices									
1 Month	34.55	33.72	20.65	68.02	9.26	0.27	1.01	0.99	151.98***
2 Month	34.25	34.26	22.59	63.50	8.75	0.26	0.98	0.72	151.46***
3 Month	33.99	33.88	23.09	58.10	8.33	0.24	0.85	0.18	134.86***
4 Month	33.81	32.95	23.07	55.60	7.95	0.24	0.73	-0.25	125.18***
5 Month	33.63	32.26	23.07	57.00	7.70	0.23	0.68	-0.39	114.48***
6 Month	33.54	31.90	22.84	61.70	7.70	0.23	0.75	-0.07	111.56***
7 Month	33.39	31.53	22.84	64.30	7.73	0.23	0.88	0.49	121.18***
8 Month	33.24	31.46	22.76	59.28	7.61	0.23	0.88	0.48	122.92***
9 Month	33.13	31.10	22.76	60.28	7.55	0.23	0.92	0.61	130.51***
10 Month	33.04	31.03	22.76	61.28	7.54	0.23	0.98	0.86	123.49***
11 Month	32.97	31.00	22.75	60.38	7.51	0.23	1.01	0.98	130.99***
12 Month	32.85	31.02	22.80	59.88	7.45	0.23	1.03	0.99	140.67***

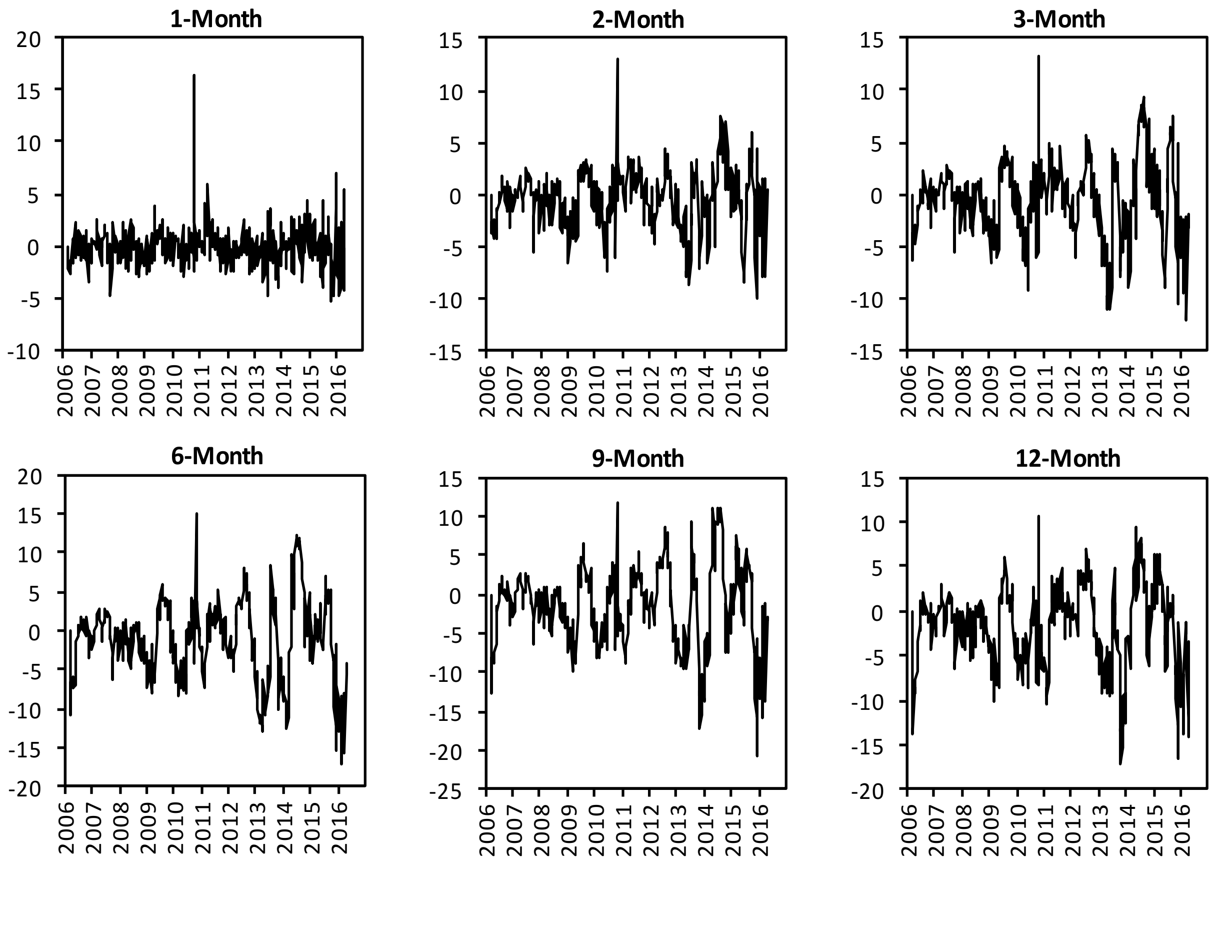
Note: *** marks significance at the 1% confidence level. Sample period is from June 2006-June 2016. Number of observations are 522.

The standard deviation of the spot price in the sample period is 9.68 NOK/kg, indicating that the salmon price is highly volatile during the sample period. With exception of the 7-month contracts, the standard deviation is generally declining with time to expiration. This is in line with the falling term structure of volatility, known as the Samuelson effect (Samuelson, 1965).

Further, the average futures prices are declining with increasing time to expiration. This indicates that the futures curve is inverted. As salmon is a perishable commodity, an inverted futures curve could suggest that short hedgers are willing to pay a risk premium by selling futures at a slightly lower price than what they expect the spot to be in the future. This would be in order to incentivize investors to take offsetting positions.

The basis for futures with 1-, 2-, 3-, 6-, 9-, and 12- months to expiration are depicted in figure 8. Although the spot price on average is higher than the futures prices, we see that there are short-term periods in which the futures prices surpasses the spot price. This cyclicality is a common characteristic in the basis for agricultural commodities that exhibit seasonal price patterns. The cyclicality is driven by the volatility of the spot price, and causes short-term

Figure 8: Weekly basis of 1-, 2-, 3-, 6-, 9- and 12-month futures contracts from June 2006 – June 2016



spikes. Such spikes will usually happen during periods of harvest. In these periods, the supply drives the spot price downward, leaving the futures prices higher than the spot prices, as shown in figure 8. During periods outside of the harvest cycles, the opposite happens, and consumers experience a shortness of supply, which drives the spot price up.

The cyclicality caused by harvesting is best represented by the 1-month graph of the basis. As the time to expiration increases, the futures prices become relatively less sensitive to short term changes in the spot price. This smoothens the futures price curve, and thus the basis for contracts maturing further into the future are better at capturing the long term volatility of the spot price instead of the short term cyclicality caused by supply spikes during harvesting.

4.4 Unit Root Testing

A prerequisite for the cointegration analysis is that the spot and 1- to 12-month futures prices are non-stationary and integrated of the same order. In this subsection, we apply *unit root* testing to assess whether the price series are stationary or non-stationary. A time-series is non-stationary if it has a unit root that causes statistical properties such as mean, variance, and covariance to change with time. One should be careful in applying statistical tests on data that are non-stationary, as test results tend to be spurious, i.e. one might discover a relationship that is not there.

To avoid spurious results from hypothesis testing, non-stationary data are often transformed to become stationary, meaning that mean, variance, and covariance are time-stable. We transform a non-stationary time series into a stationary time series by first-differencing, i.e. subtracting the observation at time t-1 on each side of the equation.

To test whether the price series are stationary or non-stationary, we apply the Augmented Dickey Fuller (ADF) test. This procedure tests the null hypothesis of a unit root. If the null is rejected, the ADF test indicates that the process is stationary. The ADF testing procedure is applied to the model:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^{h} \delta_i \Delta y_{t-i} + \varepsilon_t \tag{6}$$

Where the time-series y_t is regressed on lagged observations of itself. δ_i are parameters on the lags of y. α is a drift component and βt is a trend component. In this model, constraints can be imposed such that it corresponds to three different types of non-stationary random walk processes. If $\alpha = 0$ and $\beta = 0$, the model corresponds to a pure random walk; if $\alpha \neq 0$ and $\beta = 0$, the model corresponds to a random walk with a drift; and if no constraints are imposed, the model corresponds to a random walk with a drift and a trend. Under the null hypothesis, $\gamma = 0$ imply a unit root, which indicates that the process is non-stationary.

Before we proceed to the test results, note that we also need to select the number of lags. The specification of the lag length is important, that is, if the lag length is too small, the model will be biased due to remaining autocorrelation in the residuals. On the other hand, if there are too many lags then the model will lose statistical power. The selection of the lag length is thus a tradeoff between goodness of fit of the model, and the complexity of the model. In selecting the lag length, we primarily use Akaikes Information Criterion (AIC) and select the lag length that minimize the estimated relative information loss. If AIC does not give us a well specified model, we use other information criteria such as the Bayesian Information Criterion (BIC) which penalizes the number of lags more strongly than AIC (Akaike, 1974 and Schwartz, 1978). In the rest of the paper, the number of lags are selected based on a similar procedure.

ADF tests are carried out on the spot price and 1- to 12-month futures contracts in levels and first-differences. The tests are carried out in three different versions, one for each type of random walk. The results are presented in table A2 in the appendix. In levels, no test rejects the presence of a unit root, indicating that the spot price and the 1- to 12-month futures prices are non-stationary processes. After first-differencing however, the null hypothesis of a unit root is rejected at the 1% level for all the variables in our sample. The results clearly indicate that the spot price and the 1- to 12-month futures prices are all non-stationary processes that are integrated of the first order. As they are all integrated to the same order, we can now proceed to test for cointegration.

5. Empirical Analysis

In this section, efficiency in the salmon futures market is investigated. First, we test whether spot and futures prices are tied together in a long-run equilibrium before we test the unbiasedness hypothesis. Next, we determine the futures prices ability to provide a price discovery function. In addition to price discovery, we investigate short-run causality between the spot and the futures prices. This is in order to support the results from the cointegration tests. Sensitivity analyses on the number of lags in the cointegration and unbiasedness tests are also included. The empirical analysis consists of five subsections. First, we present the framework we use for cointegration testing along with results. In the second subsection we test the joint hypothesis of market efficiency and the absence of risk premiums. Further, in the third subsection we provide results from the weak exogeneity and Granger causality tests. A sensitivity analysis of the cointegration and unbiasedness results is covered in subsection four. The fifth, and last subsection provide a summary of the results.

5.1 Cointegration

A premise for efficiency in a spot and futures market is that the price series are cointegrated (Beck, 1994). Cointegration analysis will thus provide a critical part of the answer to our research question and it also needs to be assessed before we can test the unbiasedness hypothesis. The cointegration tests we apply in this subsection requires the non-stationary price series to be integrated of the same order. From the unit root tests, we find that the spot price and the 1- to 12-month futures prices are all integrated of order 1, i.e. they are I(1).

We test for cointegration by applying a framework that was popularized by Gonzalo and Lee (1998). The framework consists of two different cointegration approaches. The first approach is a two-step procedure developed by Engle and Granger (1987), and the second and more commonly used approach is known as the Johansen (1991) test. Even though the Johansen test is generally assumed to be superior, the Engle-Granger procedure may be better suited for our purpose. That is, the Engle-Granger procedure is more relevant in risk management applications, as it is based on a criterion of minimum variance rather than the Johansen's criterion of maximum stationarity (Alexander, 1999).

Our motivation for applying both the Engle-Granger and the Johansen tests is built further on research by Gonzalo and Lee (1998). They demonstrate that misspecifications in underlying assumptions can compromise the outcome of either test. For instance, Granger and Swanson (1996) show that the ADF test tend to be inefficient in distinguishing near I(1) processes from true I(1) processes. If the ADF test then falsely indicates that a process is integrated of order one, then the Johansen test could wrongfully reject the null hypothesis of no cointegration. Gonzalo and Lee (1998) refer to this type of misspecification as a pitfall, and they argue that if there is a pitfall, it could be discovered by running both the Engle-Granger and the Johansen tests.

Next, in order to define cointegration, we look at our example with the spot price and any of the given futures price series. Both series are non-stationary I(1) processes, and they are cointegrated if there is a linear combination between them that is stationary, i.e. I(0). Cointegration holds if the variables in equation (5) can be written as follows:

$$S_t - \beta F_{t-T} = u_t \sim I(0) \tag{7}$$

Where β is the cointegration parameter and the residuals u_t represent the stationary linear combination of S_t and F_{t-T} that tie the variables together in a long-run equilibrium. In other words, if the spot and futures prices are cointegrated, then there exists linear combination between them that would cause the stochastic trends to cancel out in the long-run. However, as both the cointegration parameter and the residuals are unobserved, a standard unit root test for stationarity cannot be carried out to test for cointegration.

The Engle-Granger procedure is a workaround to this problem. First, the residuals are estimated by running a simple ordinary least squares (OLS) regression that corresponds to equation (5), where the estimated residuals u_t define the deviation from the potential long-run equilibrium between the variables S_t and F_{t-T}. Note that the selection of the dependent variable in this regression could influence the test results as the cointegration parameter would change. For our purpose, however, it is natural to have the spot as the dependent variable, hence equation (5). Next, we proceed to testing for stationarity in the estimated residuals by applying an ADF test, this time of the form:

$$\Delta u_t = \gamma u_{t-1} + \sum_{i=1}^{h} \delta_i \, \Delta u_{t-1} + \varepsilon_t \tag{8}$$

Note that the only difference in the structure between equation (6) and (8) is that there are no constant or trend term. This is because the estimated residuals represent the deviation from the long-run equilibrium and by construction has a mean of zero (Hayashi, 2000). Further, in the case where the null hypothesis of a unit root is rejected, the estimated residuals are stationary. According to the definition above, stationarity implies that the spot and futures prices are cointegrated. The null hypothesis is then a hypothesis of no cointegration.

Results from the Engle-Granger cointegration tests are provided on the left-hand-side of table 3. The null hypothesis of no cointegration is tested against the alternative hypothesis that there exist a linear combination between S_t and F_{t-T} that is stationary. The test statistics form the Engle-Granger cointegration tests are reported in the “t-value” column of table 3. The null hypothesis of non-stationarity, i.e. no cointegration is rejected in all the cases. All maturity lengths are significant at the 1% level except for the twelve-month contracts, which are significant at the 5% level. Note that the left-hand-side variables are estimated residuals, and the ordinary ADF distribution table provide critical values that are too low. Instead, we use the corrected Engle and Yoo (1987) critical values where the distribution of the critical values is shifted. The results from the Engle-Granger approach show that the spot and futures prices are tied together in a long-run equilibrium, which supports market efficiency.

The second approach we apply to test for cointegration is known as the Johansen test (Johansen, 1991). Following this procedure, we employ maximum likelihood estimation in a Vector Error Correction Model (VECM) of the form:

$$\Delta u_t = v + \Pi u_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta u_{t-i} + \varepsilon_t \qquad (9)$$

Where u_t are the unknown residuals from equation (7). The number of linear combinations are determined by examining the rank of the coefficient matrix Π. If Π has a rank (r) lower than the number of vectors (n), then there is a linear combination of S_t and F_{t-T} that make u_t a stationary process. As we apply the VECM in a bivariate framework, the two variables are cointegrated only if the rank of Π is equal to one (Johansen and Juselius, 1990). Note that a rank of zero imply no cointegration. There are two types of the Johansen test; the trace test and the maximum eigenvalue test. A description of the test statistics for both tests are provided in exhibit 2 in the appendix.

Table 3: Results of Engle-Granger and Johansen cointegration tests

	Engle-Granger		*Johansen*				
				r = 0		*r = 1*	
	Lags	t-value	Lags	λ_{trace}	λ_{max}	λ_{trace}	λ_{max}
$S\text{-}F_1$	3	-10.38***	7	44.59***	44.24***	0.35	0.35
$S\text{-}F_2$	3	-6.14***	11	23.14***	21.90***	1.24	1.24
$S\text{-}F_3$	3	-4.53***	7	18.32**	18.00**	0.31	0.31
$S\text{-}F_4$	3	-4.47***	6	16.92**	16.48**	0.44	0.44
$S\text{-}F_5$	3	-4.54***	15	31.71***	30.01***	1.71	1.71
$S\text{-}F_6$	4	-4.75***	15	30.46***	30.46***	0.00	0.00
$S\text{-}F_7$	4	-4.92***	9	31.74***	31.74***	0.00	0.00
$S\text{-}F_8$	2	-5.03***	16	23.44***	23.42***	0.02	0.02
$S\text{-}F_9$	3	-4.75***	11	23.27***	23.26***	0.01	0.01
$S\text{-}F_{10}$	3	-4.87***	5	23.43***	23.20**	0.23	0.23
$S\text{-}F_{11}$	3	-4.67***	14	27.44***	26.98***	0.46	0.46
$S\text{-}F_{12}$	3	-3.96**	17	17.35**	16.06**	1.28	1.28

Note: Test statistics for the Engle-Granger and the Johansen tests are provided. For the trace and max eigenvalue tests, results from the hypotheses of a rank r=0 and $r=1$ are provided. Number of lags are selected based on what gives a well specified model. Critical t-values for the Engle-Granger test are -4.00, -3.37, and -3.02. ***, **, and * mark significance at the 1%, 5%, and 10% level respectively. $S\text{-}F_T$ denote the relationship between the spot price and futures price with T months to delivery.

Results from the bivariate Johansen cointegration tests are provided on the right-hand-side of table 3. Both the trace and the maximum eigenvalue tests are applied. In the table, test statistics for the trace and the maximum eigenvalue tests correspond to λ_{trace} and λ_{max} respectively. We test the null hypothesis that the coefficient matrix Π from equation (9) has a rank $r=0$ against the alternative hypothesis $r=1$.

In both the trace and the maximum eigenvalue tests, we reject the null hypothesis of a rank $r=0$ for all the contract lengths. Thus, the null hypothesis of no cointegrating relationships is rejected for all contract lengths. We are, however, not able to reject the alternative hypothesis of one cointegrating relationship. Thus, the results from the Johansen tests indicate that the spot and futures prices are cointegrated, i.e. they are tied together in a long-run equilibrium, which supports market efficiency.

The findings from the Engle-Granger and the Johansen procedures are similar. The results strongly support the theory that the spot and futures prices are cointegrated and that there are no pitfalls as described by Gonzalo and Lee (1998).

5.2 Unbiasedness Hypothesis

The unbiasedness hypothesis represents the most central part of our research question, which is to test whether futures prices are unbiased predictors of subsequent spot prices. The models we apply to test the unbiasedness hypothesis builds individually on the Engle-Granger and the Johansen tests for cointegration. As we find cointegration between the spot and the 1- to 12-month futures prices, we proceed to test the unbiasedness hypothesis for all contract lengths.

The first model we apply to test the unbiasedness hypothesis builds on the Engle-Granger procedure. As we can conclude that the variables are cointegrated, the Granger Representation Theorem (Granger and Weiss, 1983) proves that the relationship can be represented in an Error Correction Model (ECM) of the form:

$$\Delta S_t = \alpha_1 + \underbrace{\lambda_1 u_{t-1}}_{Long-run} + \underbrace{\sum_{i=1}^{m} \theta_{11,i}\Delta S_{t-i} + \sum_{i=0}^{n} \theta_{12,i}\Delta F_{t-T-i}}_{Short-run} + \varepsilon_{1,t} \tag{10}$$

where we regress the first-difference of the spot price on lagged values of itself as well as the given futures contract. The long-run part of equation (10) represents the residuals obtained from equation (7). Thus, it represents the long-run equilibrium between the spot and the futures, and is known as the error-correction term. The transformed series in an ECM are stationary, so coefficient estimates are normally distributed and hypothesis testing on parameter restrictions is valid (Beck, 1994). Later, we will utilize ECMs in order to derive information about causality and the long-run error-correcting dynamics between the spot and the futures. In this section, however, we test the unbiasedness hypothesis by imposing restrictions on the ECM. Likelihood Ratio[8] (LR) statistics are computed for the restrictions imposed by market efficiency, i.e. $\alpha = 0$, and $\beta = 1$ from equation (5). This is a test if there is a violation of the unbiasedness hypothesis in the spot-futures relationship. Significant LR statistics are thus a rejection of the null hypothesis that futures prices are unbiased estimators of subsequent spot prices.

Results from the unbiasedness tests in the ECMs are provided on the left side of table 4. The joint restrictions that $\alpha = 0$ and $\beta = 1$ are not rejected for any of the contract lengths. Thus, we cannot reject the hypothesis that the futures 1- to 12-month futures prices are unbiased

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[8] A description of the Likelihood Ratio test is included in Exhibit 3 in the appendix.

Table 4: Results from tests of the unbiasedness hypothesis

	ECM		VECM	
	Lags	LR statistic	Lags	LR statistic
$\Delta S\text{-}\Delta F_1$	5	0.779[0.677]	7	3.820 [0.051]*
$\Delta S\text{-}\Delta F_2$	6	2.382[0.304]	11	0.172 [0.679]
$\Delta S\text{-}\Delta F_3$	6	2.935 [0.231]	7	0.001 [0.982]
$\Delta S\text{-}\Delta F_4$	5	3.133 [0.209]	6	0.181 [0.670]
$\Delta S\text{-}\Delta F_5$	9	2.019 [0.365]	15	6.472 [0.011]**
$\Delta S\text{-}\Delta F_6$	7	0.807 [0.668]	15	2.818 [0.093]*
$\Delta S\text{-}\Delta F_7$	8	0.340 [0.844]	9	15.931 [0.000]***
$\Delta S\text{-}\Delta F_8$	9	1.167 [0.558]	16	3.850 [0.049]**
$\Delta S\text{-}\Delta F_9$	3	1.563 [0.458]	11	2.323 [0.128]
$\Delta S\text{-}\Delta F_{10}$	2	1.031 [0.598]	5	0.035 [0.852]
$\Delta S\text{-}\Delta F_{11}$	16	0.109 [0.947]	14	4.033 [0.045]**
$\Delta S\text{-}\Delta F_{12}$	18	0.024 [0.988]	17	2.021 [0.155]

Note: Test statistics for the results of the unbiasedness hypothesis tests are provided. Joint restrictions imposed on the models are α=0 and β=1. Numbers in brackets are p-values. ***, **, and * mark significance at the 1%, 5%, and 10% level respectively. Number of lags are selected based on what gives a well specified model. $\Delta S\text{-}\Delta F_T$ denote the relationship between the spot and futures price with T months to delivery, where the spot price is the dependent variable.

estimators of subsequent spot prices or that there are no risk premiums for any of the contract lengths. As the unbiasedness hypothesis cannot be rejected, the findings from the ECM supports that the salmon futures market is efficient.

Following the VECM from the Johansen cointegration procedure, we can also test the unbiasedness hypothesis by imposing similar restrictions to the ones above ($a = 0$ and $\beta = 1$). The coefficient matrix Π is the long-run error correcting component of the VECM and can be decomposed such that $\Pi = \alpha\beta'$. Johansen (1991) show that equation (10) may be written as:

$$\begin{pmatrix} \Delta S_t \\ \Delta F_{t-T} \end{pmatrix} = \begin{pmatrix} v_1 \\ v_2 \end{pmatrix} + \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} (S_{t-1} - \alpha - \beta F_{t-T-1}) + \begin{pmatrix} \theta_{1j} & \vartheta_{1j} \\ \theta_{2j} & \vartheta_{2j} \end{pmatrix} \begin{pmatrix} \Delta S_{t-j} \\ \Delta F_{t-T-j} \end{pmatrix} + \begin{pmatrix} \varepsilon_{t1} \\ \varepsilon_{t2} \end{pmatrix} \quad (11)$$

The matrix $\alpha\beta'$ contains the cointegrating relationship and is the error-correcting part of the equation. By testing the joint significance of the restrictions $\alpha = 0$ and $\beta = 1$, we investigate whether the futures prices are unbiased estimators of the spot price. Also in this case, we utilize LR statistics to test these restrictions.

Results from the unbiasedness tests are provided on the right part of table 4. Contrary to the results from the ECM, the VECM results are somewhat mixed. The unbiasedness hypothesis is rejected for contracts with 5-, 7-, 8-, and 11-months to maturity at the 5% level. For the rest of the contracts, the results are similar to those of the ECM, and the unbiasedness hypotheses cannot be rejected. The contradicting results from the ECM and VECM could be caused by structural differences in the models. For instance, the ECM output depend on the selection of the dependent variable, while the VECM output do not. Another reason for the contradicting results may be due to the specification of lags. In subsection 5.4, the results from the ECM and the VECM are further analyzed on the basis of sensitivity to the number of lags included in the models. Note that the significance of the LR statistics for contracts with 5-, 7-, 8-, and 11-months to maturity could either be due to a risk premium, inefficiencies in the futures market, or both. Thus, a rejection of the unbiasedness hypothesis does not have to imply that markets are inefficient.

5.3 Price Discovery and Short-Run Causality

As the spot and futures prices on salmon are cointegrated, the relationship between the spot and futures can be investigated further. In this subsection we apply two tests that are intended to support the results of the analysis of our research question, as well as contribute to existing research on the salmon futures exchange. Both tests are conducted based on ECMs from equation (10), as well as ECMs where the futures prices are dependent variables. First we apply weak exogeneity testing in order to investigate the error-correction dynamics in the long-run equilibrium between the spot and the futures prices. This is a test of the salmon futures market's ability to provide a price discovery function and thus serve as a necessary risk management tool (Asche et al., 2016). The second test, known as the Granger causality test is concerned with short-run forecastability. In addition to provide information on the short-run causality between the spot and the futures prices, this test can either back up or dispute the results from the cointegration tests.

Weak exogeneity is used to determine which of the variables that are exogenous in the system of spot and futures prices. The test is applied as a simple t-test on the error-correction parameters λ_i in equation (10), and similarly, equation (12) where we set the futures price as the dependent variable:

$$\Delta F_{t-T} = \alpha_2 + \underbrace{\lambda_2 u_{t-1}}_{Long-run} + \underbrace{\sum_{i=1}^{m} \theta_{21,i} \Delta S_{t-i} + \sum_{i=0}^{n} \theta_{22,i} \Delta F_{t-T-i}}_{Short-run} + \varepsilon_{2,t} \qquad (12)$$

In equations (10) and (12), the error correcting parameters $\lambda_1 \leq 0 \leq \lambda_2$ define the adjustment speed of deviations from the long-run equilibrium. As an example, if the spot price is too high, it will be reduced by the deviation from the long-run equilibrium by the weight of the error-correcting parameter λ_1. The same would apply to λ_2 for the futures prices. If $\lambda_1 \neq 0$ and $\lambda_2 = 0$, then the spot price is error correcting on the futures price in the long run. This would imply that the futures price is leading the price discovery function, which is in line with the notion of a mature market (Yeboah et al., 2016). This is because innovations in the futures price should reflect changes in the expected future spot price, as previously discussed in subsection 3.1.

Results from the tests of weak exogeneity are provided in table 5 on the next page. The error correcting parameter λ_i is significantly different from zero only when the spot price is the left-hand side variable. This implies that there is a unidirectional long-run information flow between the spot price and the futures prices. Moreover, these findings indicate that whenever the system is out of equilibrium, it is the spot price that is converging towards the futures prices in the long-run. Thus, it is the futures prices that lead the price discovery function. Further, by looking at the value of the coefficients on the error correction term, we can get an idea of how quickly the spot price converges towards the futures price. As an example, we see that the λ_1 coefficient on the front-month contract is -0.62. As the error correction term is lagged one week, this result indicates that on average, 62% of the deviation from the long-run equilibrium will be corrected by the spot price each week. For contracts with longer time to delivery, the coefficients are much smaller and thus they converge towards equilibrium more slowly than the front-month contract. This effect is illustrated if we look back at the basis graphs in figure 8. Here we see that the front-month contract reaches equilibrium more frequently than the longer contracts. From the perspective of market efficiency, this makes sense as the spot price will have more time to adjust when time to maturity increase. To sum up the weak exogeneity test results; all the futures contracts with time to delivery of 1- to 12-months are leading the price discovery function. This is supports the findings of Yeboah et al. (2016), but contradicts the findings of Asche et al. (2016) in that the futures market on salmon is mature. Further, these results suggest that the futures market functions as a necessary risk management tool. This is not a test that prove efficiency in the salmon futures market, but

Table 5: Results of Weak Exogeneity and Granger Causality tests

$$\Delta S_t = \alpha_1 + \lambda_1 u_{t-1} + \sum_{i=1}^{m} \theta_{11,i} \Delta S_{t-i} + \sum_{i=0}^{n} \theta_{12,i} \Delta F_{t-T-i} + \varepsilon_{1,t}$$

$$\Delta F_{t-T} = \alpha_2 + \lambda_2 u_{t-1} + \sum_{i=0}^{m} \theta_{21,i} \Delta S_{t-i} + \sum_{i=1}^{n} \theta_{22,i} \Delta F_{t-T-i} + \varepsilon_{2,t}$$

Contract length	Dependent variable			Weak Exogeneity	Granger causality
1	ΔS_t	(5)	λ_1	-0.616***	[0.000]***
	ΔF_{t-T}	(4)	λ_2	0.063	[0.024]**
2	ΔS_t	(6)	λ_1	-0.191***	[0.000]***
	ΔF_{t-T}	(6)	λ_2	-0.026	[0.121]
3	ΔS_t	(6)	λ_1	-0.116**	[0.000]***
	ΔF_{t-T}	(10)	λ_2	0.003	[0.750]
4	ΔS_t	(5)	λ_1	-0.095**	[0.000]***
	ΔF_{t-T}	(11)	λ_2	0.013	[0.229]
5	ΔS_t	(9)	λ_1	-0.088**	[0.000]***
	ΔF_{t-T}	(14)	λ_2	0.023	[0.127]
6	ΔS_t	(7)	λ_1	-0.079**	[0.000]***
	ΔF_{t-T}	(7)	λ_2	0.014	[0.207]
7	ΔS_t	(8)	λ_1	-0.089**	[0.000]***
	ΔF_{t-T}	(14)	λ_2	0.022	[0.021]**
8	ΔS_t	(9)	λ_1	-0.107***	[0.017]**
	ΔF_{t-T}	(14)	λ_2	0.016	[0.007]***
9	ΔS_t	(3)	λ_1	-0.096**	[0.086]*
	ΔF_{t-T}	(15)	λ_2	0.010	[0.000]***
10	ΔS_t	(2)	λ_1	-0.131***	[0.019]**
	ΔF_{t-T}	(18)	λ_2	0.000	[0.000]***
11	ΔS_t	(16)	λ_1	-0.124**	[0.000]***
	ΔF_{t-T}	(4)	λ_2	-0.010	[0.003]***
12	ΔS_t	(18)	λ_1	-0.129**	[0.000]***
	ΔF_{t-T}	(5)	λ_2	-0.011	[0.001]***

Note: Parameters of the error correction terms are provided in the weak exogeneity column. Numbers in brackets are p-values from the Granger causality tests. Numbers in parentheses are the number of lags included in the ECM, and are selected based on what gives a well specified model. ***, **, and * mark significance at the 1%, 5%, and 10% level respectively.

because efficient markets require the futures market to serve as a risk management tool, it could be seen as an indication that the salmon futures market might be efficient. In that sense, the weak exogeneity test results support the results from the cointegration and unbiasedness tests.

Secondly, we apply the Granger causality test to investigate the direction of short-run causality between the spot and the futures prices. This test is applied by testing the joint significance of the parameters on the lagged values of the independent variable. As an example, the parameters on the lagged futures prices ($\theta_{12,i}$) in equation (10) must be statistically significant for the futures price to provide any information that affects the future spot price in the short-run. If this is the case, then the futures price is *Granger causing* the spot price. The Granger causality test is thus an F-test for the joint significance of $\theta_{12,i}$ $(i = 1, \dots, t-1)$. Similarly, to test if the spot price Granger causes the futures price, we apply an F-test for the joint significance of $\theta_{21,i}$ from equation (12). Note that both the strength and the direction of causality can change over time.

Results from the Granger causality tests are provided in the last column on table 5. The results suggest that short-run causality is bidirectional for futures with 1-, 7-, 8-, 10-, 11-, and 12-months to delivery. For the rest of the contracts, the short-run causality is unidirectional. For the 2-, 3-, 4-, 5-, and 6-month contracts, the futures prices are Granger causing the spot price. In the 9-month contracts, on the other hand, the spot price is Granger causing the futures price. The F-statistics are significant in at least one of the two equations for all of the contracts, thus there are either uni- or bidirectional short-run causality for all the 1- to 12-month futures contracts. These results are consistent with the cointegration results, as cointegration require short-run causality in at least one direction (Granger, 1988).

5.4 Sensitivity Analysis

In this section, we look at our main results, i.e. the cointegration and unbiasedness results, and investigate how sensitive the outputs are to the number of lags we include in the models. We do this by running the cointegration and unbiasedness tests on a variety of different lags in order to see if our results would change if the number of lags were selected differently.

In the results above, the number of lags were selected based on information criteria that minimize the relative information loss of the model, given that there was no autocorrelation in the residuals. First, we chose the model based on AIC. If there are still autocorrelation in the residuals, we choose the number of lags based on the BIC. If residual autocorrelation is still present, we add lags one-by-one until there is no autocorrelation left in the residuals. Note that different lag lengths from the ones selected in our models could potentially dilute the output. The sensitivity analyses should thus only be seen as an indication of the results' sensitivity to the number of lags selected. The distribution of the number of lags we include in the sensitivity

Table 6: Unbiasedness Hypothesis – Sensitivity to Lags

ECM				
	Wald statistic			
Number of lags	2	5	10	15
ΔS-ΔF 1	2.27	0.79	0.92	0.5
ΔS-ΔF 2	4.27	2.53	1.9	0.81
ΔS-ΔF 3	8.01**	4.78	3.85	2.09
ΔS-ΔF 4	9.05**	3.37	3.34	2.85
ΔS-ΔF 5	6.95**	2.7	2.22	2.21
ΔS-ΔF 6	4.14	20.43***	0.75	0.7
ΔS-ΔF 7	2.41	5.80*	0.3	0.1
ΔS-ΔF 8	1.94	15.42***	0.91	0.94
ΔS-ΔF 9	1.09	0.81	0.69	0.92
ΔS-ΔF 10	1.03	1.29	0.16	0.6
ΔS-ΔF 11	3.2	3.2	1.3	0.13
ΔS-ΔF 12	4.26	6.78**	4.57	0.06

VECM					
	LR statistic				
Number of lags	2	4	8	16	20
ΔS-ΔF 1	1.42	10.46***	4.87**	0.09	0.02
ΔS-ΔF 2	0.14	3.92**	0.35	0.72	1.92
ΔS-ΔF 3	2.5	2.46	0.00	2.23	3.13
ΔS-ΔF 4	2.5	2.23	0.46	2.35	6.20**
ΔS-ΔF 5	0.08	0.06	2.65	7.72***	15.14***
ΔS-ΔF 6	0	0.39	4.79**	3.44	4.91**
ΔS-ΔF 7	2.34	3.06	13.90***	8.52***	3.22
ΔS-ΔF 8	6.30**	9.45***	13.07**	3.85**	3.45
ΔS-ΔF 9	11.52***	8.32**	4.89**	3.02	2.53
ΔS-ΔF 10	0.45	0.89	0.14	0.2	0.78
ΔS-ΔF 11	1.38	2.74	3.33	4.45**	2.7
ΔS-ΔF 12	0.61	3.59	3.98*	1.83	3.57

Note: ***, **, and * mark significance at the 1%, 5%, and 10% level respectively. Sample period is from June 2006 – June 2016.

analysis is selected based on how much the optimal number of lags vary between the different contract lengths in the results.

First, we investigate how sensitive the results from the cointegration tests are to the number of lags included in the different models. The output form the sensitivity analysis of the cointegration results are presented in tables A3 and A4 in exhibit 5 in the appendix. None of the results from both the Engle-Granger and the Johansen tests seems to be sensitive to the number of lags selected. This supports the results from the cointegration section, and strengthens our conclusion that there is a long-run equilibrium between the spot price and the 1- to12-month futures contracts. The results from the unbiasedness hypothesis, however, turns out to be somewhat sensitive to the number of lags selected. Table 6 show that the output from the unbiasedness testing are sensitive to the number of lags both in the ECM and the VECM. Even though the unbiasedness results from the ECM in the previous section seems more unambiguous across the different contracts, these results are also sensitive to the number of lags. Even though it looks like the ECM is slightly less sensitive to the number of lags than the VECM, it is not clear from this sensitivity analysis which model we should prefer.

This analysis show that the cointegration results are not sensitive to the number of lags included in the models. The unbiasedness results, however, seems to be somewhat sensitive. On the one hand, this sensitivity analysis strengthens the findings that the spot and futures prices are cointegrated. On the other hand, one should be somewhat critical to the results from the unbiasedness hypothesis.

5.5 Summary of the Results

Our results support that the spot price and 1- to 12-month futures prices on salmon are tied together in a long-run equilibrium, which indicates that the salmon futures market is efficient. The cointegration results are strengthened by both the sensitivity analysis and the Granger causality tests. Results from the unbiasedness hypothesis are somewhat mixed. In the ECM, unbiasedness holds for all the futures contracts, but in the VECM, unbiasedness does not hold for the 5-, 7-, 8-, and 11-month contract lengths. The contradicting results from the unbiasedness testing may be caused by structural differences in the models or the selection of lags. Output from the sensitivity analysis indicates that we should be somewhat critical to the results from the unbiasedness hypothesis. However, a rejection of the unbiasedness hypothesis does not have to imply that markets are inefficient, as a rejection could be caused by a risk premium, i.e. an unbalanced hedging demand. Overall, our results indicate that the salmon futures market is efficient. Further, the results from the weak exogeneity tests imply that the futures prices are leading the price discovery function, which indicates that the futures market is mature and serve as a necessary tool for risk management. The weak exogeneity test results supports the findings of Yeboah et al. (2016), but contradicts the findings of Asche et al. (2016).

6. Discussion

As the spot and futures prices are cointegrated and the unbiasedness hypothesis holds for most contract lengths, our findings support market efficiency. Further, we find that futures prices are able to provide a price discovery function for expected spot prices and thus satisfies as a risk management tool. In the following, we first discuss our results in the light of earlier research. Then we discuss possible limitations of our study from the perspective of our data set and choice of empirical strategy, and present possible alternative methods. Finally, we discuss how our study contributes to the existing literature.

6.1 Discussion of Results

Despite that our findings have both similarities and differences from earlier studies in terms of methodology and results, findings in earlier studies and our findings should be seen as complementing each other. In this subsection, we discuss similarities and differences between our results and earlier studies done by Asche et al. (2016) and Yeboah et al. (2016).

The cointegration tests in this paper show that spot and futures prices are cointegrated for futures contracts with 1-12 months to delivery. Asche et al. (2016) investigate contract lengths up to 6 months and find that spot and futures prices are cointegrated for all contract lengths. Yeboah et al. (2016) consider contract lengths up to 12-months and finds that spot and futures prices are cointegrated except for the 8-, 10-, and 11- month contracts. In terms of unbiasedness, Yeboah et al. (2016) do not consider contracts that are not cointegrated, and show that unbiasedness holds for all remaining contracts except for the 12-month contract. Similarly, Asche et al. (2016) finds that unbiasedness holds for all of the contract lengths in their study. From our Engle-Granger test results, we find that unbiasedness holds for all contracts. However, the Johansen procedure leads to rejection of unbiasedness for the 5-, 7-, 8-, and 11-month contracts.

There are different findings on whether the futures market for salmon provides a price discovery function as well. Asche et al. (2016) finds that only the spot prices are exogenous in the systems for futures up to 6 months to maturity. Based on these findings, Asche et al. (2016) concludes that the futures market on salmon is immature since it does not provide a price discovery function. Regarding price discovery, Yeboah et al. (2016) do not consider the 7-month contracts or the contracts that are not cointegrated with the spot prices. They find that the spot price is exogenous in the models with 1-, 2-, and 6-months to maturity, while the futures prices are exogenous in the models 3-, 4-, 5-, 9-, and 12-month models. Yeboah et al. (2016) states that these findings are consistent with the characteristics of a maturing futures market, and that the salmon futures market is mature or near matured. In our study, we find that futures prices are exogenous in the system for all contract lengths. This suggests that the futures market for salmon is able to provide a price discovery function. Based on our findings, we conclude that the futures market for salmon is mature in the sense of functioning as a risk management tool.

Granger causality tests are conducted in order to investigate short-run causality and test whether Granger causality is consistent with the cointegration results. Yeboah et al. (2016) applied a similar method to infer the short-run causality, but based on a VECM. We find the relationship to be bidirectional for all contract lengths except for the models with 2-, 3-, 4-, 5-, 6, and 9-month contracts. For the contract lengths with a unidirectional relationship, futures prices Granger-cause spot prices, except for the model with the 9-month contract. Yeboah et al. (2016) only find significant Granger causality in the contracts lengths between 1 to 6 months. They find a unidirectional relationship for all contract lengths between 1 to 6 months, except for the 4-month contracts. For the models with a unidirectional relationship, they find that spot prices Granger causes futures prices.

As discussed in this subsection, there are several similarities and differences in our study compared to earlier studies. Like previous research, we find evidence that support market efficiency. Spot and futures prices are cointegrated and futures prices are, for most contract lengths, unbiased predictors of future spot prices. However, our tests show stronger evidence than previous research on the salmon futures market´s ability to provide a price discovery function. The differences between previous studies and our study could stem from differences in methodological approaches as well as the length and adjustments to the data set. Previous research by Asche et al. (2016) and Yeboah et al. (2016) apply Johansen´s cointegration procedure to test for cointegration and unbiasedness, while we employ both the Engle-Granger and the Johansen procedure to test for cointegration and unbiasedness. Next, Asche et al. (2016) and Yeboah et al. (2016) perform weak exogeneity tests on the VECMs, while we perform weak exogeneity tests on the ECMs. Regarding the data, we use a longer data set of weekly observations between 2006 – 2016, while Asche et al. (2016) and Yeboah et al. (2016) use monthly observations in the period 2006 – 2014 and 2006 – 2015 respectively. Note that the overlapping observations futures prices discussed in subsection 4.2, might lead to different adjustment procedures. Lastly, we do not apply seasonal adjustments to the data set similarly to Asche et al. (2016), while Yeboah et al. (2016) adjusts for seasonality.

6.2 Limitations of the Data Set

Using weekly data might give rise to some issues. Floating holidays like Thanksgiving, Easter, Ramadan and Chinese New Year change every year and might disrupt the weekly coefficients. Further, sample frequency can affect the cointegration analysis. When the frequency of the data becomes high, the distributions become non-normal as indicated in our descriptive statistics. Deviations from normality can affect the cointegration tests (Cheung and Lai, 1994).

As discussed earlier, seasonality is an essential characteristic of salmon aquaculture. We have not adjusted for seasonality in the spot and futures prices because excluding seasonal components in the price path could impair our assessment of market efficiency. This is primarily due to our choice of using weekly data. Not all of the years in our sample have 52 weeks, as there are 53 weeks in 2009 and 2015. Seasonality can thus not be modeled by a set of dummy variables (Harvey et al., 1997). On the other hand, not adjusting for seasonality could lead us to discover relationships that are only caused by seasonal effects.

Fish Pool´s overlapping series of futures prices are also something that might cause problems. As mentioned earlier, the maturity date of the futures contracts is set to the second Friday in the following month. Trading the contract into the delivery period has the consequence of incorporating observations of the realized spot in the same period. This creates overlapping observations which we have adjusted for. However, adjusting for overlapping observations by replacing rollover dates might not reflect the actual trading dynamics at Fish Pool.

6.3 Alternative Models and Limitations of Methods

There are some limitations that can be identified in our methodological approach. First, Engle-Granger and Johansen cointegration procedures are only applicable if the time series are integrated of the same order. In our paper, we perform ADF tests for unit roots in order to determine the order of integration for our price series. Our test output shows that both spot and futures prices were integrated of order one. However, Dickey and Pantula (1987) show that the ADF test can lead to incorrect conclusions if there are more than one unit root, because the ADF test is based on the assumption of a single unit root. Instead, they suggest the Dickey

Pantula test to determine the order of integration. This test is performed by testing for three unit roots, two unit roots, then one unit root. If the spot and futures prices are shown to be integrated of different orders, one can implement the Bounds test for cointegration developed by Pesaran et al. (2001).

Next, the Engle-Granger and Johansen cointegration techniques assume a linear relationship between spot and futures and a constant cointegrating vector. These tests do not account for possible shifts in the cointegrating vector that arise from economical changes. Rejections of the unbiasedness hypothesis in our VECMs might be a consequence of the model not correctly reflecting real-life dynamics, such as non-linearity and changes in the underlying variables. If there is a non-linear relationship, Lin and Granger (2004) provide a residual-based framework for testing non-linear cointegration. Next, Gregory and Hansen (1996) and Hatemi (2008) introduced tests that take account for changes in the cointegrating vectors. Gregory and Hansen (1996) introduced tests with one unknown structural break and Hatemi (2008) introduced tests with two unknown structural breaks.

One could consider other models and approaches to investigate the cointegration relationship between spot and futures prices. In addition to the Engle-Granger and Johansen cointegration procedures, methods developed by Pillip Oularis (1990) are commonly used. Ssekuma (2011) show that all these three cointegration methods does not give consistent output and might give reason to add the methods developed by Phillip Oularis. As with the Engle-Granger procedure, Phillip Oularis only estimate a single cointegrating relationship and is applicable for testing cointegration between spot and futures prices.

6.4 Implications of the Study

Our study finds evidence that support the efficient market hypothesis. Using both the Engle-Granger and the Johansen cointegration procedures, we find that spot and futures prices are cointegrated and that the unbiasedness hypothesis holds for most contract lengths. Even though spot and futures prices deviate from each other in the short-run, they are tied together in a long-run equilibrium. For most of the contract lengths in our sample, futures prices provide unbiased predictions and are thus the best forecast of subsequent spot prices. This suggests that efficiency holds in the futures market for salmon and thus there are no significant risk premiums. Since the futures market for salmon provides a price discovery function for expected spot prices, the market is mature in the sense of functioning as a risk management tool.

To the best of our knowledge, no one have assessed efficiency and unbiasedness in the salmon futures market by applying Engle-Granger cointegration techniques on weekly data. Even though there are some differences, our study supports previous studies done by Asche et al. (2016) and Yeboah et al. (2016), and the results should be seen as complementing each other. Differences in the results might stem from differences in methodological approaches including: cointegration procedures, data length, data frequency, and treatment of seasonality.

Based on earlier studies and our findings, the futures contracts at Fish Pool seems to function as a risk management tool. Since futures prices have proven to be unbiased predictors of future spot prices, commercial participants in the salmon farming industry can use futures contracts as a tool to reduce uncertainty and provide predictability. Traders and risk managers should incorporate this evidence into their analyses. Even though our analysis supports market efficiency, we cannot conclude that speculating in this futures market is a wasted effort. This is something that could be considered for further studies. It could be interesting to test for cointegration between futures contracts with different time horizons like the study on crude oil futures done by Kawamoto and Hamori (2010), and then incorporate the deviations from the long-run equilibrium in a trading strategy and test if it would yield excess returns.

7. Conclusion

This thesis aims to analyze the research question: Is the futures market for salmon efficient? In order to assess efficiency in the salmon futures market, we test for cointegration between spot and futures prices and test whether futures prices are the best forecast of subsequent spot prices. In futures markets literature, this is referred to as the unbiasedness hypothesis and represents joint tests of efficiency and the absence of risk premiums. Since the spot and futures prices on salmon are found to be non-stationary, we apply cointegration procedures in order to answer our research question. Moreover, our thesis investigates the salmon futures market´s ability to provide a price discovery function with weak exogeneity tests.

The data used in this thesis is publicly available, and we consider weekly spot and futures prices with 1- to 12-months to maturity in the period June 2006 – June 2016. We find that spot and futures prices are cointegrated for all contract lengths. The unbiasedness hypothesis holds for all contract lengths when using the Engle-Granger procedures, but is rejected for the 5-, 7-, 8-, and 11-, month contract lengths when the Johansen approach is applied.

This thesis contributes to prior conflicting research by providing additional methodological frameworks that strengthen the cointegration results. We find stronger evidence that futures prices are exogenous in all systems and thus provide a price discovery function. Further, sensitivity analyses indicate that we should be somewhat critical to results from the unbiasedness hypothesis.

The results support efficiency in the futures market for salmon. Spot and futures prices are tied together in a long-run equilibrium and futures prices are for most contract lengths unbiased predictors of subsequent spot prices. In the cases where the unbiasedness hypothesis is rejected, market efficiency could still hold if the hedging demand is unbalanced. Further, the futures market for salmon has the ability to provide a price discovery function and is thus mature in the sense of functioning as a risk management tool.

The salmon farming industry has been growing rapidly over the last three decades and has a huge potential for future growth. As the price of farmed salmon is volatile and heavily influenced by political and environmental conditions, salmon farmers need to manage their risk exposure. This paper suggests that salmon futures contracts can provide predictability and reduce uncertainty for hedgers and commercial participants in the salmon farming industry.

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9. Appendix

Exhibit 1: Descriptive Statistics

Figure A1: Weekly futures prices for 1-, to 12-month time to maturity, June 2006 – June 2016

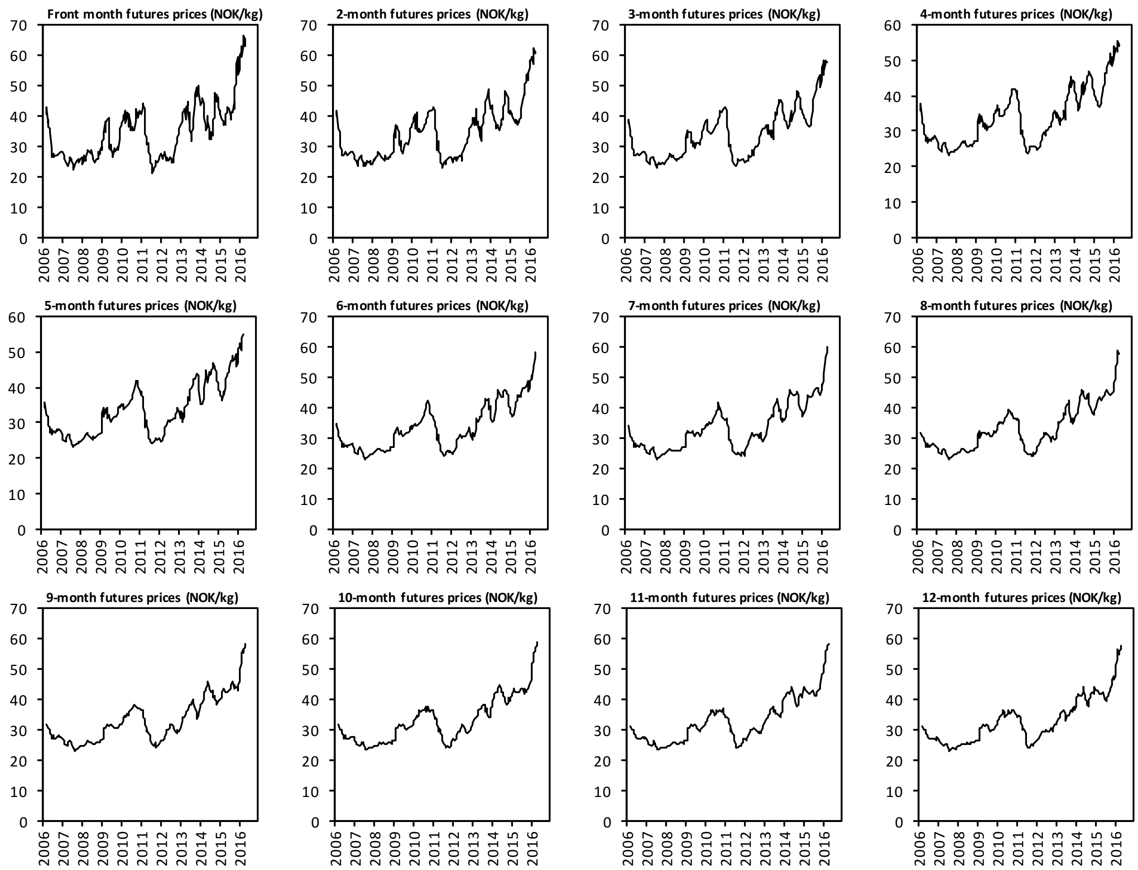

Table A1: Descriptive statistics of weekly price returns between June 2006-June 2016

	Mean	Median	Min.	Max.	St. dev.	Coef. of variation	Skewness	Excess kurtosis	Normality (Chi-squared)
Spot price	0.32%	0.00%	-16.95%	17.96%	6.08%	18.962	0.152	-0.074	2.244
Futures prices									
1 Month	0.18%	0.22%	-15.61%	19.53%	3.71%	20.432	0.147	4.038	167.59***
2 Month	0.13%	0.08%	-15.34%	10.18%	2.83%	22.350	-0.485	3.270	98.824***
3 Month	0.10%	0.04%	-9.00%	9.49%	2.26%	21.981	-0.183	3.175	116.55***
4 Month	0.11%	0.05%	-11.00%	7.80%	2.18%	20.644	-0.458	3.458	110.74***
5 Month	0.11%	0.04%	-8.50%	7.72%	1.99%	18.012	-0.232	3.617	138.51***
6 Month	0.13%	0.10%	-10.57%	7.88%	1.92%	14.754	-0.560	5.042	181.87***
7 Month	0.15%	0.08%	-8.21%	7.59%	1.76%	11.854	-0.208	4.035	164.19***
8 Month	0.14%	0.09%	-8.67%	7.81%	1.70%	11.736	-0.298	4.428	180.44***
9 Month	0.14%	0.14%	-6.71%	8.74%	1.52%	10.793	0.106	4.169	177.02***
10 Month	0.14%	0.16%	-6.45%	7.06%	1.43%	9.871	-0.179	3.274	122.18***
11 Month	0.14%	0.14%	-5.56%	7.30%	1.41%	10.175	0.208	4.751	207.33***
12 Month	0.14%	0.15%	-6.97%	6.61%	1.44%	10.358	-0.227	4.054	164.02***

Note: Extreme observations of week 52 2010 and week 1 2011 are dropped from the sample. Significance at the 1% level is denoted by ***. Number of observations are 520.

Figure A2: Basis of spot price and 1- to 12-month futures prices, June 2006-June 2016

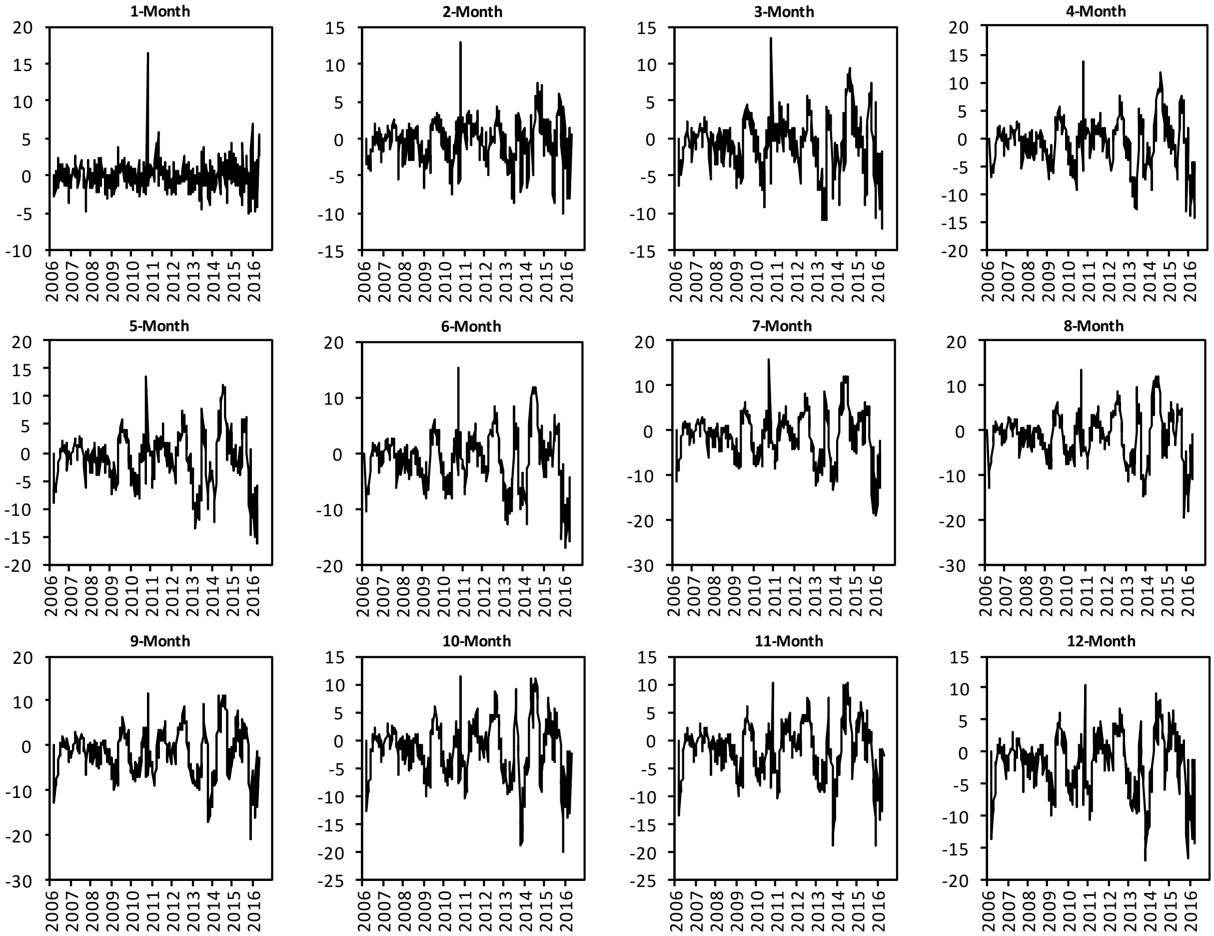

Exhibit 2: Unit Root Testing

Table A2: Unit root tests on weekly prices in levels and first-differences

$\Delta y_t = \alpha + \beta_t + \gamma y_{t-1} + \sum_{i=1}^{h} \delta_i \Delta y_{t-i} + \varepsilon_t$

	Levels			First-Differences		
	$\alpha = 0, \beta = 0$	$\alpha = 0, \beta \neq 0$	$\alpha \neq 0, \beta \neq 0$	$\alpha = 0, \beta = 0$	$\alpha = 0, \beta \neq 0$	$\alpha \neq 0, \beta \neq 0$
S	0.805(3)	-0.294(3)	-2.041(3)	-22.3(0)***	-22.3(0)***	-22.3(0)***
F_1	0.876(5)	-0.454(5)	-1.969(5)	-13.8(2)***	-18.2(0)***	-18.3(0)***
F_2	0.336(5)	-1.233(5)	-2.347(5)	-7.3(4)***	-7.3(4)***	-16.4(1)***
F_3	0.743(6)	-0.623(6)	-2.321(6)	-7.4(5)***	-7.4(5)***	-7.6(5)***
F_4	0.677(5)	-0.467(4)	-2.273(4)	-8.3(3)***	-8.3(3)***	-8.5(3)***
F_5	1.291(7)	0.186(7)	-1.533(8)	-7.8(3)***	-6.6(6)***	-6.8(6)***
F_6	0.506(4)	-1.359(4)	-3.062(4)	-7.0(3)***	-7.1(3)***	-6.9(7)***
F_7	1.041(4)	-0.233(4)	-2.033(4)	-8.2(3)***	-8.3(3)***	-8.4(3)***
F_8	1.268(5)	0.054(5)	-1.696(5)	-7.3(4)***	-8.5(3)***	-7.5(4)***
F_9	1.662(4)	0.750(4)	-1.051(4)	-8.2(3)***	-8.4(3)***	-8.6(3)***
F_{10}	1.816(5)	0.781(5)	-1.803(8)	-5.3(7)***	-5.4(7)***	-8.1(4)***
F_{11}	1.149(4)	-0.250(4)	-1.906(4)	-7.7(3)***	-7.8(3)***	-7.8(3)***
F_{12}	0.969(6)	-0.432(6)	-2.221(6)	-7.4(5)***	-7.5(5)***	-7.6(5)***

Note: t-values for the null hypothesis of a unit root from the ADF-tests are reported. *** marks significance at the 1% level. Numbers in parentheses are the number of lags included, and is selected by AIC. Tests in a pure random walk, a random walk with a drift, and a random walk with a drift and a trend are denoted by $\alpha = 0, \beta = 0$; $\alpha = 0, \beta \neq 0$; and $\alpha \neq 0, \beta \neq 0$ respectively.

Exhibit 3: Test Statistics for the Johansen Cointegration Method

The test statistics used for testing the hypothesis that there are K stationary linear combinations are based on the trace and maximum eigenvalue tests (Johansen, 1991), and are expressed as

$$\lambda_{trace} = -T \sum_{i=r+1}^{n} \ln\left(1 - \hat{\lambda}_r\right) \quad \text{(A1)}$$

$$H_0: K = 0$$

$$H_1: K > 0$$

$$\lambda_{max} = -T \ln\left(1 - \hat{\lambda}_{r+1}\right) \quad \text{(A2)}$$

$$H_0: K = 0$$

$$H_1: K = 1$$

where T is the sample size and $\hat{\lambda}_i$ is the ith largest canonical correlation[9] of Δu_t with u_{t-1} after correcting for lagged differences. We select the lag length in equation (11) such that there is no autocorrelation in the residuals ε_t.

In the trace test, the null hypothesis of r cointegrated vectors are tested against the alternative hypothesis of n cointegrated vectors. The maximum eigenvalue test, on the other hand, tests the null hypothesis of *r* cointegrating vectors against the alternative hypothesis of *r+1* cointegrating vectors.

[9] If we have two variables *S* and *F*, and there are correlations among the variables, then canonical-correlation analysis will find linear combinations of *S* and *F* that maximizes the correlation.

Exhibit 4: The Likelihood Ratio Test

The likelihood ratio (LR) test is used to compare the goodness of fit between two models. It is done by estimating and comparing two models, one of which (restricted model) is a special case of the other (unrestricted model). If $\widehat{L_R}(\widehat{\theta_R})$ is the maximum value of likelihood of the data in the restricted model and $\widehat{L_{UR}}(\widehat{\theta_{UR}})$ is the maximum value of the likelihood in unrestricted model, the LR test statistics is computed as:

$$\lambda = \frac{\widehat{L_R}(\widehat{\theta_R})}{\widehat{L_{UR}}(\widehat{\theta_{UR}})} \quad \text{(A3)}$$

The LR test statistics is used to test single or multiple constraints and is distributed by:

$$-2\ln(\lambda) = -2(\ln[\widehat{L_{UR}}(\widehat{\theta_{UR}})] - \ln[\widehat{L_R}(\widehat{\theta_R})]) \sim X^2 \quad \text{(A4)}$$

Degrees of freedom are equal to the number of parameters that are constrained. The null hypothesis that the restricted model fits the data better is rejected if X^2 is larger than than a Chi-Square percentile given the degrees of freedom, where the percentile corresponds to the confidence level.

Exhibit 5: Sensitivity Analysis

Table A3: Sensitivity to number of lags Engle-Granger cointegration

	Lags				
Number of lags	2	3	4	5	6
S-F_1	-13.37***	-10.38***	-9.02***	-7.84***	-7.18***
S-F_2	-7.11***	-6.14***	-5.90***	-5.38***	-5.32***
S-F_3	-5.77***	-4.53***	-4.59***	-4.64***	-4.51***
S-F_4	-5.18***	-4.47***	-4.12***	-4.08***	-4.30***
S-F_5	-5.14***	-4.54***	-4.66***	-4.36***	-4.47***
S-F_6	-4.85***	-4.44***	-4.75***	-4.75***	-4.75***
S-F_7	-4.70***	-4.50***	-4.92***	-5.03***	-5.23***
S-F_8	-5.03***	-4.55***	-4.80***	-5.04***	-5.37***
S-F_9	-5.38***	-4.75***	-5.00***	-4.95***	-5.04***
S-F_{10}	-5.53***	-4.87***	-4.79***	-4.78***	-4.83***
S-F_{11}	-5.49***	-4.67***	-4.69***	-4.61***	-4.67***
S-F_{12}	-4.72***	-3.96**	-4.09***	-4.08***	-4.18***

Note: ***, **, and * denote significance at the 1%, 5%, and 10% level respectively.

Table A4: Sensitivity to number of lags Johansen cointegration

	λ_{trace} *(r=0)*				λ_{trace} *(r=1)*			
Number of lags	5	10	15	20	5	10	15	20
S-F_1	71.55***	36.70***	23.61***	18.42**	0.04	1.49	0.29	0.02
S-F_2	44.80***	26.83***	22.55***	18.07**	1.46	1.22	0.46	0.24
S-F_3	19.54**	27.54***	22.50***	19.39**	0.44	0.71	0.02	0.00
S-F_4	18.67**	18.54**	23.02***	25.71***	0.40	0.05	0.03	0.22
S-F_5	30.43***	22.54***	31.71***	40.60***	0.26	0.56	1.71	0.81
S-F_6	36.72***	22.30***	30.46***	32.31***	0.04	0.00	0.00	0.10
S-F_7	37.64***	27.67***	33.31***	32.63***	2.23	0.00	0.02	0.14
S-F_8	30.34***	29.31***	27.50***	24.64***	2.47	0.14	0.09	0.07
S-F_9	31.39***	23.70***	25.82***	22.44***	2.42	0.02	0.00	0.03
S-F_{10}	30.43***	25.01***	24.31***	18.83**	0.26	0.16	0.07	0.01
S-F_{11}	31.58***	32.06***	24.06***	15.60**	0.79	2.43	0.79	0.54
S-F_{12}	36.93***	42.81***	25.39***	16.97**	2.18	3.10	1.09	0.97

Note: ***, **, and * denote significance at the 1%, 5%, and 10% level respectively.