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The Nordic electricity market: The risk premium in mid-term futures contracts

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Preface

This Master's thesis, titled *The Nordic electricity market: The risk premium in mid-term futures contracts*, was written as our final work at the Norwegian University of Science and Technology (NTNU), Department of Industrial Engineering and Technology Management, within the field of Financial Engineering, more specifically, Empirical Finance. This is the result of one intense semester spent in the complex world of electricity markets. The barrier of entry in understanding the market dynamics was tough, and entailed us to use every bit of experience, patience and knowledge we have gained throughout our years as students.

There are several people we would like to direct our gratitude to. Special thanks goes to our supervisor and professor Sjur Westgaard. During interesting discussions we gained a deeper understanding of the electricity market dynamics than we would have obtained on our own. We would also like to thank Erik Haugom, Peter Molnar, Martin Frigaard and Knut Strømnes for valuable input during the process. The authors alone are responsible for all content and any errors.

Trondheim, May 30, 2014

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Abstract

This thesis investigates weekly futures contracts in the Nordic power market, covering the time period from January 2004 to December 2013. The futures contracts investigated have holding periods between one and four weeks. We investigate three different pricing alternatives for the futures contracts and how they influence the risk premium: the closing price on the last day of trading, the closing price on the day with highest traded volume and the average closing price during the final week of trading. Regression on the unbiased forward rate hypothesis (UFH) provides evidence of futures prices in the final week of trading being downward biased predictors of future spot prices. Rolling and recursive estimation of the coefficients in the UFH are provided to investigate behaviour over time. Futures prices have evolved into becoming downward biased predictors of future spot price during the most recent years. However, more data is needed to draw conclusions. Further investigation confirms presence of a significant risk premium. We find positive and significant premiums during fall and winter for all contract maturities. Also, a positive and significant premium is found during summer for contracts with holding periods of three and four weeks. We approximate the expected risk premium in the final week of trading by the realised risk premium, i.e. the difference between the closing futures price on the last day of trading and the average spot price in the delivery week. Several factors expected to have an influence on the risk premium are analysed and we propose their possible effects. An OLS regression model is formulated, intending to describe the variation in the expected risk premium from information available to all market participants at the time of trading. Potential pitfalls relevant for OLS regression are discussed and accounted for, if possible. The average spot price and deviation in inflow are found to have a significant positive influence on the risk premium. The same applies to the variance of the spot price for the contract closest to delivery. We also find weak evidence of a seasonal component describing the variation in the premium.

Sammendrag

Denne oppgaven tar for seg futures-kontrakter i det nordiske kraftmarkedet. Kontraktene vi ser på har leveringsperiode på én uke, og mellom én og fire uker til levering. Vi undersøker kontrakt- og spotpriser i perioden januar 2004 til desember 2013. Vi ser på tre ulike alternativer for futures-pris og hvordan disse påvirker risikopremien: sluttpris på kontrakt siste handelsdag, sluttpris den dagen høyest volum er handlet siste handelsuke, og gjennomsnittlig sluttpris siste handelsuke. Regresjon på "Unbiased forward rate hypothesis" (UFH) finner bevis for at kontraktsprisene gir skjeve prediksjoner på fremtidig spotpris. Vi bruker rullerende og rekursiv regresjon for å se på utviklingen av koeffisientene i UFH over tid. Dette viser at futuresprisene de siste årene har utviklet seg til å gi skjeve prediksjoner på fremtidig spotpris, og at de overestimerer denne. Lite data gjør det vanskelig å konkludere ut i fra dette. Videre undersøkelser bekrefter at det er en signifikant risikopremie i det nordiske kraftmarkedet. Premien er positiv og signifikant for alle kontrakter levert om høsten og vinteren. Dette gjelder også kontrakter om sommeren med tre og fire uker til levering. Forventet risikopremie siste handelsuke approksimeres med realisert risikopremie, det vil si differansen mellom futures-pris siste handelsdag og gjennomsnittlig spotpris i leveringsuken. Faktorer som er forventet å ha en innvirkning på risikopremien er analysert og vi foreslår hvilken innvirkning hver av disse vil ha. En regresjonsmodell formuleres med hensikt å forklare variasjon i forventet risikopremie ut i fra informasjon kjent i handelsuken. Vi tar hensyn til ulike utfordringer knyttet til OLS-regresjon. Vi finner at gjennomsnittlig spotpris siste handelsuke og avvik i tilsig har en signifikant positiv innvirkning på forventet risikopremie. Varians i spotpris har en positiv innvirkning på risikopremien til kontrakten nærmest levering. Vi finner også svake bevis på at en sesongkomponent kan beskrive varisjonen i risikopremien.

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Chapter 1

Introduction

The Nordic power market has experienced several deregulations since it was liberalized in 1991. The financial market has opened up for risk management and speculation in a highly volatile physical market. Power producers want to hedge their physical delivery, while retailers want to hedge their sales obligations. The market also includes speculators willing to unload risk from producers and retailers, and bet against movement in the spot price. Futures and forward contracts are the main derivatives in the financial market. Understanding the relationship between spot and futures prices is crucial for the participants in the market. Proof of the existence of a risk premium in the Nordic market is provided in several studies. We analyse weekly futures with holding periods between one and four weeks. Our data set consists of 10 years of data, spanning from 1 January 2004 to 31 December 2013, representing 522 observations. The main reason for this choice of data is to avoid the Nordic supply shock period during winter 2002/2003, which led to a rise in spot price and risk premium level (Lucia and Torró, 2011).

The goal of this thesis is to formulate a regression model describing variation in the expected risk premium in the Nordic electricity market, using fundamental factors observable in the final week of trading of the futures contracts. We make the popular assumption that the forecast error in future spot prices is zero on average, i.e. we assume the expected spot to equal the realised spot. Thus, we approximate the expected premium using the realised premium[1]. This allows us to compare our results with previous studies, e.g. Botterud et al. (2010), Gjolberg and Brattested (2011), Lucia and Torró (2011) and Weron and Zator (2013). However, to be able to describe the premium from an ex-ante perspective, we

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[1] The realised premium is the difference between the futures price in the trading week and the spot price at delivery.

make a slightly different assumption than in previous studies. We apply information available at the time of trading, and assume the current market conditions to influence hedging demand and expectations of future spot prices. All market participants compute the expected spot price using different models, and the assumption that all participants have the same forecasts is strict, and may lead to biased estimates. Thus, approximating forecasts using realised values as Botterud et al. (2010) precludes an ex-ante interpretation of the risk premium.

The thesis makes contributions to the literature on the risk premium in Nord Pool. We analyze the most recent data on the futures prices with holding periods between one and four weeks. The prices of all contracts are collected at three different points in time, which enables us to investigate how the timing of hedging influences the premium. We apply the unbiased forward rate hypothesis to investigate whether there is evidence of a systematic risk premium in the futures prices, and if the prices are unbiased predictors of spot price. The results of Haugom and Ullrich (2012) from the US market motivate us to perform a similar analysis in the Nordic market. We apply rolling windows and a recursive extending sample to investigate the time-variation in the relationship between spot and futures prices. The regression model is formulated in light of the model given in Weron and Zator (2013), and takes potential pitfalls of an OLS linear regression into account, in addition to including a variable for produced wind power.

The remainder of this thesis is outlined as follows: Section 2 discusses the relationship between spot and futures prices, and defines the risk premium. Section 3 gives a review of previous studies on relevant and related topics. Section 4 gives an introduction to the physical and financial Nordic electricity market, with emphasis on futures contracts. Section 5 provides a preliminary data analysis on spot prices, futures prices, risk premium and physical conditions describing the Nordic power market. Also, the unbiased forward rate hypothesis is tested on the futures prices using rolling and recursive windows. Section 6 presents the regression model used to describe the variation in the ex-post risk premium. Section 7 provides an empirical analysis of the data sample and reports the results from the regression. Finally, section 8 concludes with a summary of the main results and findings.

Chapter 2

The relationship between futures and spot prices

This chapter provides a brief introduction to the theory of futures pricing for commodities, with emphasis on electricity. Definitions and assumptions applied in the further analysis are presented and discussed.

2.1 The theory of storage

Fama and French (1987) elaborate on two different models for futures pricing of commodities. The first model is known as the theory of storage, while the second model explains the futures price as the sum of the expected spot price and a risk premium. The theory of storage applied to futures pricing considers the basis, i.e. the difference between spot and futures prices at a specified point in time, and is based on the argument of no arbitrage between the spot and futures market. The basis can therefore be explained as interest foregone by storing a commodity, storage costs and convenience yield on inventory, i.e. the benefit of holding inventory[2]. The convenience yield can be represented by water stored in reservoirs. Stored water may be used by producers to meet unexpected electricity demand and the producers can take advantage of the accompanied high electricity prices. In the same setting, the storage cost is interpreted as the cost of water overflow. As consumers are not able to store electricity, the common conclusion is that cost-of-carry relationships between spot and futures prices do not exist.

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[2] Interest foregone and storage costs increase the basis as these favor holding a futures contract instead of the commodity, while it is reduced by the convenience yield, which favors holding the commodity.

Thus, the second model is the most applied when pricing futures contracts on electricity.

2.2 Futures price as expected spot price and a risk premium

In the second model, Fama and French (1987) explain the basis as the sum of the expected risk premium and the expected change in the spot price,

$$F_{t,t+T} - S_t = RP^{ea}_{t+T} + E_t[S_{t+T} - S_t]. \tag{2.1}$$

$F_{t,t+T}$ is the time t futures price with holding period T and delivery in $t+T$, and S_t is the spot price at time t. RP^{ea}_{t+T} is the expected, ex-ante, risk premium, i.e. $RP^{ea}_{t+T} = F_{t,t+T} - E_t[S_{t+T}]$. This approach of describing the ex-ante risk premium has its origin in theory proposed by Keynes (1930). The basis gives us the bias of the futures price as a prediction of the time $t+T$ spot price. Hence, it is also referred to as the futures bias.

Previous studies do not clarify whether the risk premium is seen from the producer's or retailer's point of view. Our interpretation indicates that a positive premium implies that the producers earn a premium when selling futures contracts. We use the definition of the realised, or ex-post, risk premium in our thesis,

$$RP^{ep}_{t+T} = F_{t,t+T} - S_{t+T}, \tag{2.2}$$

where S_{t+T} is the average spot price in the delivery week $t+T$ and $F_{t,t+T}$ is the futures price. A choice has to be made on which futures price to use in the risk premium representation. We will consider three alternatives: the closing futures price on the last trading day of the final trading week, t, the average closing futures price during week t and the closing futures price on the day with highest traded volume during week t. The different alternatives will be assessed in Section 5.2 and 5.3.

The ex-post risk premium is equal to the ex-ante risk premium plus the deviation in realised future spot price from expected future spot price,

$$RP^{ep}_{t+T} = RP^{ea}_{t+T} + E_t[S_{t+T}] - S_{t+T}. \tag{2.3}$$

We also investigate the log ex-post risk premium, LRP^{ep}_{t+T}, given as

$$LRP^{ep}_{t+T} = lnF_{t,t+T} - lnS_{t+T}. \tag{2.4}$$

Previous studies do analyses on the basis, e.g. Gjolberg and Johnsen (2001), Lucia and Torró (2011) and Redl and Bunn (2013). As seen from Equation (2.1), the basis gives information on the expected risk premium, in addition to the expected change in the spot price. The ex-ante risk premium is investigated in Bessembinder and Lemmon (2002), but the expected spot price at delivery is hard to measure and results depend on the model applied. As a consequence, studies may not be comparable. When the realised risk premium is used, as in e.g. Botterud et al. (2010), Lucia and Torró (2011), Gjolberg and Brattested (2011), Haugom and Ullrich (2012) and Weron and Zator (2013), it is assumed that the difference between the expected spot price and realised spot price acts as noise. The realised premium will then equal the sum of the expected risk premium and a noise term,

$$F_{t,t+T} - S_{t+T} = RP^{ea}_{t+T} + \epsilon_{t+T}. \tag{2.5}$$

The noise term is assumed to be white noise, which is uncorrelated to information known at time t. It corresponds to the forecast error, being zero on average. Hence, the ex-ante risk premium can be approximated by the ex-post premium.

Chapter 3

Literature review

This chapter provides a review of relevant literature on the risk premium. The main focus is the Nordic electricity market, but interesting and applicable findings from other markets are also included. Studies having direct importance to our analysis are given greater attention in the review. We conclude the chapter with remarks on where our analysis fits in.

3.1 Studies on the risk premium

The electricity spot price, futures prices and several forms of relationships between these are described and modeled in a growing number of research papers. Data sets of varying size, spanning in time from 1993 to 2012 are used in the analyses. Different electricity markets are studied, e.g. the Pennsylvania-New Jersey-Maryland Interconnection (PJM), the European Energy Exchange (EEX) and Nord Pool. As deregulated power markets have existed for a relatively short time period, an extensive part of the research is conducted using few observations. Contract standards have changed since the introduction of the first financial contracts, and changes in the power producers' cost structure[3], make much of earlier research outdated.

Botterud et al. (2002) were among the first to provide empirical evidence of a risk premium in the Nordic market. Their data set consists of observations between 1996 and 2001, for weekly and seasonal contracts. They find significant and positive risk premiums, and also reveal that the magnitude increases with the length of the holding period. This is later confirmed by e.g. Gjolberg and Johnsen

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[3] See Botterud et al. (2010) for further details.

(2001), Mork (2006), Weron (2008) and Redl et al. (2009). Redl et al. (2009) conclude that this may be caused by supply and demand shocks in the period between trading and delivery, while not ruling out market inefficiency. Botterud et al. (2002) try to explain the premium by looking at deviations from normal in the reservoir levels. They plot observations of spot and futures prices and reservoir levels, and use visual inspection to identify a relationship. Botterud et al. (2010) inspect this relationship further in their study. By studying weekly futures with one to six weeks to delivery, Botterud et al. (2010) find futures prices between 1996 and 2006 to be above the spot price on average. OLS regression on the risk premium gives significant coefficients for reservoir level and average spot price in the trading week, and deviations in inflow and consumption from a long-term average in the period between trading and delivery. Botterud et al. (2010) argue that the theory of storage applies to a hydro-dominated market, due to the possibility of water storage in reservoirs. They find evidence that both storage cost and risk premium increase with the reservoir level, as there is a higher probability of water overflow. Stan (2012) reaches the same conclusion when studying the basis in the Nordic market in the period 1998-2009. Weron and Zator (2013) study a longer price series and find limited support for the theory of storage in their data.

Stan (2012) finds a cointegrated relationship between futures and spot prices in the long run, making futures prices able to forecast spot prices. Huisman and Kilic (2012) conclude similarly. They find that futures prices in an electricity market dominated by hydro power, or other fuels which are not perfectly storable, incorporates information about expected changes in the spot price and are able to forecast spot prices.

Bessembinder and Lemmon (2002) study the PJM and CALPX[4] market, using data sets for the periods 1997-2000 and 1998-2000, respectively. They develop an equilibrium model for electricity forward prices based on the assumptions of risk averse demand and supply sides, and that electricity cannot be stored. They argue that the forward premium is a function of the variance and skewness of the spot price, having a negative and positive influence on the premium, respectively. Bessembinder and Lemmon (2002) focus on the risk averse behaviour of the market participants when explaining the size of the risk premium. They find that the premium correspond to the net hedging cost in the market. Botterud et al. (2010) criticize the model and argue that it cannot be transferred to a hydro-dominated market, because of its simplifying assumptions. The model assumes no speculators, a fixed retail price for the load serving entities and that each producer has a

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[4] California Power Exchange.

fixed convex cost function.

Longstaff and Wang (2004) analyze the forward premium in the PJM electricity market in the period 2000-2002, using hourly spot and day-ahead forward prices. They find significant positive forward premium in the data. The premium is found to be related to the volatility of unexpected changes in three risk factors: consumption, spot prices and total revenues for the system. Their analysis provides support for the model presented by Bessembinder and Lemmon. Haugom and Ullrich (2012) repeat the study of Longstaff and Wang (2004) for a longer data set in the PJM market, analyzing day-ahead futures between 2000 and 2010. They find that the premium is still positive and significant, even though it has decreased in the more recent period. Their results indicate that the short-term forward prices are unbiased predictors of the future spot price. Further, they find that including additional publicly known information gives little improvement in the forecast of spot prices. They conclude that (1) market efficiency has increased, (2) the risk premium has decreased or (3) both, as the agents have gained experience. In addition, they find no support for the Bessembinder and Lemmon (B&L) model in the data.

Lucia and Schwartz (2002) find evidence of a predictable pattern in Nordic spot prices in the period 1993-1999. Visual inspection of futures term structures reveals a seasonal pattern. Weron and Misiorek (2008) use air temperature as an exogenous variable to describe the spot price and find that seasonal fluctuations in water levels have impact on the influence of the temperature variable. Low reservoir levels make the temperature variable less important, and a system load variable is most likely a stronger driver in these situations.

Lucia and Torró (2011) repeat the study of Botterud et al. (2010), looking at weekly futures with time to delivery between one and four weeks in the period from 1998 to 2007. They analyze the whole sample period, and a sample excluding the supply shock during winter 2002/2003[5], in addition to study the pre- and post-shock data. They confirm the risk premium to be positive on average, but find variation throughout the year; being zero in the summer and spring, and positive in the autumn and winter. Their analysis provides evidence that futures prices were mainly based on risk considerations, in addition to support the Bessembinder and Lemmon model, prior to the supply shock. However, they find sound evidence

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[5] In 2002, water reservoirs were well above normal during the summer. Thus, power producers started to draw down water reservoirs to make room for the autumn precipitation. The expectations on water inflow failed and the reservoir levels fell far below its normal values, making the spot prices increase to extreme levels. This is known as the Nordic supply shock.

that circumstances changed after the shock; the spot price and risk premium increased and the seasonal pattern faded away. Mork (2006), on the other hand, found no evidence for changes in the risk premium level for block and monthly contracts in the year following the supply shock[6].

Gjolberg and Brattested (2011) name the difference between the futures and spot prices a forecast error. They argue that if this forecast error is a risk premium, it should follow a seasonal pattern based on risk expectations. Analyzing variations in the forecast error by season over the period from 1995 to 2008, they find that season in general explains little. Still, they find the error to be greatest in the winter months (December, January and February) and mid-summer (June and July), when analyzing the forecast error by calendar month. Gjolberg and Brattested (2011) reach the conclusion of highly significant forecast errors, and their magnitude can hardly be explained from the level of risk alone. They point out that the premium may be explained simply as a peso problem[7], although this is not likely.

Veka (2013) uses a sample of daily observations between 2006 and 2012. The paper is an extension of the work by Gjolberg and Brattested (2011). It is found that the mean risk premium is higher than the median risk premium for weekly and monthly contracts, also when the most extreme observations are removed. Veka (2013) suggests that there may exist structural or informal barriers preventing outside speculators from entering the financial market. The premium shows no clear seasonal pattern, confirming the results of Gjolberg and Brattested (2011) and Botterud et al. (2010). Veka (2013) also investigates if perceived risk influences the risk premium. He finds that the premium may include some element of risk, represented by dependence with the implied volatility of contracts derived from the options market[8], and some element of systematic risk, represented by the dependence with returns in the equity market[9]. This is valid for contracts of longer delivery periods. Still, it is hard to explain the magnitude of the premium

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[6] Block contracts were offered until the start of 2003. One block amounts to four weeks. These were later replaced by monthly contracts. A small data sample in the period after the supply shock results in non-significant risk premiums. More data is needed to make further conclusions. It is possible that the supply shock made a larger impact on the long-term contracts.

[7] Market participants strongly believe that the spot price will rise dramatically as a reaction to cold weather or a dry year, and hedge against the expected high prices. If this event finally occurs after some time, the market has been ”wrong” for a longer period. However, it is not irrational to hedge against events that might take place in the future.

[8] The options are at-the-money, and have quarterly contracts as underlying assets. The implied volatility is interpreted as the forward-looking risk the participants are facing at the time of trading.

[9] Three different benchmark indices are used: OMX Copenhagen 20, DAX and FTSE 100.

from these findings.

Cartea and Villaplana (2008) model the Nord Pool electricity spot price in the period 2003-2006, using variables for generation capacity, approximated by hydro reservoir level, and consumption. The model makes it possible to express the expected spot price and forward contract price. Thus, the ex-ante forward premium is given. It is found that the variable for consumption strongly follows a seasonal pattern. The volatility in consumption has influence on the forward premium. High volatility results in a higher forward premium for monthly contracts. During less volatile demand periods, producers want to hedge against unexpected price falls caused by positive shocks in generation capacity. Thus, contracts are offered at a discount.

Weron and Zator (2013) apply linear regression to model the ex-post risk premium for weekly futures contracts traded on Nord Pool in the period 1998-2010. Emphasis is put on potential pitfalls applying to linear regression. They include variables observable in the trading week only: deviation in reservoir level, long-term median reservoir level and deviation in consumption and inflow[10]. To assess the validity of the Bessembinder and Lemmon (2002) model, variance and skewness of the spot price are included. Two models for the ex-post premium are formulated; one including the spot price, the other not. As a high variance is observed in the residuals, few variables turn out to be significant. To account for the low model fit and correlated residuals, GARCH residuals are included in the regression. The coefficient associated with deviation in reservoir level is not always significant, but negative[11]. This is consistent with the results of Lucia and Torró (2011)[12], but opposite to what Botterud et al. (2010) found. Similarly, the deviation in consumption and inflow usually have negative and positive impact, respectively. The model does not provide evidence for the model of Bessembinder and Lemmon (2002), although it is not rejected. The results give only limited support for the storage cost theory in describing the convenience yield, as proposed by Botterud et al. (2010). Weron and Zator (2013) cannot give a clear indication on whether the risk premium corresponds to the price of risk, or if is partly

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[10] The trading week deviations are used as forecasts of future deviations in consumption and inflow. Weron and Zator (2013) believe this makes the model valid for ex-ante estimation of the risk premium.

[11] The sign is positive according to the definition of Weron and Zator (2013), which transforms to a negative sign using our definition of the premium.

[12] Weron and Zator (2013) have generalized the results of Lucia and Torró (2011) to make this conclusion.

due to market inefficiencies[13]. Still, the risk premium can to a certain degree be described from fundamental risk factors, which may give indications of the risk premium incorporating the price of risk.

Gjolberg and Johnsen (2001), Redl and Bunn (2013) and Gjolberg and Brattested (2011) argue that the size of the risk premium may give indication of market power among producers. Gjolberg and Johnsen (2001) analyze monthly futures and spot prices between 1995 and 2001, and argue that the Nordic market is not informationally efficient. They find futures prices and the basis to be biased and poor predictors of future spot prices, and show that including easily available information improves the forecasts of the spot price. Gjolberg and Johnsen (2001) point out a possible abuse of market power from the producers' side, but have no statistical evidence to support this. However, Hjalmarsson (2000) performs a study of market power in Nord Pool, using weekly Nord Pool spot price data in the period 1996-1999. He is not able to reject the null hypothesis of perfect competition. Fridolfsson and Tangerås (2009) find no evidence of market power in their empirical studies of the Nordic power exchange, when comparing the output price of electricity with the marginal cost of producing it as a short-term competitive benchmark. Even though there exists some evidence of power producers taking advantage of constraints in transmission capacity, an intervention in the Nordic electricity market cannot be properly argued for. Amundsen and Bergman (2006) reason that use of market power in a hydropower dominated market is hard to detect, and convincing evidence is lacking. They claim that, among other factors, the flexibility in choice of power suppliers, and the ”public service attitude”[14] in the power companies, have reduced the possibility of market power abuse.

Benth et al. (2008) investigate relationships between the risk premium and the behaviour and risk preferences of the market participants in the German electricity market. They find that in cases with high probability of price spikes and during short-term horizons, power producers have the largest market power as consumers are more eager to hedge their obligations. This results in consumers paying a high premium. On the other hand, the market risk premium for contracts with delivery further into the future trades at a lower premium, and often at a discount. Hence, the producers' market power and risk premium is a decreasing function of maturity for monthly, quarterly and yearly forward contracts.

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[13] See Christensen et al. (2007), Gjolberg and Brattested (2011) and Kristiansen (2007) for more details.

[14] The Nordic power industry is committed to deliver a public service, although market competition has existed for several years (Amundsen and Bergman, 2006).

Redl and Bunn (2013) focus on monthly front EEX futures in the period 2003-2010 [15], and models for the ex-post risk premium in the base and peak load cases are formulated. Emphasis is put on the ex-post risk premium being a consistent estimator of the ex-ante risk premium. Redl and Bunn (2013) point out that it is hard to make a distinction between the part of the ex-post premium representing the price of risk, and the part corresponding to a forecast error of the spot price. Hence, they make a distinction between the variables observable in the trading week, and the variables incorporating possible shock effects on the spot price between the trading and delivery week. In addition, myopic expectations among the market participants are assumed [16]. Redl and Bunn (2013) try to include variables of temperature and temperature shocks on the risk premium, but do not find these to be significant.

Kristiansen (2007) evaluates the efficiency of seasonal forward contract prices. Prices for contracts in the period 2003-2004 are found to be inefficient, as the price of a portfolio consisting of the time-weighted average of monthly forward prices deviates too much from the seasonal contract prices. It is argued that the deviation from the synthetic prices may be caused by market immaturity. However, more years of data is needed to make any further conclusions. Wimschulte (2010) does a similar analysis of monthly contracts and portfolios consisting of daily and weekly contracts at Nord Pool in the period 2003-2008. The forward price is on average higher than the portfolio price, but he does not find the difference to be significant. A large part of the difference can be linked to transaction costs. Thus, he finds indications of Nord Pool being an efficient market regarding pricing of contracts.

Our thesis will contribute to the literature on the relationship between spot and futures prices on mid-term contracts in the Nordic market. The literature on weekly futures is growing, but there are still areas for further research. The advantage of studying weekly contracts is the sufficient sample size, allowing for consistent and reliable analyses. The analysis of Haugom and Ullrich (2012) on US day-ahead prices is interesting, but the results cannot be directly transferred to other markets or contract standards. The unbiased forward rate hypothesis on futures prices is analysed in previous papers, but the use of rolling windows and recursive extending samples to investigate the time variation in the relationship

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[15] Monthly futures are chosen as these are the most liquid contracts (Redl and Bunn, 2013) and the contracts for which most price data is available. Front contracts are also subject to the smallest forecast errors.

[16] Myopic expectations entail that market participants are affected by historic and current events influencing the spot prices, which results in a certain behaviour among the participants, leading to changes in the risk premium.

between spot and futures prices, is not performed in the Nordic market. Several papers investigate the expected risk premium using the realised premium as an approximation, e.g. Weron and Zator (2013) and Botterud et al. (2010). We want to extend the study performed by Weron and Zator (2013) by using a more recent data sample (2004-2013) and by including a new explanatory variables for the Nordic market. We believe the introduction of a variable for wind power produced will be able to capture some of the effects of the increased use of this energy source. Also, we believe assumptions for some of the explanatory variables made by Botterud et al. (2010) may preclude an ex-ante interpretation of the risk premium. We will perform an OLS regression with a slightly different focus, i.e. we assume the information at the time of trading to have an influence on variation in the expected risk premium.

Chapter 4

The Nordic Electricity Market

This chapter provides information on the physical and financial Nordic electricity market. The chapter ends with a discussion on the current trading status in the financial market.

4.1 Background

The Energy Act of 1990 aimed at restructuring and liberalization of the Norwegian power market. It went into effect 1 January 1991. Market-based principles were now introduced on both production and consumption side, opening up for competition. The goal was to increase efficiency and lower consumer prices. Through liberalization of the electricity market, risk was transferred from consumers to producers. Now, consumers were given freedom in the choice of power supplier. The other Nordic countries went through similar deregulations in the following years. Sweden became part of the Norwegian market place in 1996, and Statnett Marked AS was renamed Nord Pool ASA. This opened up for trade across the national border. Finland joined in 1998, followed by Denmark in 2000. The result was the first international power exchange (Nord Pool Spot, 2013c). Today, the Nordic electricity market consists of several independent entities. These are producers, network owners, system operators, consumers and traders.

4.2 The physical market

The power market providing physical delivery is organized through Nord Pool Spot[17]. Nord Pool Spot consists of a day-ahead market, Elspot, and an intraday market, Elbas[18]. In 2013, 84% of all physical power consumption in the Nordic and Baltic states was traded on Elspot. The rest was bilaterally traded. 370 participants from 20 different countries trade directly in the physical market through Nord Pool Spot (Nord Pool Spot, 2014a). Total power generated and consumed in the Nordic countries in 2013, amounted to 379 TWh and 380 TWh respectively (402 TWh and 387 TWh in 2012 (Nord Pool Spot, 2014c)).

At Elspot, power sellers and buyers submit bids for next-day delivery. The system price is set through a double auction, and is the equilibrium price found from where the aggregated supply and demand curves cross, assuming no transmission restrictions[19] (Nord Pool Spot, 2013a). The prices calculated are hourly prices for the following day.

As market participants' predictions of supply or demand might be uncertain, intraday physical trade is possible through Elbas. Elbas makes it possible to trade power until one hour prior to delivery. Buyers and sellers can therefore adjust power sold or bought to meet their obligations. Consequently, power balance will be maintained (Nord Pool Spot, 2013b).

In periods when high demand makes the power production approach the capacity limit, power plants having higher marginal costs generate the requested power. This makes the supply curve convex, and spikes in the electricity price may occur. Similar to Bessembinder and Lemmon (2002), Cartea and Villaplana (2008) apply empirical observations to confirm electricity prices to be increasing in demand and decreasing in supply. Economic activity and weather conditions are found to be the key influences on demand.

The demand curve for electricity is inelastic, which often is the case for necessities. Small changes in supply may lead to drastic changes in the price of power. However, this has little effect on the consumed amount, at least in the short run. Amundsen and Bergman (2006) state that the dominating position of

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[17] In 2010, the physical power trade also opened up for Estonia. All Baltic countries were included after Latvia joined in 2013 (Nord Pool Spot, 2014b).

[18] Nord Pool spot also operates N2EX, a UK power trading market offering day-ahead and intraday trading (Nord Pool Spot, 2014a).

[19] The area prices are decided in the same way, with total supply and demand in the given area. Thus, these prices will differ between geographical areas. Power flows from the low price areas to the high price areas until capacity limits are reached. This is seen as a shift in either the supply or demand curve.

hydro power in Nord Pool, and the extensive use of electricity for heating purposes, make weather conditions a key influence on the spot price. As a result, supply and demand shocks often appear, which is reflected in the volatile spot price.

4.3 The financial market

The market place for sale of financial derivatives on Nord Pool was previously known as Eltermin. After the market was acquired by NASDAQ OMX in 2010, it was renamed NASDAQ OMX Commodities Europe. Trading of cash-settled contracts has been offered since the beginning of 1995. These are used by producers, retailers and end-users as risk management tools, and by traders who speculate in future spot prices. The derivatives comprise futures, forwards, EPADs[20] and options with forward contracts as underlying assets. All of the financial contracts use the system price as reference price.

In the beginning, futures contracts had a time horizon of up to 3 years. After the introduction of cash settled forward contracts in 1997, the time horizon was reduced to 8-12 months. More changes to the structure of the futures contracts were made in 2003. Since the liquidity was highest for the contracts closest to delivery, the horizon was further decreased to 8-9 weeks, and monthly and quarterly contracts were introduced (NASDAQ OMX, 2013c). In 2006 all contracts were quoted in Euro. The intuition behind the decision was to make cross-border trade easier, in addition to the contracts becoming more standardized compared to similar products on other exchanges (NASDAQ OMX, 2013a). Structural changes in contract standards must be considered when analyzing price data (Veka, 2013). Today, futures contracts are available for the next 3-9 days and the next 6 weeks (NASDAQ OMX, 2013c). Forward contracts are available for the next 6 months, the remaining quarters of the current year and quarters of 2 rolling years, and 10 future years (NASDAQ OMX, 2013b). The liquidity is low for contracts with long holding periods. In case of zero trades, the bid and ask prices are set by market makers, and there will not be a closing price corresponding to the last trade as for the other traded contracts. In this case, the closing price is calculated as the average of the bid and ask price (NASDAQ OMX, 2013c).

The differing preferences for futures and forward contracts are partly due to different financial settlements. For futures contracts, daily mark-to-market settle-

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[20] Electricity Price Area Differentials, formerly known as Contracts for Difference, CfDs.

ment is performed in the period until delivery, in addition to spot reference cash settlement in the delivery period. This requires a margin account, and the longer time until delivery, the larger amount of cash is needed. This partly explains the low liquidity for futures contracts with longer holding periods. The mark-to-market settlement adds or subtracts money from the margin account, depending on positive or negative day-to-day changes in the market price of the contract. In the final settlement of the futures contract, the difference between the final closing price of the contract and the system price in the delivery period is credited or debited the contract owner. Forward contracts entail daily margin call in the delivery period only[21]. Since the payoff of the contracts is calculated as the difference between the contract price and the system price over a period of time, futures and forwards contracts act as swaps (Benth and Koekebakker, 2008). Sanda et al. (2013) show that yearly contracts dominate the traded derivatives among producers.

4.4 Trading status in the financial market

The development in volume and value turnover for all financially traded power contracts from 1998 to 2012 is shown in Figure 4.1. In the period 2000-2001, several non-Nordic speculators, e.g. Enron, entered and exited the financial market. This can be seen as a large increase and decrease in volume turnover. Mork (2006) conducts tests to indicate if this event reduced the risk premium. Considering contracts with 60 days to delivery, a significant positive premium is found prior to the entrance of non-Nordic speculators, while premiums are not significantly different from zero in the subsequent periods. One possible explanation is a small sample including large movements in the spot price, which are difficult to predict. Also, several other speculators continued to speculate in the market, even though non-Nordic speculators left. A trend analysis is performed to reveal possible trends as the contracts approach maturity. This analysis indicates that premiums became negative in the period following the withdrawal of speculators.

When investigating the traded volume turnover for weekly futures contracts, cf. Figure 4.2, we notice a sharp decrease in traded volume from 2005 to 2006. Although not reported in the figure, the traded volume in 2004 corresponded to 12.1 million MWh. Most of the decrease can be related to private end users enter-

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[21] The mark-to-market amount from the trading period is accumulated, but not realised until the settlement in the delivery period. The spot reference cash settlement is performed in the same way as for futures contracts. A margin account is required at the due date of the trading period.

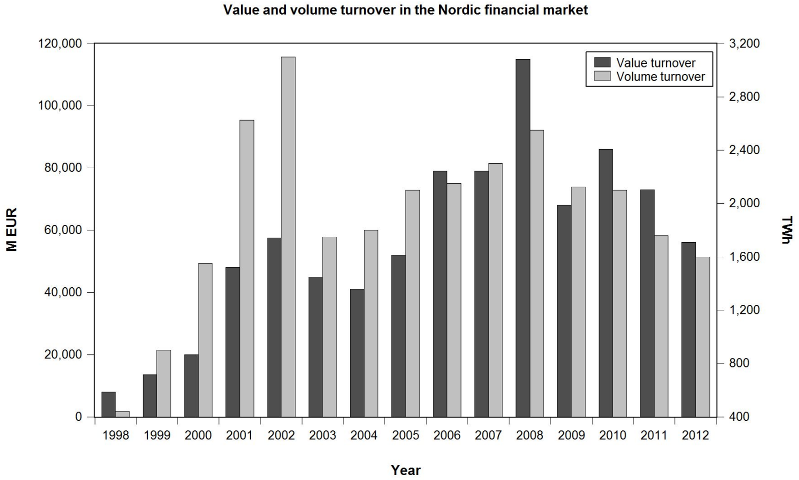

Figure 4.1: The figure shows the value and volume turnover for the Nordic financial market from 1998 to 2012. The value turnover is measured on the left axis and given in million euros [M EUR], while the volume turnover is measured on the right axis and given in TWh.

ing spot price contracts instead of variable price contracts in the period following the supply shock. Variable price contracts force retailers to notify end users of increases in the power price at least 14 days in advance. Hence, the short-term hedging demand among retailers diminished. From 2007, the traded volume has stayed relatively stable slightly below 100,000 MWh. Botterud et al. (2010) confirm the volume decrease in traded short-term contracts, and find the entrance of several new financial traders whose demand were in long-term contracts, i.e. monthly, quarterly and yearly contracts, to be the most likely reason. We also believe the introduction of monthly and quarterly contracts[22] further reduced the demand for weekly and day-ahead contracts.

Carr (2012) confirms that the liquidity has decreased the last couple of years, but emphasizes that the fall in liquidity is due to a reduction in speculative players in the market following the financial crisis. Typically, traders are imposed constraints when it comes to risky investments. A large presence of renewable energy sources makes the power prices volatile, and this is reflected in the power derivatives prices, making them behave as risky investments. For instance, wind energy phased into the grid can give electricity prices close to zero in windy peri-

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[22] The first monthly contract was delivered in 2003, while the first quarterly contract, replacing the seasonal contract, was delivered in 2006.

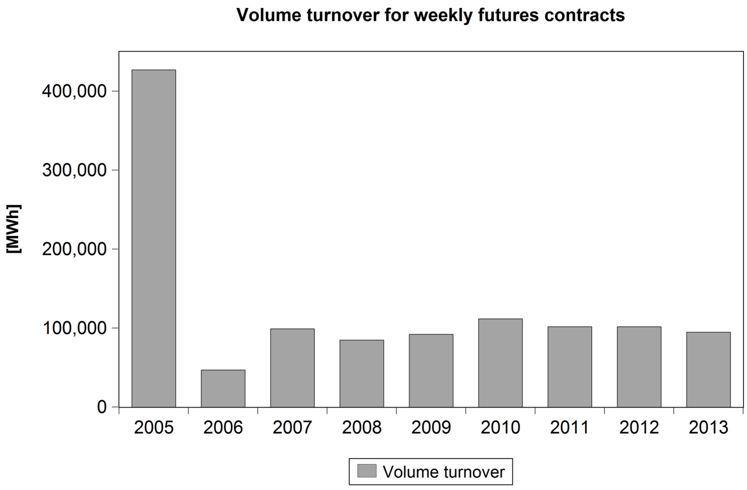

Figure 4.2: The figure shows the traded volume for Nordic weekly power futures in the period 2005-2013. The data is given in MWh.

ods (Carr, 2012). This volatility effect has become particularly evident as markets have become closer integrated. Grid improvements are necessary to reduce this volatility and price differences between areas.

To relate these findings closer to producers, traders and retailers behaviour, we use Fleten et al. (2013) description of possible scenarios resulting from differing hedging demands. Power producers wanting to hedge their future production, can either have natural buyers, e.g. retail companies, or financial traders as counterparts. Retailers tend to wait until their obligations are known before they enter the derivatives market. Hence, financial traders are often the counterpart of the hedging, and these typically require a risk premium. When the retailers enter the market to hedge their physical sales obligations, the financial traders are trading counterparts, as no physical delivery commitments give them incentives to hold the contracts in the delivery period. If the total demand for contracts is equal amongst producers and retailers, the risk premium should diminish. However, the second scenario involves that the demand for hedging is larger amongst retailers. The financial traders will then be net short, and require a premium to hold the price risk. The decrease in number of financial traders indicates that the hedging demand between producers and retailers, to a higher degree, will decide the risk premium. The increased use of renewable energy gives risk averse producers incentives to hedge, as the probability of sudden drops in electricity prices increase. An overweight of producers wanting to hedge their production should make the risk premium diminish, and it can also become negative.

Seasons may also partly describe the risk premium and trading patterns. During winter, an overweight of risk averse retailers want to hedge their obligations, in this case paying a premium. Conversely, low electricity consumption during summer make producers wanting to hedge their production, paying a premium.

Chapter 5

Preliminary Analysis

This chapter provides a detailed preliminary analysis of spot price, futures prices, risk premium and physical conditions in the Nordic market. The analysis presents three different pricing methods for the futures price, i.e. the price is observed at three different points in time. The impact of differing futures prices on the premium is investigated. Also, an analysis similar to Haugom and Ullrich (2012) is performed to investigate a possible unbiasedness in futures prices.

5.1 Spot price

The daily spot or system price data is collected from the information provider Montel, cf. Table A1 in the appendix. A time series of weekly prices is generated using the arithmetic average of daily spot prices from Monday to Sunday[23]. The spot prices have also been divided into seasons[24], which allows us to observe seasonal dynamics. Table 5.1 provides descriptive statistics for the weekly average spot price in the period 1 January 2004 to 31 December 2013.

The mean spot price is 308.99 NOK/MWh for the entire sample. We observe the highest mean price during winter (336.71 NOK/MWh), and the lowest during summer (276.25 NOK/MWh). This is as expected in a Nordic climate. Figure 5.1 plots the spot price and its changes in the period 2004-2013. The figure does not indicate a distinct seasonal pattern.

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[23] Starting from 2006, all contracts were quoted in Euro. We use the daily exchange rates from Norges Bank (Norges Bank, 2013) to convert the futures prices to NOK.

[24] Winter is defined as week 47 to 7. The other seasons are defined using consecutive thirteen-week periods.

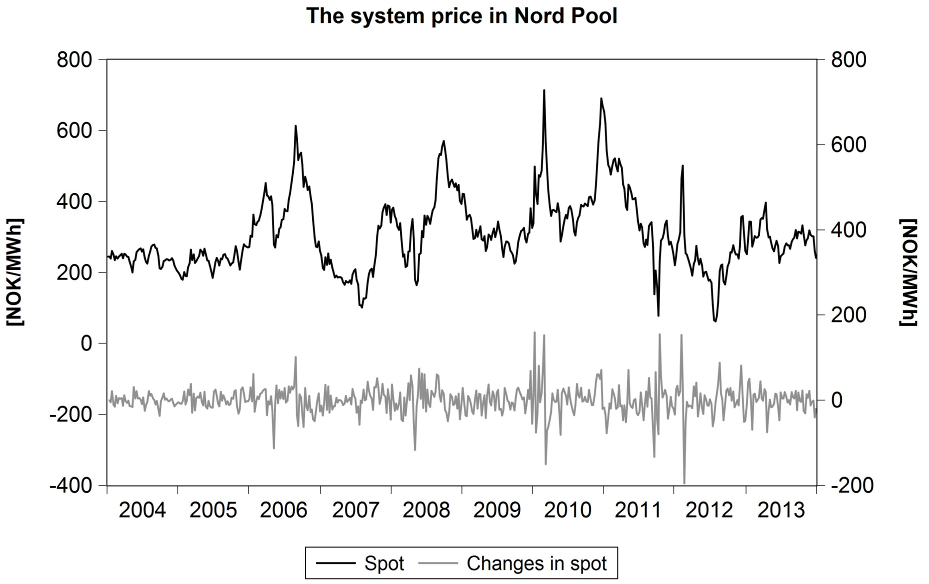

Figure 5.1: The figure shows the daily system price in Nord Pool for the period 2004-2013. Changes in the system price is plotted in the bottom graph. All data is given in NOK/MWh.

We observe an increase in spot price level after 2005. Sijm et al. (2006) find that the introduction of ETS explains much of this increase in spot prices[25]. The market also experienced high spot prices in 2010. Maintenance on several Swedish nuclear power plants was performed during this year to prevent unscheduled stops in production. The plants downtime contributed to a high spot price level. In addition, this was a dry year with low reservoir levels[26] and with both winters 2009/2010 and 2010/2011 being unusually cold. Relatively high temperatures and substantial precipitation, accompanied by high production of wind power in Denmark, caused the spot price to plummet to a low level in 2011. A low spot price was also observed in 2012, due to high inflow caused by late snow melting in the mountains.

The spot price is highly volatile with a standard deviation of 103.71 NOK/MWh

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[25] The introduction of ETS in 2005 changed the cost structure for the power producers with carbon emissions. In an integrated market, this will influence the water values and the scheduling of hydro resources.

[26] The deficit in reservoir levels reached a maximum value of 30 TWh (NordREG, 2011).

Table 5.1: The table provides descriptive statistics for the weekly spot price. Winter is defined from week 47 to 7, and the other seasons are defined by the subsequent 13 week periods. All prices are in NOK/MWh. ***, **, and * indicate rejection of the null hypothesis stating normal distribution at a 1%, 5% and 10% level, respectively.

	Prices				
	All	Winter	Spring	Summer	Fall
Mean	308.99	336.71	304.22	276.25	318.36
Std. error	4.54	9.53	8.63	7.55	9.68
Std. deviation	103.71	109.49	98.37	86.14	110.41
Minimum	62.14	180.34	165.11	62.14	78.29
Median	290.47	307.93	277.04	273.86	290.68
Maximum	714.08	690.52	714.08	511.93	613.37
Skewness	0.84	1.10	1.08	-0.15	0.68
Excess Kurtosis	0.97	0.92	1.39	0.03	-0.23
Jarque-Bera	81.76***	31.16***	35.82***	0.50	10.40*

for the entire sample. Fall and winter have the highest volatilities of 110.41 NOK/MWh and 109.49 NOK/MWh, respectively. The lowest volatility is experienced during summer (86.14 NOK/MWh). The extreme volatility is well documented in the literature, e.g. Lucia and Schwartz (2002), Lucia and Torró (2011), Weron and Zator (2013) and Gjolberg and Johnsen (2001). The excess kurtosis in the sample (0.97) reflects the frequent spikes observed in spot prices. We notice a positive skewness in the sample, which signals a more frequent occurrence of positive spikes in the spot price. The excess kurtosis is highest for spring (1.39), indicating that extreme values are more likely to occur during this season. The fall statistic has a negative value of -0.23, which implies the opposite. The skewness is close to zero for summer, which suggests an approximately equal probability of spikes in both directions. It is highest during winter and spring, with values of 1.10 and 1.08, respectively.

The Jarque-Bera test statistics rejects the null hypothesis of a normal distribution for the whole sample. The hypothesis cannot be rejected for the summer sample, and the fall sample is only rejected at a 10% significance level. The whole sample is tested for stationarity using the ADF unit root test (Dickey and Fuller, 1979). The null hypothesis stating non-stationarity is rejected at a 5% significance level for both raw and log prices.

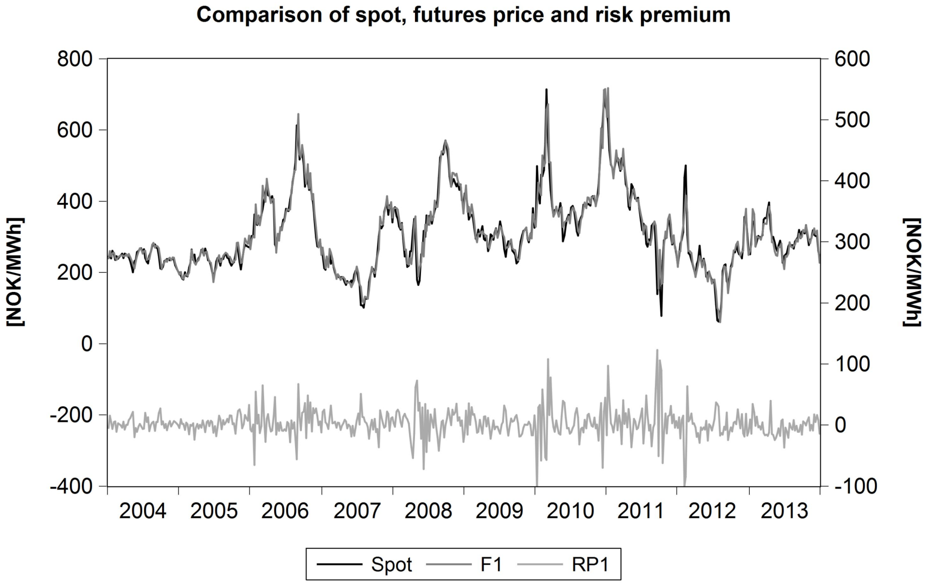

Figure 5.2: The figure shows the daily Nord Pool system price and the F1 contract price in the period 2004-2013. The raw risk premium, given in Equation (2.2), is plotted on the bottom graph. All data is given in NOK/MWh.

5.2 Futures prices

This thesis focuses on weekly futures with time to delivery between one and four weeks[27]. The weekly futures prices are provided from Montel, cf. Table A1, and cover the period corresponding to the spot price data, i.e. 2004-2013.

The choice of weekly futures has two main advantages. The sample size of weekly futures data is sufficient to draw valid and persistent conclusions. Also, several other papers consider weekly futures, e.g. Botterud et al. (2010), Lucia and Torró (2011) and Weron and Zator (2013), which allows us to compare our results with previous research. A drawback with weekly futures is the low liquidity of contracts with long holding periods, which may result in inefficient pricing. Still, we consider the prices set by market-makers to represent an efficient market, cf. section 4.3. We believe the dynamics of the F4 contract is representative

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[27] Hereinafter, we will refer to a futures contract with one week to delivery as F1, a futures contract with two weeks to delivery as F2, and so on.

Table 5.2: The table shows the descriptive statistics for the futures contracts. The mean and standard deviation are given in NOK/MWh. The columns reflect holding periods of one, two, three and four weeks. ***, **, and * indicate rejection of the null hypothesis stating normal distribution at a 1%, 5% and 10% level, respectively.

	Closing prices			
	1	2	3	4
Mean	311.99	317.12	320.04	321.06
Std. deviation	104.93	103.56	100.77	98.76
Skewness	0.96	0.93	0.88	0.86
Excess Kurtosis	1.24	1.00	0.71	0.57
Jarque-Bera	112.95***	97.58***	79.08***	72.14***

	Average prices			
	1	2	3	4
Mean	313.37	317.75	319.50	320.76
Std. deviation	103.28	101.27	98.79	97.10
Skewness	0.95	0.91	0.85	0.83
Excess Kurtosis	1.24	0.94	0.61	0.48
Jarque-Bera	112.01***	90.30***	70.36***	64.17***

	Volume prices			
	1	2	3	4
Mean	313.09	316.74	319.52	320.73
Std. deviation	104.55	101.17	98.36	97.94
Skewness	0.97	0.91	0.83	0.86
Excess Kurtosis	1.22	1.01	0.49	0.64
Jarque-Bera	114.45***	93.43***	65.45***	73.27***

	Log closing prices			
	1	2	3	4
Mean	5.69	5.71	5.72	5.73
Std. deviation	0.33	0.32	0.31	0.30
Skewness	-0.24	-0.07	0.06	0.11
Excess Kurtosis	1.07	0.42	-0.15	-0.30
Jarque-Bera	29.71***	4.35	0.82	3.06

for contracts of longer holding periods. Thus, we will not analyse the F5 and F6 contracts.

Futures prices are collected at three different points in time: (1) The closing price on the last day of trading (hereinafter called *closing price*), (2) the average closing price during the last trading week (hereinafter called *average price*) and (3) the closing price on the day with the highest trading volume during the last trading week (hereinafter called *volume price*). Descriptive statistics are provided for the different alternatives, cf. Table 5.2. For space considerations, we only report the logarithmic closing prices. The statistics for the logarithmic average and volume prices are very similar.

Figure 5.2 compares the spot price to the F1 closing price[28]. As can be seen from the figure, the price of the contract follows the spot price closely throughout the entire sample. Figure B1 in the appendix compares the spot price to the F4 closing price[29]. By visual inspection of Figure 5.2 and B1, we observe that futures contracts with longer holding periods appear to react slower to changes in the spot price, compared to futures with shorter holding periods. As the forecasts are made weeks in advance, the futures prices will not be able to capture sudden and unexpected spikes or drops in the spot price. Thus, as the spot price reverts back to normal levels, the futures prices still incorporate the previous price level. Consequently, the futures contracts with long holding periods appear smoother, yet delayed compared to the spot price.

The futures prices show many of the same features as the spot price. Considering the closing prices, the excess kurtosis is 1.24 for F1 and 0.57 for F4. The negative relationship between the kurtosis and the holding period is expected as contracts with longer holding periods do not reach extreme values as frequently as the spot price and the contracts in front. This can be seen from Figure 5.2 and B1, and also explains the lower volatility these contracts. The mean value of the contracts increase with the holding period, as the cost of hedging is higher several weeks in advance of delivery. The findings are related to the contracts' inability to forecast and follow the spot price when the time to delivery increases.

The Jarque-Bera test statistic rejects the null hypothesis of normality at a 1% significance level. However, the natural logarithm of the closing prices are normally distributed for the contracts with two, three and four weeks to delivery. This displays the smoothing effect of the logarithm operator. The null hypothe-

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[28] The plots for the average and volume prices are very similar, thus not reported.

[29] As for the F1 contract, the average and volume prices are very similar to the closing prices and not reported.

sis of non-stationarity is rejected at a 10% significance level for futures and log futures prices using an ADF unit root test.

5.2.1 Unbiased forward rate hypothesis

The unbiased forward rate hypothesis, UFH, can be used to test whether futures prices are unbiased predictors of future spot prices. It is based on a weak-form efficient market view, where all historical spot price information is included in the futures prices. According to this, UFH explains the spot price at time $t + T$ as

$$S_{t+T} = \alpha + \beta F_{t,t+T} + \epsilon_{t+T} \tag{5.1}$$

The null hypothesis states that futures prices are unbiased forecasts of future spot price, i.e. $\alpha = 0$, $\beta = 1$, and uncorrelated residuals with a mean value of zero. The market is then said to be efficient[30]. We assume, as Haugom and Ullrich (2012), that alpha significantly different from zero provides evidence of a systematic premium, and beta significantly different from one gives evidence of a forecast error.

As high-frequent spot prices tend to experience spikes, Haugom and Ullrich (2012) perform UFH regression using the natural log of futures and spot prices, to make the distributions smoother. We obtain the following expression

$$lnS_{t+T} = \alpha + \beta lnF_{t,t+T} + \epsilon_{t+T}. \tag{5.2}$$

As all time series are stationary, neither of the UFH equations are favored. We test UFH using both Equation (5.1) and (5.2). Table 5.3 and C1 present the results from the regressions using the closing, average and volume futures prices on raw and log prices, respectively.

Gjolberg and Brattested (2011) emphasize on two additional problems which may arise when performing the regression. If the risk premium is time-varying, the alpha coefficients will try to capture all of the time-varying risk premiums and be a mixture of these. This may not be favorable and will influence the beta estimates. The second problem is the overlapping observation problem. The overlapping observation problem may arise when we test the forecasting power of futures contracts with different holding periods than the observation frequency of the

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[30] Haugom and Ullrich (2012) point out that these conditions are not necessary for market efficiency.

Table 5.3: Tests of unbiased forward rate hypothesis on raw prices, defined in Equation (5.1), using OLS regression. The sample period is from January 1 2004 to December 31 2013. The columns reflect holding periods from one to four weeks. Q(10) is the Ljung-Box Q-statistic using 10 lags. ***, **, and * indicates significance at a 1% level, 5% level and 10% level, respectively, based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator. Note: The stars on Q(10) reflect significance based on the χ^2 test statistic. The null hypothesis states that $\alpha = 0$ and $\beta = 1$.

	Closing prices			
	1	2	3	4
α	8.20**	15.43*	20.53	27.94*
β	0.96***	0.93***	0.90**	0.88**
R^2	0.95	0.85	0.77	0.70
$Q(10)$	16.25*	110.43***	306.95***	472.50***
	Average prices			
	1	2	3	4
α	5.38	13.17	20.13	27.79*
β	0.97**	0.93**	0.90**	0.88**
R^2	0.93	0.83	0.74	0.67
$Q(10)$	37.127***	175.93***	377.36***	533.55***
	Volume prices			
	1	2	3	4
α	9.19**	12.58	15.96	29.30*
β	0.96***	0.94**	0.92*	0.87**
R^2	0.93	0.83	0.76	0.68
$Q(10)$	26.784***	153.19***	342.53***	500.96***

spot price, e.g. we let futures contracts with holding periods of four weeks predict weekly spot prices. The result may be autocorrelated and often heteroskedastic residuals. Gjolberg and Brattested (2011) address this problem in their study, and Hansen and Hodrick (1980) discuss different model formulations to escape it. Letting the forecast horizon of the futures contracts equal the observation frequency is a simple way to escape the problem. The spot price is averaged over the same number of weeks as the holding period of the contracts studied, and the raw and log risk premium are calculated. There are no changes in the results, i.e. none of the coefficients differ in significance and only slightly in value. Breusch-Pagan-

Godfrey (Breusch and Pagan, 1979; Godfrey, 1978) test for heteroskedasticity and Breusch-Godfrey (Breusch and Godfrey, 1980) test for autocorrelation give support for autocorrelated and heteroskedastic residuals in the new time series. Thus, we do not expect the observation frequency to have a large impact on the regression coefficients.

Regression on Equation (5.2) gives no evidence of the futures prices being biased forecasts of the subsequent spot prices, cf. Table C1. Autocorrelation in the residuals is the only factor contradicting the null hypothesis, i.e. we find no evidence of biased futures prices. The residuals with 10 lags are autocorrelated for all contracts at a 1% significance level.

Regression on the raw spot and futures prices in Equation (5.1) provides different results, cf. Table 5.3. The results vary slightly depending on which futures prices are used, but the overall findings suggest that futures prices are biased predictors of future spot prices. However, we cannot reject the hypothesis of no autocorrelation, but the residuals are less autocorrelated than for the log futures prices. Closing, average and volume futures prices for all maturities provide significant beta estimates lower than one. The beta estimates decrease with time to maturity. When interpreting the beta estimate as a forecast error, this is consistent with the difficulties related to prediction of the spot price far from delivery. The closing futures prices give significant alpha estimates for contracts of one, two and four weeks of holding. Alpha, representing the systematic risk premium, increases with time to maturity. The average futures prices give the least significant alpha estimates, and the only significant value is found for the contract with four weeks of holding. The volume prices give significant alphas for the contracts with one and four weeks to delivery.

The autocorrelated residuals resulting from regressions using raw and logarithmic prices implies that we cannot easily state whether the futures prices are biased forecasts of the future spot prices. The results of both regressions are unreliable, and the presence of a risk premium is not yet confirmed. Varying results provide motivation for further investigation of a possible risk premium in mid-term futures contracts. The coefficients' behaviour over time is investigated using rolling and recursive estimation. We choose to do these analyses on raw numbers, due to the slightly better residual properties, in addition to the coefficients being significantly different from the null hypothesis.

5.2.2 Rolling estimation

Rolling estimation on the whole sample is performed using a window size corresponding to one year of data, i.e. 52 observations. The window size is kept constant and moves one week at a time. This gives us the opportunity to investigate the coefficient estimates in a short-term picture. Figure 5.3 plots the results from the regression on Equation (5.1) with rolling estimation of the parameters. The futures closing prices are used, and the contracts have a holding period of one and two weeks. The confidence bands reflect a confidence level of 95.4%. The plots reveal highly time-varying coefficients throughout the entire time period, without any clear pattern. The number of observations in the rolling window is too small to produce stable short-term estimates of the coefficients. Still, the rolling regression is advantageous as we escape the problem described by Gjolberg and Brattested (2011), i.e. the time-varying properties of the estimators are retained.

A mature market should produce stable estimates for alpha and beta. Unstable parameters with wide confidence bands are observed in the period from winter 2009/2010 to 2013. We believe the variation in this period is caused by extremely high and low spot prices, cf. Section 5.1. The parameters significantly differ from their null values occasionally, but no persistent pattern is observed. Wider confidence intervals and more volatile estimates are observed for the F2 contract, which coincides with a higher risk premium for contracts of longer holding periods. Rolling regression on volume and average futures prices exhibits the same properties. The figures for these are included in the appendix, see D1 and D2, and will not be commented further.

5.2.3 Recursive estimation

The recursive estimation starts with a window size of one year. The window size increases with one week for each iteration, and let us investigate the long-term coefficient estimates. Figure 5.4 plots the results from the recursive estimation of Equation (5.1) using closing futures prices with holding periods of one and two weeks. The corresponding figures for volume and average futures prices are included in appendix E.

All figures show volatile coefficient properties during the first three years. In the remaining period, alpha does not deviate from its null value[31]. For both con-

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[31] The alpha estimate is slightly above zero in a short period in 2011, and towards the end of 2013 for the F1 contract.

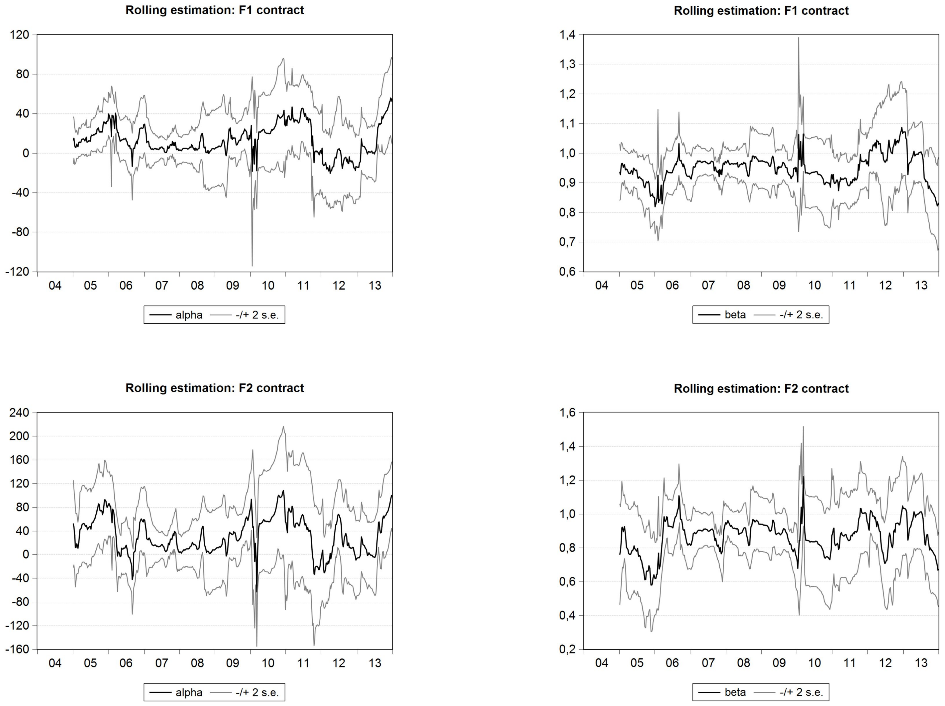

Figure 5.3: Tests of unbiased forward rate hypothesis on closing prices, defined in Equation (5.1), using OLS regression with rolling estimation of the coefficients. The holding period for the futures contracts on the top row is one week, while the bottom row report holding period of two weeks. The window size is 52 weeks. The standard errors are based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator, and plotted in the figure to reflect 95.4% confidence intervals. Alpha is reported in the left column, while beta is reported in the right column. The sample period is from January 1 2004 to December 31 2013.

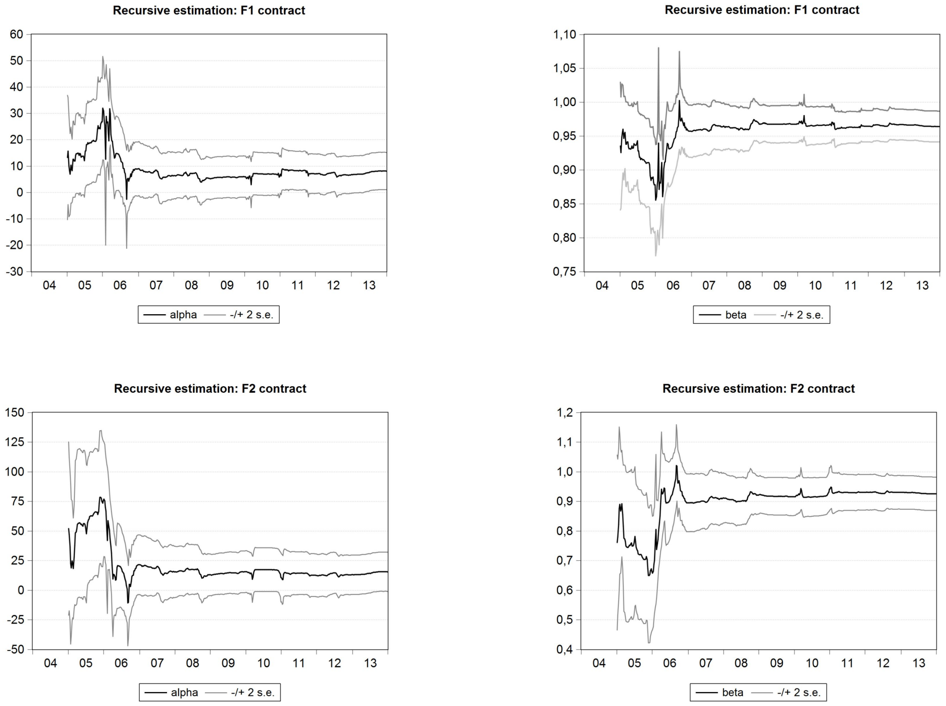

Figure 5.4: Tests of unbiased forward rate hypothesis on closing prices, defined in Equation (5.1), using OLS regression with recursive estimation of the coefficients. The holding period for the futures contracts on the top row is one week, while the bottom row report holding period of two weeks. The window size is 52 weeks. The standard errors are based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator, and plotted in the figure to reflect 95.4% confidence intervals. Alpha is reported in the left column, while beta is reported in the right column. The sample period is from January 1 2004 to December 31 2013.

tracts, beta slightly deviates from its null value towards the end of the sample. We also notice narrower confidence bands and that the contracts have moved towards being downward biased predictors. Still, more data is needed to draw conclusions.

5.2.4 The unbiasedness of futures prices

The analysis performed on the UFH provides contradicting results depending on whether raw or logarithmic prices are investigated; the raw prices suggest that the futures prices are biased predictors of the future spot price, while the logarithmic prices give no indications of this. The autocorrelated residuals make none of the results reliable. There are only small deviations depending on which futures price alternative used. In the most recent years, we find weak evidence of the futures prices becoming downward biased predictors of future spot price. However, the sample is too small to draw conclusions.

5.3 Risk premium

Descriptive statistics are provided for the logarithmic and raw risk premium, cf. Table 5.4 and F1. The bottom graph in Figure 5.2 plots the raw risk premium for the F1 contract. The premium exhibits relatively stable properties until 2006. The volatility increases in the subsequent period.

As can be observed in Table 5.4 and F1, the futures prices give mean risk premiums significantly different from zero. To arrive at this result, we perform the following regressions,

$$LRP_{t+T} = \alpha \quad \text{and} \quad RP_{t+T} = \gamma, \tag{5.3}$$

where the significance level is based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator (Newey and West, 1986).

The risk premium increases with time to delivery. As it is harder to predict the spot price several weeks in advance, a larger risk premium is included. This is true for all futures pricing alternatives. Considering the log risk premiums for the different maturities, the closing prices for the F1 and F2 contracts give the smallest premiums. The average prices give the highest, 1.1% against 1.8% for the F1 contract. This confirms the results of Redl et al. (2009). They find that using futures prices on the last trading day, instead of monthly averages in the last trading month, lowers the difference between spot and futures prices. This is

Table 5.4: The table shows the descriptive statistics for the log risk premium based on the different pricing methods. The columns reflect holding periods of one, two, three and four weeks. Equation (5.3) gives the significant mean of the log risk premium. ***, **, and * indicates significance at a 1%, 5% and 10% level, respectively, based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator.

	Closing log prices			
	1	2	3	4
Mean	0.011***	0.031***	0.044***	0.050***
Std. deviation	0.088	0.143	0.174	0.198
Skewness	2.51	2.42	1.39	1.43
Excess Kurtosis	18.96	17.68	6.32	6.89
	Average log prices			
	1	2	3	4
Mean	0.018***	0.036***	0.044***	0.050***
Std. deviation	0.103	0.153	0.183	0.203
Skewness	3.02	2.16	1.46	1.36
Excess Kurtosis	23.23	13.94	6.90	6.76
	Volume log prices			
	1	2	3	4
Mean	0.016***	0.032***	0.045***	0.049***
Std. deviation	0.101	0.149	0.178	0.201
Skewness	2.80	2.18	1.42	1.38
Excess Kurtosis	22.82	14.70	6.06	6.94

reasonable, as the futures prices closest to delivery include more information and are better suited to predict the spot price.

The difficulties related to prediction of future spot price, increase the standard deviation as the holding period increases for raw and log premiums. The skewness and excess kurtosis decrease with time to maturity for the first three contracts of log prices. No pattern is observable when moving from F3 to F4. The risk premiums for the contracts with longer holding periods have more symmetric and less leptokurtic distributions. The raw risk premiums also exhibit decreasing excess kurtosis and skewness[32]. We also observe that the distribution of the raw risk

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[32] An exception is the skewness for closing and volume prices, which increases when the holding period increases from one to two weeks.

premiums is closest to normal, having noticeable lower values for skewness and kurtosis. Still, the Jarque-Bera test statistics rejects normality.

Table F2 in the appendix shows descriptive statistics for the logarithmic risk premium, calculated for each season separately. Due to space considerations and small variations in results depending on the different futures prices applied, we report only premiums for the log closing prices.

The fall contracts have the highest risk premium, with significant values for all holding periods. The premiums are also characterized by the highest volatility, excess kurtosis and skewness. Similar to the fall risk premium, the winter contracts have significant risk premiums for all holding periods. Botterud et al. (2002) suggest that hydro power producers' ability to scale production up and down on short notice depending on spot price, reduces the need for hedging as they can profit from price spikes typical in winter. Retailers have physical delivery obligations and want to lock in future delivery at a fixed price. An excess demand for futures contracts results in risk averse retailers paying a premium. The volatility of the winter premiums is the lowest[33], which suggests that premiums are more stable during winter compared to other seasons. The skewness for winter has a negative value indicating the largest deviations occur below the mean. We find significant premiums for the F3 and F4 summer contracts. According to Botterud et al. (2002), an overweight of risk averse producers wanting to hedge their summer production may result in futures prices lower than, or close to, expected spot price. Retailers have fewer sales obligations during summer, and a lower spot price level reduces the hedging demand. However, the significant and relative high risk premium for contracts with three and four weeks holding period, gives indications of a retailer hedging demand during summer. Neither of the spring futures contracts exhibit significant risk premiums.

5.4 Physical variables

In previous literature, physical conditions are found to have an essential impact on spot and futures prices. The Nordic climate is characterized by cold winters and relatively warm summers. Temperature is therefore decisive for power consumption. As 50% of the power produced is hydropower, the hydrologic conditions will influence the market. Also, the production of wind power has increased in

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[33] For the contract with holding period of four weeks, the standard deviation is slightly lower for the corresponding spring futures contract.

the recent years and influence the power dynamics due to low marginal costs.

Figure 5.5 plots the temperature, inflow and consumption in the period 2004-2013. Inflow is the total inflow in Norway and Sweden. The consumption is the total consumption in Norway, Sweden, Denmark and Finland. Temperature is an approximation of the mean temperature in Norway, calculated as the average of five geographically spread Norwegian cities. We observe a clear negative dependence between temperature and consumption, and a positive dependence between temperature and inflow. Both findings are as expected; the consumption decreases due to a lower power demand for heating purposes. The inflow increases due to the snow melting in the spring and precipitation throughout the year. We notice a distinct seasonal pattern for consumption and temperature. This is also true for the inflow, but this pattern is more unstable. Figure 5.6 reveals some evidence of low spot prices when the inflow reaches its maximum during spring and early summer, but this pattern is not consistent throughout the entire time period.

Figure 5.7 plots the reservoir level, the deviation in reservoir level from median and the spot price. The reservoir level is the water level given as a percentage of total capacity in Norway and Sweden, and is a direct consequence of inflow and consumption. We observe a seasonal pattern in the water level, although the top and bottom values vary over the time period. The deviation in reservoir level is calculated as the difference between the actual reservoir level and a long-term median. Water levels in the period 1995-2013 are used to construct the median. The vertices of the reservoir level and the spot price coincide in the period 2006-2008, but in the subsequent period the spot curve is delayed. This may be related to the increasingly negative deviation in reservoir level, caused by the cold winters in 2009/2010 and 2010/2011. High spot prices are observed when the deviation is furthest below the normal, e.g. late 2006 and during winter 2010/2011. Besides from this, there is no evident pattern related to the deviation in reservoir level. Figure 5.8 plots the spot price and the wind power in the period 2004-2013. The wind power is the actual wind power produced in Denmark. As can be seen from the figure, the amount of power produced is very volatile. However, there is a weak seasonal pattern representing more wind during the winter. We find it difficult to observe any pattern between the wind power produced and spot price.

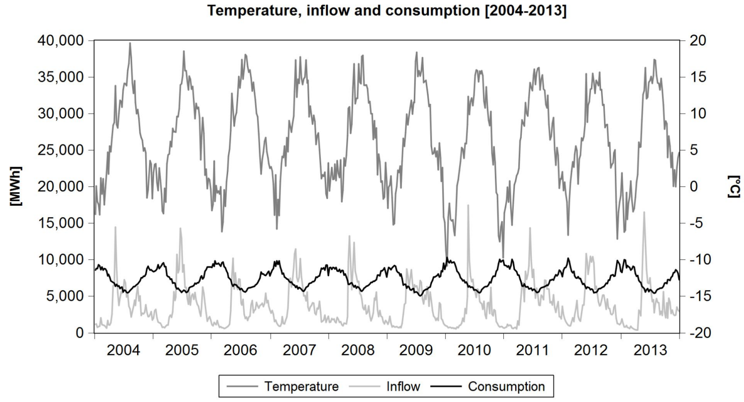

Figure 5.5: The figure plots temperature, inflow and consumption in the period 2004-2013. The temperature is an approximation of the mean temperature in Norway. Inflow is the total inflow in Norway and Sweden. Consumption is the total consumption in Norway, Sweden, Denmark and Finland. Inflow and consumption($\times 10^{-3}$) are measured on the left axis and given in MWh. The temperature is measured on the right axis and given in °C.

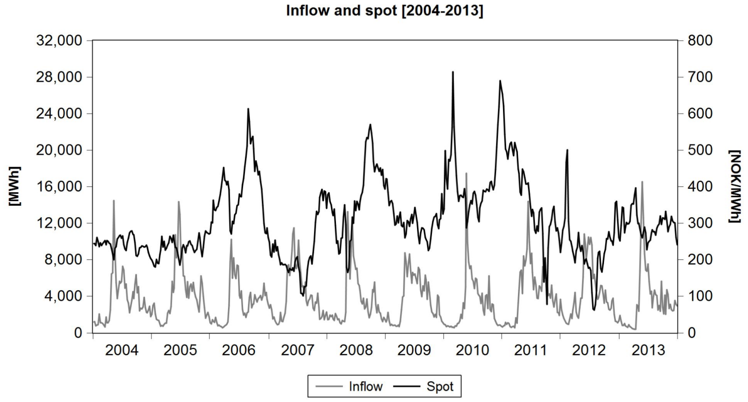

Figure 5.6: The figure plots the inflow and spot price in the period 2004-2013. The inflow is the total inflow in Norway and Sweden. The spot price is measured on the right axis and given in NOK/MWh, while the inflow is measured on the left axis and given in MWh.

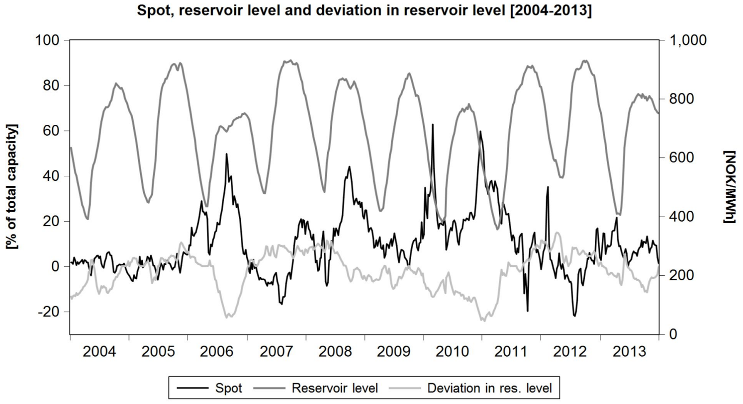

Figure 5.7: The figure plots the reservoir level, the deviation in reservoir level from a long-term median and the spot price in the period 2004-2013. The reservoir level is the actual water level in Norway and Sweden, divided by the total reservoir capacity. The median reservoir level is calculated from weekly average reservoir levels in the period 1995-2013. Both the reservoir and deviation are measured on the left hand scale and given as percentages. The spot price is measured on the right axis and given in NOK/MWh, while the inflow is measured by the left axis and given in MWh.

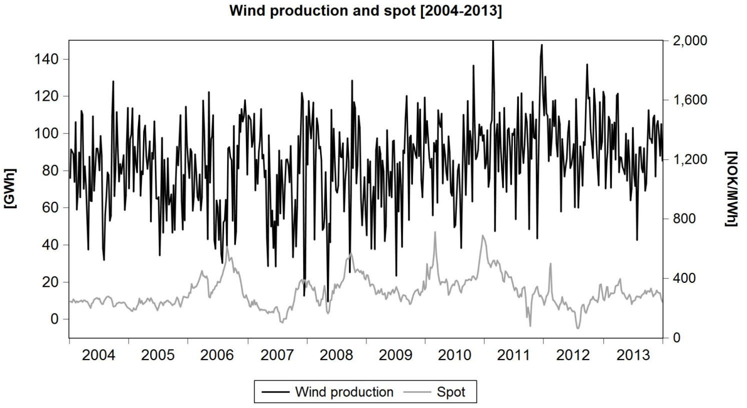

Figure 5.8: The figure plots the actual produced wind power in Denmark, and the spot price, in the period 2004-2013. The wind power is measured on the left axis and given in GWh, while the spot price is measured on the right axis and given in NOK/MWh.

Chapter 6

The Model

This chapter presents the model applied to describe the variation in the risk premium. A thorough discussion on the explanatory variables is included. Also, their expected influence on the risk premium is presented.

6.1 Model specifications

Weron and Zator (2013) emphasize on the advantages of applying OLS regression to econometric data. If certain conditions are met, the model will provide unbiased, efficient and consistent estimators.

Calculation of the expected risk premium includes an estimate for the expected spot price. Models used to compute expected spot prices differ between market participants. A model generating expected spot prices is subject to the joint hypothesis problem. As emphasized by Haugom and Ullrich (2012), the formulated model will also be a test of the particular model itself. Even though common information is used, it is unknown whether all participants use this information in the same way, or use it at all. Hence, neither computation of the expected spot price can be interpreted as correct. We escape this problem by using the realised premium as an approximation for the expected premium.

The goal of this thesis is to describe the variation in the expected risk premium. Careful consideration is necessary when specifying the explanatory variables in the regression model, in order to reduce the likelihood of biased estimators. The timing of observations is particularly important. The futures price is determined at time t, for delivery of power in week $t+T$. The price is the sum of the expected spot price in week $t+T$, plus a premium[34] arising from expected risk in the period from trading to delivery. Previous literature collects explanatory variables in the trading week, in the delivery week, or in the time between when investigating the expected risk premium. Unfortunately, all three alternatives may produce biased or inconsistent estimators when the goal is to describe the ex-ante premium.

(1) Forecasts made by market participants in the trading week may be approximated by realised values in the delivery week, or in the period between trading and delivery. Thus, the forecasts are assumed to be correct on average. In our opinion, the market participants will possess different forecasts, varying in reliability and prediction power. The assumption stating that all market participants have access to the same forecasts is strict, and may cause bias in the estimators. Weron and Zator (2013) also encounters this problem. Letting RP^{ep} be the ex-post premia, RP^{ea} be the ex-ante premia and ϵ_t the error term, Equation (2.3) states that,

$$RP^{ep}_{t+T} = RP^{ea}_{t+T} + \epsilon_t.$$

This also applies to the explanatory variables. Var_{t+T} is the realised value, Var^{*}_{t+T} is the forecast for time $t + T$ made at time t, and ε_t is the forecast error,

$$Var_{t+T} = Var^{*}_{t+T} + \varepsilon_t.$$

A forecast error in the expected risk premium is likely to be caused by a forecast error in one or more of the explanatory variables. Thus, we can easily assume that ϵ and ε are correlated. As a result, we get correlation between the dependent and independent variables, leading to biased estimators.

(2) The only way we can make sure all market participants have the same amount and quality of information, is by using information known at the time of trading. However, using the observations made at time t as approximations for the time $t + T$ values in a market where unstable physical conditions affect the power consumption and supply, can lead to inconsistent estimators. This is true, even when dealing with mid-term contracts with only up to four weeks holding period. Weron and Zator (2013) applies this approach to the variables for deviation in inflow and consumption. The alternative is to let the observed values describe the current situation at the time of trading.

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[34] As defined in Equation (2.3), the ex-post premium equals the ex-ante premium plus the spot price forecast error, i.e. the difference between the expected and realised spot price. The forecast error is assumed to be zero on average.

(3) Combining observations from both trading week, delivery week and the time between, will result in biased estimators due to a combination of the reasons discussed above. Botterud et al. (2010) include variables observed in the trading week and variables from the time between trading and delivery. This is justified by an assumption of market participants having access to reliable forecasts. The information can therefore be treated as common information at the time of trading, and increase the explanation power of the model. However, based on the discussion above, this method will preclude the ex-ante interpretation of the risk premium.

We focus on the risk the market participants face at the time the futures contracts are traded. Using information known at the time of trading gives us the opportunity to assume that all market participants have the same information. This allows us to construct a model describing how fundamental factors affect the expected risk premium. We investigate how current market conditions, i.e. conditions described by the explanatory variables, affect the perceived risk related to the future spot price. We emphasize that we do not intend to approximate forecasts. To make the analysis comparable to Weron and Zator (2013) and Botterud et al. (2010), the model is formulated with the log risk premium as dependent variable.

6.2 Model formulation

$$\begin{aligned} LRP_{t+T} = & \alpha + \beta_1 CONSD_t + \beta_2 INFD_t + \beta_3 WINDP_t \\ & + \beta_4 RESM_t + \beta_5 RESD_t + \beta_6 VAR_t + \beta_7 S_t + \epsilon_t \end{aligned} \tag{Model 1}$$

where,

LRP_{t+T}	Realised log risk premium in week $t + T$
$CONSD_t$	Total deviation in actual electricity consumption in Norway, Sweden, Denmark and Finland from average (2000-2013), in week t [MWh]
$INFD_t$	Total deviation in actual inflow in Norway and Sweden from average (1996-2013), in week t [MWh]
$WINDP_t$	Wind production in Denmark in week t [GWh]
$RESM_t$	Median reservoir level in Norway and Sweden (1995-2013) in week t [%]
$RESD_t$	Deviation in actual reservoir level in Norway and Sweden from median ($RESM_t$) in week t [%]
VAR_t	Variance of hourly spot prices in week t
S_t	Spot price in week t [NOK/MWh]
ϵ_t	Regression error

6.3 Explanatory variables

The regression variables used in Model 1 are chosen based on previous studies on the risk premium, and the preliminary analysis on conditions in the Nordic market, cf. chapter 5. We only include variables from the trading week, and investigate how these drive the realised risk premium, cf. Section 6.1. Table A1 in the appendix lists the variables, the data source and frequency.

6.3.1 Consumption and inflow

Weron and Zator (2013) and Botterud et al. (2010) include consumption and inflow variables in their analyses, and find significant coefficients for these. However, they define them differently. Botterud et al. (2010) use the sum of deviations in the period from trading to delivery. They argue that forecasts are available for all market participants at the time of trading, which are accurate T weeks into the future. Weron and Zator (2013) use deviations during trading week as approximations of future values. They claim that the realised values of deviations cannot be interpreted in the context of an ex-ante risk premium model. We apply the definition of Weron and Zator (2013) in our analysis, but interpret the observations as current conditions.

We believe higher inflow than normal in the trading week will give expectations of a lower future spot price due to a reduced probability of spikes occurring. Thus, increasing the premium. Opposite, higher than normal consumption reflects a right shift in the demand curve, increasing the expected spot price and reducing the risk premium.

6.3.2 Wind production

High production of wind power reduces the current spot price and may influence the risk premium. As the demand curve in a power market is inelastic, small changes in the supply curve may induce large changes in the spot price. An increase in production of wind power will shift the supply curve to the right, and reduce the spot price. Large amounts of wind power produced in the trading week will not influence long-term spot prices. However, we believe it may reduce the current hedging demand among retailers and lower the premium for the front contracts.

6.3.3 Reservoir level

We follow the argumentation of Cartea and Villaplana (2008), and use hydro reservoir level as an approximation of total capacity in Nord Pool[35]. Botterud et al. (2010) find reservoir level to have a significant influence on the risk premium. Weron and Zator (2013) argue that the water level is seasonal, and may capture the seasonal influence of other omitted variables, cf. Section G.2. We apply the approach of Weron and Zator (2013), and divide the reservoir level into two parts: a seasonal component, RESM_t, and a stochastic component, RESD_t. RESM_t is

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[35] Hydro power constitutes about 50% of generation capacity in the Nordic countries. The hydro power shares in Norway and Sweden cover the major part of the production. Thus, data on reservoir levels in Norway and Sweden will be sufficient to describe the reservoir levels in the whole Nordic area.

the median reservoir level in Norway and Sweden, in a given week t and RESD_t is the deviation in reservoir level from this median.

Visual inspection of Figure 5.7 reveals that some of the highest and lowest risk premiums are observed during periods of abnormally low reservoir levels. It is difficult to reveal any obvious pattern. We believe a high positive deviation in reservoir level in the trading week will give expectations of a lower future spot price due to a reduced probability of spikes occurring. Thus, increasing the premium. The seasonal component of the reservoir level is anticipated to be significant. Further, as this variable captures the effects of several variables, we do not propose any hypothesis on the potential effect it has on the risk premium.

6.3.4 Variance in the spot price

We include a variable for the variance in hourly spot prices during the trading week. From section 5.1, we know the spot price to be extremely volatile and this is reflected in the futures prices. Several studies include this variable in addition to a skewness variable, in order to assess the findings of Bessembinder and Lemmon (2002) in the Nordic market, e.g. Botterud et al. (2010), Lucia and Torró (2011) and Weron and Zator (2013). Neither studies find support for the model using recent data samples. Botterud et al. (2010) argues that the storage possibilities in hydro-dominated power market makes the skewness in the spot prices less evident than in a fossil fuel-dominated power market. Based on this, a skewness variable is not included. Still, we believe the variance in the spot price to be able to describe some of the variation in the expected risk premium. Contradicting the finding of Bessembinder and Lemmon (2002), a high variance in the spot price in the trading week is assumed to increase the hedging demand and futures prices. As a result, the risk premium will increase.

6.3.5 Spot price

The spot price sensitivity is highly dependent on the spot price level. Low power demand indicates that the equilibrium spot price is on the gradual part of the convex supply curve. Changes in the demand will only lead to small changes in the spot price. On the other hand, a situation characterized by high demand and an equilibrium price on the steep part of the supply curve, will result in the spot price being extremely sensitive to changes in demand. The current spot price level will therefore provide information on the sensitivity in the spot price. A highly sensitive spot price is believed to increase the hedging demand and risk premium, in fear of even higher spot prices.

As the spot may be influenced by current futures prices, simultaneity bias may occur, cf. section G.2. The model should therefore also be tested with the restriction $\beta_8 = 0$, and the results should be investigated for consistency.

Chapter 7

Empirical analysis of the risk premium

This chapter describes the empirical analysis performed and provides results. The time series of explanatory variables used in the regression model are computed. Next, multivariate linear regression on Model 1 is performed. Problems encountered are outlined and solutions are presented. Finally, a thorough discussion of the results is given.

7.1 Computing the time series

Structural breaks in the log risk premium are tested for using Quandt-Andrews Breakpoint test (Quandt, 1960; Andrews, 1993). Breakpoints are detected for all contract maturities, thus, stationarity is tested for using the Phillips-Perron test (Phillips and Perron, 1988). The remaining time series are tested for stationarity using the ADF unit root test. The null hypothesis of no stationarity is rejected for all time series. Next, correlation between the dependent and independent variables is examined. Visual inspection of the scatter plots of the log risk premium and the explanatory variables, cf. Figure H1 in the appendix for LRP1, reveals no clear pattern, and we assume no correlation to be present.

The correlation matrix for the variables is included in the appendix, cf. Table I1. We do not test whether variables are correlated through their higher moments. We notice the lowest correlation value, -0.605, between the spot price and deviation in reservoir level. As we do not know how the time series are distributed, we do not know if this value corresponds to highly negatively correlated variables[36]. The relationship is investigated further in a scatter plot, cf. Figure I1 in the appendix. No clear pattern is revealed by visual inspection. A ”rule of thumb” for the presence of multicollinearity is that the square of the correlation between any two explanatory variables is greater than the R^2 of the regression, i.e. to be sure multicollineary is not present, we need a model explaining at least 0.366 of the variance.

7.2 Performing the regression

Based on the discussion on the OLS assumptions in appendix G.2, an OLS regression on Model 1 is performed for all contract maturities.

First, the model is tested for linearity, i.e. if the model is correctly specified, cf. section G.2. If the model is misspecified the results will be biased and inconsistent. The Ramsey RESET test rejects linearity for LPR1, LRP3 and LRP4 with two fitted terms[37]. Testing reveals that the model is very sensitive to the input variables, especially INFD. A closer investigation of the scatter plot, cf. Figure H1, reveals no distinct relationship between the premium and the variable. Nonlinear transformations[38] of this variable are included in the model to try to solve the problem. As we do not succeed with any of the transformations, we extend the observation period for the affected variable with one week[39], making the assumption of linearity satisfied for all variables.

The residual plot from the regression on the one week premium is reported in the appendix, cf. Figure J1. We observe several outliers in both directions, in addition to volatility clustering. Based on the preliminary analysis, we are able to identify the events leading to the extreme values in the residuals. One way to get a smoother residual plot is to include dummy variables[40] in the regression. However, all the events causing the extremes can be rationally explained from

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[36] See Section G.1 for a closer discussion.

[37] The number of fitted terms corresponds to the powers of the fitted values tested for dependence with the premium. Two fitted terms tests for the square and the cubic of the fitted value.

[38] E.g. $\frac{1}{X}$, X^2, lnX^2 and e^{X^2}

[39] We use an observation period of two weeks, consisting of the trading week and the week before. Based on the weak-form efficient market view, incorporating previous public information should not change the results.

[40] One dummy should be included for each extreme observation in order to smooth the plot.

regular market dynamics[41], and we therefore choose to not include dummies in the regression. Instead, we apply a method from Weron (2006) to reduce the spikes in the time series causing the spikes in the residuals[42]. Weron (2006) finds that the *Damped* method performs the best, and Weron and Misiorek (2008) applies this method to their time series of hourly spot prices. We set an upper and lower limit for the log premium. If LRP$_{t+T}$ is outside the interval, the premium is set to

$$LRP^*_{t+T} = T + T \times log_{10} \frac{LRP_{t+T}}{T}. \tag{7.1}$$

The upper and lower limits are

$$T = \mu + N \times \sigma \qquad \text{and} \qquad T = \mu - N \times \sigma, \tag{7.2}$$

respectively, where μ is the mean log risk premium and σ the standard deviation. N is the number of standard deviations, and the lower the number the stricter damping of the premium. Weron (2006) proposes using $N = 3$. We also calculate the limits using two standard deviations, $N = 2$. Hereinafter, the models with damped spikes will be referred to as Model 2 ($N = 2$) and Model 3 ($N = 3$). Residual plots for LRP1 and LRP4 are included for all models in appendix J. The figures display outliers closer to the mean. However, we still observe volatility clustering and therefore expect to find heteroskedastic residuals.

Autocorrelation is detected using both the Ljung-Box test and the Breusch-Godfrey test. For the contracts with two, three and four weeks of holding, we find autocorrelation in all three models for all lags. The F1 contract displays better results, but the null hypothesis of no autocorrelation is still rejected. The White (White, 1980) test and Breusch-Pagan-Godfrey test confirm presence of heteroskedasticity for all three models and all maturities. The regression is reestimated using Newey-West robust standard errors. All models reject the assumption of normality for all maturities. However, based on the discussion in section G.2, we believe that the sample size is large enough to assume an asymptotic normal distribution.

The results from the regression are shown in Table 7.1, and will be discussed in the next section. Due to possible problems with both multicollinearity and

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[41] The unscheduled stops in the Swedish nuclear plants are the only events we would consider explaining with dummy variables. However, the high spot prices accompanied with these events do not cause outliers.

[42] We will not elaborate on the different methods, and refer to Weron (2006) for more details.

endogeneity, cf. section G.1 and G.2, regression results when excluding the spot price from the models are also reported in the table.

The significance of variables may be affected by other variables included or not included in the model. Simple linear regression on each explanatory variable is performed and reported in Table K1,

$$LRP_{t+T} = \alpha + \beta Var_t + \epsilon_t. \tag{7.3}$$

Due to different notation of the variables, the regression is performed with standardized variables to assess the impact of each variable on the risk premium. The standardized variables are calculated from

$$X_t^* = \frac{X_t - \mu_X}{\sigma_X}. \tag{7.4}$$

The standardized regression coefficients give us the opportunity to assess how many standard deviations the dependent variable changes, given one standard deviation change in the independent variable - all else being equal. The results are given in Table 7.2.

7.3 Results

The results from the regressions are reported in Table 7.1 and 7.2, with regular and standardized coefficients, respectively.

Generally, we find that the models explain little. The explanation power decreases with time to maturity for Model 1; the explanation power is highest for the contracts in front, as the trading week conditions are most relevant for the risk premiums in these contracts. Considering Model 1a, R^2 is 0.043 for the contracts with one to three weeks holding period, while it is 0.040 for the contract with four weeks holding period. The low explanation power can be related to noise in the variables (Black, 1986). Seen in light of the low explanation power and the discussion on the regression residuals, cf. Section 7.2, the model is weak. Still, important findings will be highlighted and described in more detail.

According to the ”rule of thumb” given in Section G.1, multicollinearity may be present for several of the variables due to the low explanation power of the models for all contract maturities[43]. The spot price is particularly exposed to mul-

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[43] Multicollinearity may be present for variables in Model 1a having a correlation exceeding ±0.20, cf. Table I1.

ticollinearity, having correlations exceeding ± 0.20 for the following explanatory variables: CONSD, INFD, RESD and VAR. Model 1b forces β_8 to equal zero which may cause omitted variable bias. However, removal of the spot will let us investigate a possible presence of simultaneity bias and/or multicollinearity caused by the spot price. The results from regressions on Model 1a and 1b reveal small deviations. INFD remains significant and positive in both models. The same applies to the significant VAR coefficient for the contract closest to delivery. The RESM coefficient loses significance for some contract maturities, but remains positive. However, this may indicate bias. The overall deviations resulting from removing the spot price are small, and we assume the spot price to not cause severe bias from omitted variables, simultaneity or multicollinearity. Still, we are not able to preclude the possible presence of bias. The remaining variables are not significant and therefore not relevant to interpret in light of possible simultaneity and omitted variable bias. Studying R^2 of the three models, the highest explanation is obtained when the spot price is included. Damping improves the explanation of the models including the spot price, but provides poor results on the models with the spot price excluded. The highest R^2 is found in Model 2a, and ranges from 0.044 to 0.048. Further, the significant variables remain significant after damping[44].

INFD is the only variable with significant coefficients for all models and contract maturities[45]. The coefficient is positive, which is in accordance with our proposition in Section 6.3.1 and the results of Botterud et al. (2010) and Weron and Zator (2013). Weron and Zator (2013) find significance for the two contracts in front only. The low significance of the RESM coefficient in Model 1a provides weak evidence of a seasonal component, representing the seasonal effects of all included and omitted variables. The significance of the seasonal component diminishes with removal of the spot price and damping. Weron and Zator (2013) find stronger evidence and argue that the seasonal component of electricity demand is likely to be the most important. The non-significant RESD coefficients make it is difficult to interpret the real effect of reservoir level on the premium.

The variance in spot price, VAR, is significant for the contract in front in all models. The variable has a positive effect on the premium, as suggested in Section 6.3.4. This is also consistent with Botterud et al. (2010) and Weron and Zator

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[44] Only small deviations are observed: The RESM coefficient for LRP1 loses its significance when the spot price is included, and the LRP2 coefficient for RESD becomes significant for the same model. These findings will not be discussed further.

[45] The damped models excluding the spot price do not have a significant INFD coefficient for LRP4.

(2013). We do not obtain significance for CONSD, WINDP or RESD, and are therefore not able to discuss the coefficient estimates. However, we notice that the RESD coefficient changes sign from positive to negative when the spot price is removed. This may give indications of multicollinearity. Weron and Zator (2013) and Lucia and Torró (2011) found the deviation in reservoir level to be significant. As different time series are analysed, this indicates that deviation in reservoir level at the time of trading is not able to describe the premium.

The significance of the variables can be interpreted in two ways: (1) The significant variables contribute in explaining the variation in the premium, (2) the variables do not describe variation in the premium, but captures the effects of other variables included or not included in the model. To interpret the significance of the variables, simple linear regression is performed on each of the explanatory variables in the model, cf. Figure K1. INFD is significant for all models and contract maturities, which is consistent with the results from Table 7.1. Simple linear regression on RESM does not give significant coefficients, which provides evidence that the seasonal component of the reservoir level captures the seasonal effects of other variables included or not included in the model. VAR is significant for the contract in front in all models. Simple linear regression on the spot price is invalid when the risk premiums are not damped. However, the multivariate regression gives some significance for the spot price in Model 1a and for all contract maturities in the damped models.

The significance of VAR, INFD and the spot price indicates that these are risk factors in the trading week driving the realised risk premium. Changes in these variables will alter the market participants' predictions of the future spot price, and therefore lead to different expectations of the risk premium. Consequently, this provides evidence of the risk premium partly representing the price of risk.

Table 7.2 reports the results of the regression using standardized coefficients. This allows us to confirm a logic influence of the coefficients. One standard deviation increase in INFD, results in a 1.19 % increase in LRP1 and a 2.67 % increase in LRP4. Increasing the VAR variable with one standard deviation, increases LRP1 with 1.06 %, while a one standard deviation increase in the spot price increases LRP4 with 3.28 %. We believe the numbers are reasonable.

Table 7.1: Regression results from Model 1, Model 2 and Model 3. The sample period is from January 1 2004 to December 31 2013. The columns report the coefficients of the explanatory variables.***, **, and * indicates significance at a 1%, 5% and 10% level, respectively, based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator. R^2 and $R^2(adj)$ are reported in the rightmost colums.

			CONSD	**INFD**		**WINDP**	**RESM**		**RESD**	**VAR**		**S**		**C**	R^2	$R^2(adj.)$
			$(\times 10^7)$	$(\times 10^4)$		$(\times 10^6)$				$(\times 10^5)$		$(\times 10^3)$				
M1	**a**	LRP1	-1.300	0.899	**	-2.460	0.034	*	0.000	3.550	*	0.615		-0.014	0.043	0.030
		LRP2	-1.500	1.760	*	-2.830	0.066		0.031	2.230		1.800	*	-0.045	0.043	0.030
		LRP3	-1.860	2.210	**	-0.809	0.091	*	0.029	0.862		2.200		-0.075	0.043	0.030
		LRP4	-2.840	2.010	*	-1.560	0.103	*	0.078	0.457		3.160	*	-0.098	0.040	0.027
	b	LRP1	-1.020	0.844	**	-2.340	0.034		-0.044	4.020	**			0.002	0.040	0.029
		LRP2	-0.664	1.600	*	-2.480	0.064		-0.099	3.590				0.004	0.034	0.023
		LRP3	-0.818	2.010	*	-0.388	0.089	*	-0.129	2.520				-0.016	0.034	0.023
		LRP4	-1.310	1.730	*	-0.952	0.100		-0.148	2.830				-0.013	0.026	0.015
M2	**a**	LRP1	-1.150	0.622	**	-2.030	0.023		0.018	2.370	*	0.939	**	-0.021	0.044	0.031
		LRP2	-2.230	1.270	*	-2.700	0.054		0.038	2.490		1.940	**	-0.047	0.049	0.036
		LRP3	-2.740	1.700	*	-0.783	0.079	*	0.056	0.357		2.530	**	-0.080	0.046	0.033
		LRP4	-3.840	1.630	*	-1.640	0.088		0.101	0.099		3.490	**	-0.102	0.048	0.035
	b	LRP1	-0.722	0.538	*	-1.840	0.022		-0.050	3.080	**			0.005	0.034	0.022
		LRP2	-1.330	1.100	*	-2.320	0.052		-0.102	3.960				0.006	0.034	0.023
		LRP3	-1.550	1.480	*	-0.299	0.077	*	-0.126	2.260				-0.012	0.030	0.019
		LRP4	-2.150	1.320		-0.976	0.085		-0.148	2.720				-0.008	0.025	0.014
M3	**a**	LRP1	-1.150	0.720	**	-2.180	0.025		0.014	2.450	*	0.892	**	-0.019	0.040	0.027
		LRP2	-1.910	1.440	*	-2.700	0.056		0.035	2.390		1.880	**	-0.045	0.045	0.032
		LRP3	-2.310	1.910	**	-0.884	0.083	*	0.050	0.402		2.450	*	-0.078	0.043	0.030
		LRP4	-3.160	1.800	*	-2.110	0.093		0.092	-0.007		3.340	**	-0.094	0.042	0.029
	b	LRP1	-0.739	0.641	*	-2.000	0.024		-0.050	3.120	**			0.005	0.032	0.021
		LRP2	-1.030	1.270	*	-2.340	0.054		-0.101	3.800				0.006	0.032	0.021
		LRP3	-1.150	1.690	*	-0.415	0.081		-0.126	2.250				-0.012	0.031	0.019
		LRP4	-1.540	1.500		-1.470	0.090		-0.147	2.500				-0.004	0.024	0.013

Table 7.2: Regression results from Model 1, Model 2 and Model 3, based on standardized explanatory variables. The sample period is from January 1 2004 to December 31 2013. The columns report the standardized coefficients of the explanatory variables.***, **, and * indicates significance at a 1%, 5% and 10% level, respectively, based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator. R^2 and $R^2(adj)$ are reported in the rightmost colums.

			CONSD	**INFD**		**WINDP**	**RESM**		**RESD**	**VAR**		**S**		R^2	$R^2(adj.)$
M1	**a**	LRP1	-0.052	0.135	**	-0.064	0.075	*	0.000	0.121	*	0.073		0.043	0.030
		LRP2	-0.037	0.162	*	-0.045	0.088		0.018	0.047		0.130	*	0.043	0.030
		LRP3	-0.037	0.167	**	-0.011	0.101	*	0.014	0.015		0.131		0.043	0.030
		LRP4	-0.051	0.135	*	-0.018	0.101	*	0.033	0.007		0.166	*	0.040	0.027
	b	LRP1	-0.041	0.127	**	-0.061	0.074		-0.042	0.137	**			0.040	0.029
		LRP2	-0.016	0.147	*	-0.040	0.086		-0.058	0.075				0.034	0.023
		LRP3	-0.016	0.152	*	-0.005	0.098	*	-0.062	0.043				0.034	0.023
		LRP4	-0.023	0.116	*	-0.011	0.097		-0.063	0.043				0.026	0.015
M2	**a**	LRP1	-0.059	0.120	**	-0.068	0.064		0.022	0.104	*	0.142	**	0.044	0.031
		LRP2	-0.066	0.142	*	-0.052	0.089		0.027	0.063		0.170	**	0.049	0.036
		LRP3	-0.063	0.147	*	-0.012	0.100	*	0.031	0.007		0.172	**	0.046	0.033
		LRP4	-0.078	0.124	*	-0.022	0.098		0.049	0.002		0.208	**	0.048	0.035
	b	LRP1	-0.037	0.104	*	-0.062	0.062		-0.061	0.135	**			0.034	0.022
		LRP2	-0.039	0.123	*	-0.045	0.085		-0.072	0.100				0.034	0.023
		LRP3	-0.035	0.127	*	-0.004	0.097	*	-0.068	0.044				0.030	0.019
		LRP4	-0.044	0.100		-0.013	0.094		-0.071	0.047				0.025	0.014
M3	**a**	LRP1	-0.053	0.126	**	-0.066	0.064		0.016	0.097	*	0.122	**	0.040	0.027
		LRP2	-0.052	0.149	*	-0.048	0.084		0.023	0.056		0.153	**	0.045	0.032
		LRP3	-0.049	0.155	**	-0.012	0.098	*	0.025	0.007		0.156	*	0.043	0.030
		LRP4	-0.060	0.128	*	-0.026	0.097		0.042	0.000		0.188	**	0.042	0.029
	b	LRP1	-0.034	0.112	*	-0.061	0.061		-0.055	0.124	**			0.032	0.021
		LRP2	-0.028	0.132	*	-0.042	0.081		-0.066	0.090				0.032	0.021
		LRP3	-0.025	0.137	*	-0.006	0.095		-0.064	0.041				0.031	0.019
		LRP4	-0.029	0.107		-0.018	0.093		-0.066	0.041				0.024	0.013

Chapter 8

Conclusion

The conditions in the physical and financial market have changed considerably since Nord Pool was established, and the first financial contracts were offered. An increasingly volatile spot price, due to more extensive use of renewable energy sources and closer integrated markets, is reflected in the futures prices. These are also influenced by changes in contract standards and economic turbulence in other financial markets. A volatile spot price is hard to predict, and the incentives for including a risk premium are large. Even though forecast errors are likely to be present and may explain some of the difference between futures prices and the realised spot price, the risk premium dynamics are important for participants hedging their obligations and traders speculating in the future spot price. Important findings may be beneficial in developing hedging and trading strategies. We formulate a regression model to describe variation in the expected risk premium in the Nordic electricity market, using fundamental factors observed in the final week of trading, i.e. we investigate how the current market conditions influence the expected spot price. We approximate the expected premium using the realised premium, and assume the forecast error to be zero on average. The observations are not treated as forecasts of future values, as this precludes an ex-ante interpretation of the premium.

We find strong evidence of biased futures prices when testing the unbiased forward rate hypothesis on raw numbers. Also, by applying rolling windows and recursive extending samples, we find weak evidence of the futures prices becoming downward biased predictors of future spot prices in the most recent years. Still, more data is needed to draw conclusions. We find significant premiums for all contract maturities, which confirm the results from the UFH. Analysis of the seasonal premiums provides surprising results compared to previous studies. The premium is significant for all holding periods for the winter and fall season. Also, the summer contracts with three and four weeks of holding include a significant positive risk premium. The retailers hedging demand during summer is known to be small compared to the hedging demand of producers wanting to hedge their production, due to lower prices and demand. This suggests the premium to be zero or negative. The positive premium may provide evidence of downward biased futures prices also during summer. The premium is analysed using futures prices collected at three different points in time: (1) The closing prices on the last day of trading, (2) the average closing price during the last trading week and (3) the closing price on the day with the highest trading volume during the last trading week. The premium is significant for all alternatives of the futures prices, but varies in size. The average prices provide the largest premium, while the closing prices on the last trading day provide the smallest premium. This suggests that the additional information available at the last trading day has value in the calculation of the expected spot price.

The regression model explains little of the variation. In addition to autocorrelated and heteroskedastic residuals, and a possible presence of biased estimators, we consider the model to be weak. Still, we are able to obtain some significant results. As proposed by Weron and Zator (2013), we perform the regression with and without the spot price variable. Only small deviations are found, and we assume that the spot price does not cause any severe bias. Damping of LRP is applied to reduce spikes in the residuals, as performed in Weron and Misiorek (2008). We find that damping makes small improvements in the explanation power when the spot is included, but do not improve the residuals besides removal of spikes.

We find INFD to be significant for all holding periods. Also, we find RESM and the spot price to be significant for some of the maturities. The significance of INFD provides evidence of fundamental factors describing the variation in the risk premium, i.e. the deviation in inflow from normal during the trading week partly describes the risk premium one to four weeks into the future. This may represent that the premium is the price of risk. The significance of RESM provides weak evidence of a seasonal component in the premium. The significant spot price variable shows that the current spot price level is able to describe part of the premium in the delivery week. Also, we find evidence in the front contract of the variance in the spot price explaining the premium. Contrary to Botterud et al. (2010) and Weron and Zator (2013), we find no evidence of deviation in reservoir level to explain the premium.

Due to the low explanation power, the model may suffer from multicollinearity between several of the variables. Also, the model is very sensitive to input variables, due to non-linearity, and we find it strange that this problem is not encountered by Botterud et al. (2010). Weron and Zator (2013) mention that linearity may be a reason to the low explanation power in two of their model formulations, and that non-linear terms are included to test for improvements in the explanation power. The results do not change, and the model formulations are maintained in their original forms. Further, we believe the low explanation power formulated by Weron and Zator (2013) makes it natural to include a discussion on multicollinearity. We do not find it meaningful to interpret results from a regression analysis without careful consideration of all potential pitfalls. Also, we believe the assumptions made by Botterud et al. (2010) precludes an ex-ante interpretation of the premium.

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Appendix

A Data collection

Table A1: The table provides the source of the data, time period and frequency.

Data	Source	Time period	Frequency
Spot	Montel[46]	1996-2013	Hourly
Futures	Montel	2004-2013	Hourly
Consumption	Montel	2000-2013	Hourly
Inflow	Nord Pool FTP server	1996-2013	Weekly
Wind production	Energinet.dk[47]	2000-2013	Daily
Reservoir level	Nord Pool FTP server	1996-2013	Weekly

A.1 Comments to the collection process

After an inspection of the data collected from Montel, we discovered that several observations were missing. For the variables which are accessible on both Nord Pool FTP server and Montel, we were able to collect some of this data from Nord Pool FTP. If the data was missing from both sources, we used the observation from the previous hour for the variables with an hourly frequency, and an average of observations from the previous and next day for the variables with a daily frequency. In the case of a non-trading day, we use data from the last available day of trading. This applies to the futures contracts only.

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[46] Montel (2014)

[47] Energinet.dk (2014)

B Comparison of spot and F4

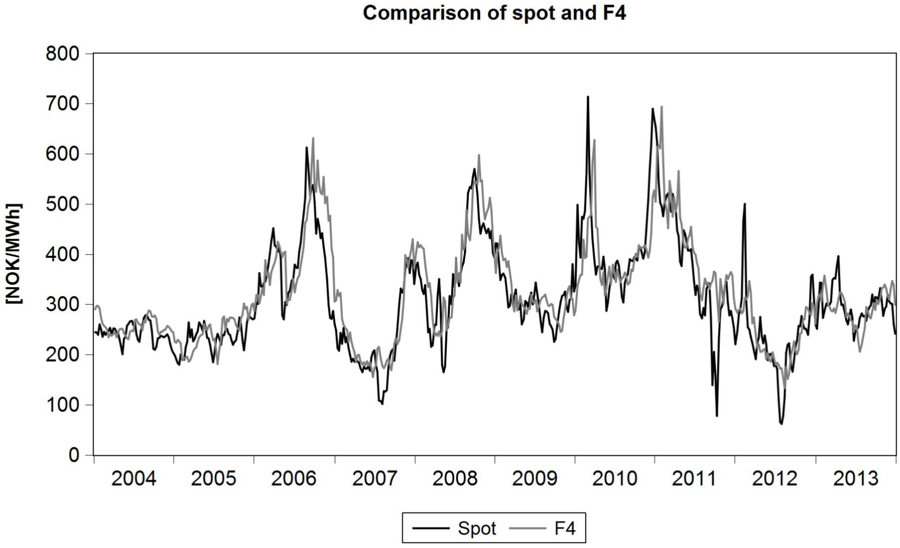

Figure B1: The figure shows the daily Nord Pool system price and the F4 contract price in the period 2004-2013. All data is given in NOK/MWh.

C UFH on logaritmic prices

Table C1: Tests of unbiased forward rate hypothesis on logarithmic prices, defined in Equation (5.2), using OLS regression. The sample period is from January 1 2004 to December 31 2013. The columns reflect holding periods from one to four weeks. Q(10) is the Ljung-Box Q-statistic using 10 lags. *, ** and *** reflect significance based on the χ^2 test statistic. The null hypothesis states that $\alpha = 0$ and $\beta = 1$.

	Closing log prices			
	1	2	3	4
α	0.020	0.112	0.155	0.280
β	0.994	0.975	0.965	0.942
R^2	0.934	0.827	0.742	0.672
$Q(10)$	27.88***	141.03***	309.96***	415.45***
	Average log prices			
	1	2	3	4
α	-0.049	0.046	0.173	0.293
β	1.005	0.986	0.962	0.940
R^2	0.911	0.802	0.716	0.653
$Q(10)$	73.92***	209.91***	348.87***	459.02***
	Volume log prices			
	1	2	3	4
α	-0.013	0.058	0.078	0.306
β	0.999	0.984	0.979	0.938
R^2	0.914	0.812	0.732	0.659
$Q(10)$	61.67***	171.85***	333.32***	435.41***

D Rolling estimation

Average

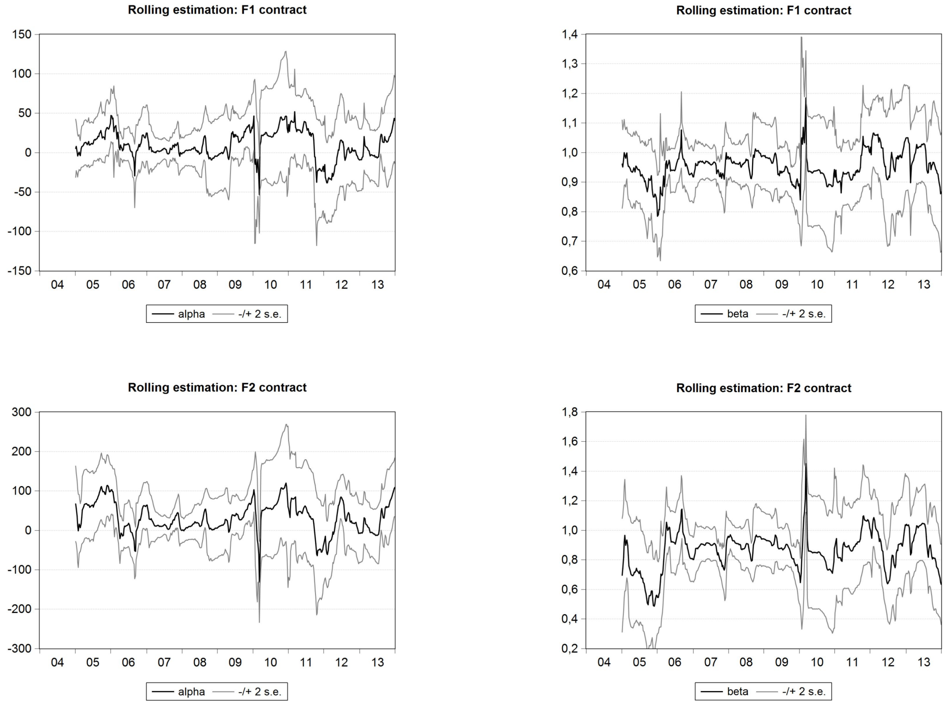

Figure D1: Tests of unbiased forward rate hypothesis on average prices, defined in Equation (5.1), using OLS regression with rolling estimation of the coefficients. The holding period for the futures contracts on the top row is one week, while the bottom row report holding period of two weeks. The window size is 52 weeks. The standard errors are based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator, and plotted in the figure to reflect significance levels of 95.4%. Alpha is reported in the left column, while beta is reported in the right column. The sample period is from January 1 2004 to December 31 2013.

Volume

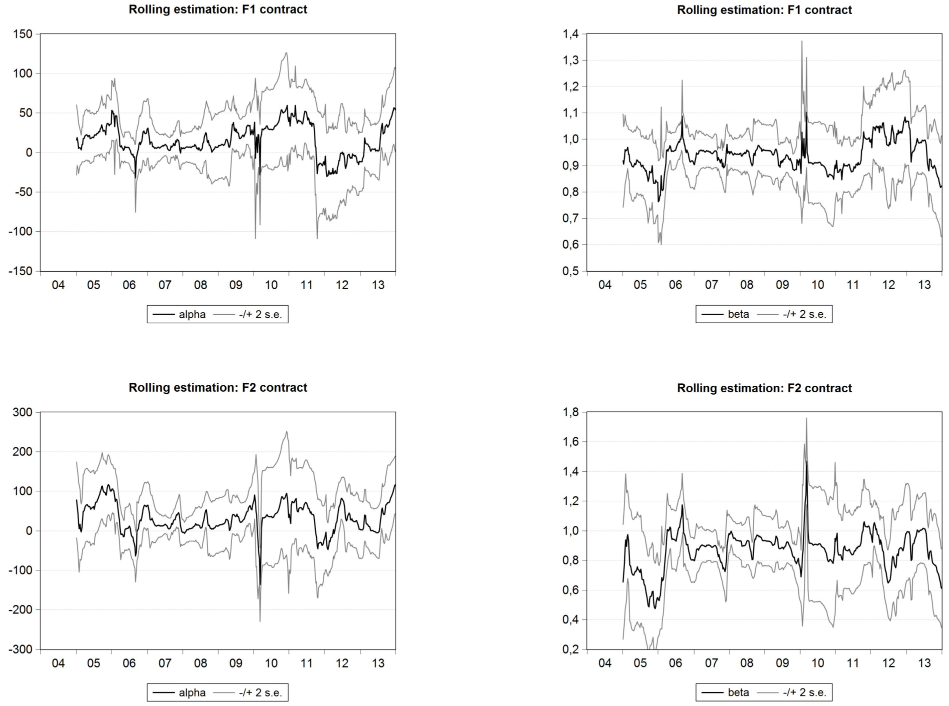

Figure D2: Tests of unbiased forward rate hypothesis on volume prices, defined in Equation (5.1), using OLS regression with rolling estimation of the coefficients. The holding period for the futures contracts on the top row is one week, while the bottom row report holding period of two weeks. The window size is 52 weeks. The standard errors are based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator, and plotted in the figure to reflect significance levels of 95.4%. Alpha is reported in the left column, while beta is reported in the right column. The sample period is from January 1 2004 to December 31 2013.

E Recursive estimation

Average

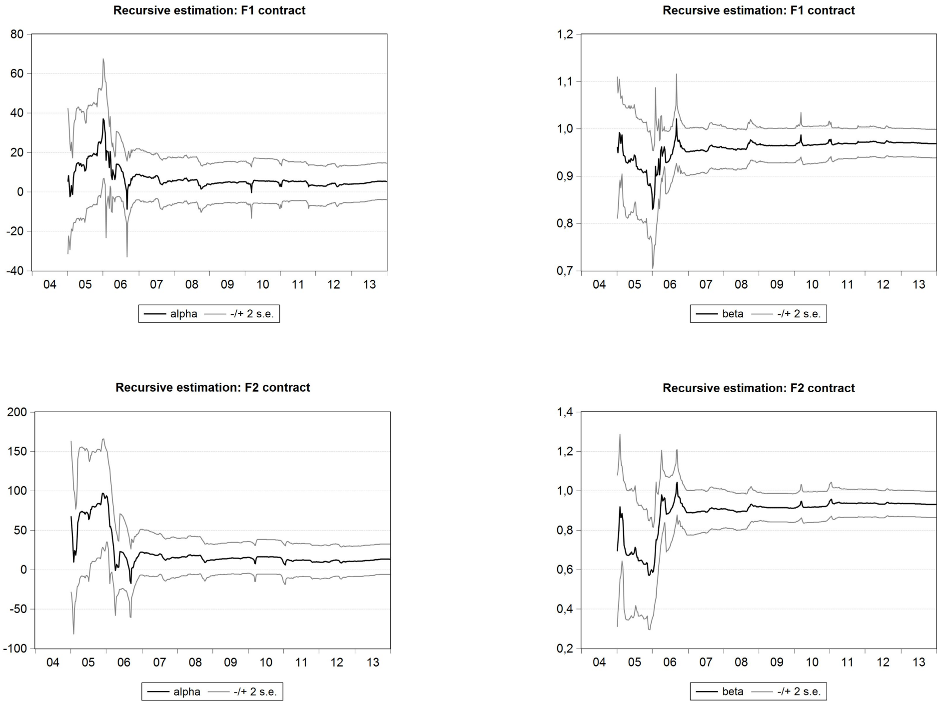

Figure E1: Tests of unbiased forward rate hypothesis on average prices, defined in Equation (5.1), using OLS regression with recursive estimation of the coefficients. The holding period for the futures contracts on the top row is one week, while the bottom row report holding period of two weeks. The window size is 52 weeks. The standard errors are based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator, and plotted in the figure to reflect significance levels of 95.4%. Alpha is reported in the left column, while beta is reported in the right column. The sample period is from January 1 2004 to December 31 2013.

Volume

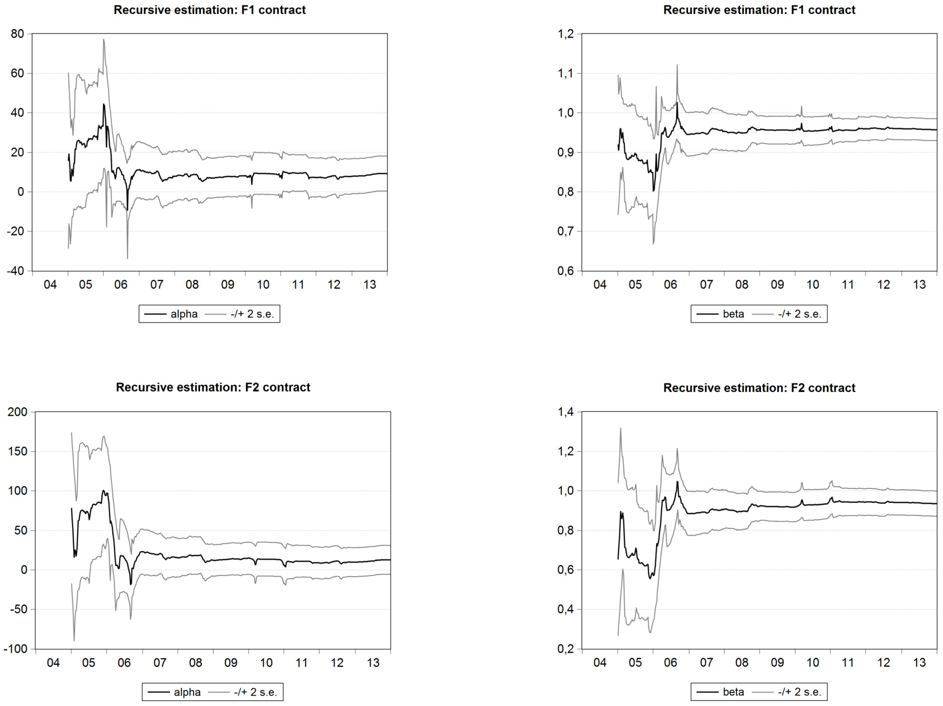

Figure E2: Tests of unbiased forward rate hypothesis on volume prices, defined in Equation (5.1), using OLS regression with recursive estimation of the coefficients. The holding period for the futures contracts on the top row is one week, while the bottom row report holding period of two weeks. The window size is 52 weeks. The standard errors are based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator, and plotted in the figure to reflect significance levels of 95.4%. Alpha is reported in the left column, while beta is reported in the right column. The sample period is from January 1 2004 to December 31 2013.

F Descriptive statistics for risk premium

F.1 Raw risk premium

Table F1: The table shows the descriptive statistics for the raw risk premium based on the different pricing methods. The columns reflect holding periods of one, two, three and four weeks. Equation (5.3) gives the significant mean of the risk premium. ***, **, and * indicates significance at a 1%, 5% and 10% level, respectively, based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator.

	Closing prices			
	1	2	3	4
Mean	2.998***	8.132***	11.051***	12.069***
Std. deviation	23.117	40.300	51.034	58.580
Skewness	0.37	0.48	0.18	0.01
Excess Kurtosis	5.81	5.52	3.04	2.62
	Average prices			
	1	2	3	4
Mean	4.379***	8.755***	10.511***	11.766**
Std. deviation	27.428	43.752	53.543	60.431
Skewness	0.37	0.22	0.07	-0.16
Excess Kurtosis	6.71	5.83	2.81	2.96
	Volume prices			
	1	2	3	4
Mean	4.102***	7.747***	10.531***	11.739**
Std. deviation	27.436	42.804	51.809	60.139
Skewness	0.14	0.28	0.06	-0.09
Excess Kurtosis	6.22	5.50	2.73	2.96

F.2 Logarithmic risk premium by season

Table F2: The table shows the descriptive statistics for the realised log risk premium by season. Closing futures prices on the last day of trading are used in the calculations. The columns reflect holding periods of one, two, three and four weeks. ***, **, and * indicate rejection of the normal distribution hypothesis at a 1%, 5% and 10% level, respectively, based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator.

	Winter			
	1	2	3	4
Mean	0.012**	0.035***	0.049**	0.059**
Std. deviation	0.067	0.113	0.152	0.185
Skewness	-1.03	-0.58	-0.27	-0.48
Excess Kurtosis	3.13	1.55	0.48	0.67
	Spring			
	1	2	3	4
Mean	0.008	0.022	0.028	0.028
Std. deviation	0.069	0.132	0.165	0.183
Skewness	1.19	0.98	0.71	0.51
Excess Kurtosis	4.35	3.54	2.11	0.65
	Summer			
	1	2	3	4
Mean	0.006	0.026	0.044*	0.052*
Std. deviation	0.092	0.149	0.183	0.202
Skewness	1.68	1.69	1.88	2.20
Excess Kurtosis	7.32	6.86	7.42	7.20
	Fall			
	1	2	3	4
Mean	0.019*	0.042**	0.056**	0.061*
Std. deviation	0.116	0.174	0.196	0.219
Skewness	3.48	4.11	2.13	2.48
Excess Kurtosis	20.28	26.70	8.75	12.16

G Regarding the OLS regression

G.1 Concerns regarding correlation in the regression

Multicollinearity arises when two or more variables in a regression model are highly correlated. Correlated explanatory variables will decrease the efficiency of the OLS estimators. The standard errors become biased, and positively correlated variables often appear to be less significant than they are, while all collinear variables may appear more significant than they are. The coefficients will also lack robustness, i.e. they vary a lot depending on input data (Alexander, 2009a).

Using correlation as a dependency measure makes only sense if the time series are constructed from stationary stochastic processes and have a bivariate normal distribution (Alexander, 2009a). If the distributions of the variables are unknown, the feasible values for the correlation measure will not necessarily have limits -1 and 1, but most likely lie in a smaller interval (Alexander, 2009b). Hence, it is hard to detect which variables are close to being perfectly positively or negatively correlated. Even though the raw numbers do not seem to be particularly correlated, variables may be correlated through higher moments, e.g. the first difference, variance and skewness.

G.2 Assumptions of the OLS regression

Linear OLS regression requires certain assumptions to hold. If these are not met, the coefficient estimates may be invalid. We state the different assumptions, and relate them to power market data. Due to space considerations and relevance, we will not elaborate on statistical details.

Residuals equal zero on average

$$E(u_t) = 0$$

The average value of the residuals equal zero. This is achieved by including a constant in the regression, cf. α in Model 1.

Homoscedasticity

$$Var(u_t) = \sigma^2 < \infty$$

The variance of the residuals has the same finite variance. A violation of this assumption, heteroskedasticity, makes it difficult to gauge the true standard deviation of the forecast errors, usually resulting in confidence intervals that are too wide or too narrow. A usual approach for dealing with heteroskedasticity is robust standard errors. We apply the Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator (Newey and West, 1986). The Breusch-Pagan-Godfrey test (Breusch and Pagan, 1979; Godfrey, 1978) and White test (White, 1980) are applied to check for heteroskedasticity.

No autocorrelation

$$Cov(u_i, u_j) = 0, \text{ for } i \neq j$$

The covariance between the residuals is zero. If this assumption is violated, the consequences are the same as for heteroskedasticity. We can solve the problem with both heteroskedasticity and autocorrelation with HAC robuste standard errors. The Ljung-Box test (Ljung and Box, 1979) and Breusch-Godfrey test (Breusch and Godfrey, 1980) are applied to check for autocorrelation.

Exogeneity

$$Cov(x_t, u_t) = 0, \text{ holds if we make the assumption } E(u_t|x_t) = 0$$

The usual approach is to assume that the covariance between the residuals and the explanatory variables is zero. Several studies, e.g. Botterud et al. (2010), make this assumption without carefully considering any obvious reasons for why it does not hold. The violation of this assumption is called endogeneity of regressors, and gives invalid OLS estimates. Weron and Zator (2013) point out three reasons[48] of endogeneity; (1) Omitted variables, (2) simultaneity[49] and (3) correlated measurement errors.

Weron and Zator (2013) argues that the spot price may be influenced by the current situation in the futures market. The spot is calculated at the same time as the futures price is determined, and they are subject to common shocks. This may lead to simultaneity bias. We propose the same solution as Weron and Zator (2013), i.e. to include and exclude the spot price in the regression. If the results

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[48] See Weron and Zator (2013) for a more detailed explanation.

[49] Simultaneity arises when one or more of the explanatory variables is jointly determined with the dependent variable.

from both models are consistent, we choose to disregard bias due to simultaneity. The exclusion of the spot price from the regression will also solve the potential problem with multicollinearity related to this coefficient, cf. section G.1. However, excluding the spot price may result in omitted variable bias, i.e. that some of the other coefficients are assigned too high or too small estimates to compensate for the missing variable.

Weron and Zator (2013) use realised deviations in consumption and inflow from average the trading week[50]. They claim that the realised deviations from average in the period between trade and delivery will produce correlated measurements errors. Thus, the regression estimates cannot be interpreted in the context of an ex-ante model. Botterud et al. (2010) claim that the market participants have access to credible forecasts, making them aware of possible deviations from average at time of trading.

Normality

$$u_t \sim N(0, \sigma^2)$$

The residuals are normally distributed. This assumption is not a requirement for the OLS method to be valid. In practice, few financial and economic variables are normally distributed. However, if the sample size is large enough, and the other assumptions are true, the test statistics follow the central limit theorem and the law of large numbers. Under these assumptions, the variables are asymptotic normally distributed, thus, also the residuals. The Jarque-Bera (Jarque and Bera, 1987) statistic is applied to test for normality.

Linearity

Linear models must be an accurate description of the true relationship between the variables. We can test whether the model is misspecified by using the Ramsey RESET test (Ramsey, 1969). If the null hypothesis of a linear relationship between the variables is rejected, there exist non-linear combinations that have explaining power for the risk premium, making the results biased and inconsistent.

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[50] Botterud et al. (2010) use realised deviations from average in the period from trade to delivery.

Seasonality

Seasonality is not an OLS assumption, but Davidson and MacKinnon (1993) argue that stationary and ergodic[51] time series yield the best regression results. Similar to Weron and Zator (2013), we have separated the reservoir level into two variables; A stochastic (RESD) and seasonal (RESM) component. RESM should capture the seasonal effects of all the other variables. Also, by separating the reservoir level into two components we are able to detect the true influence of varying water levels.

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[51] The observations can be sampled over time on a single process with no change in the measured result, i.e. the observations are independent of season.

H Scatter plots - LRP1

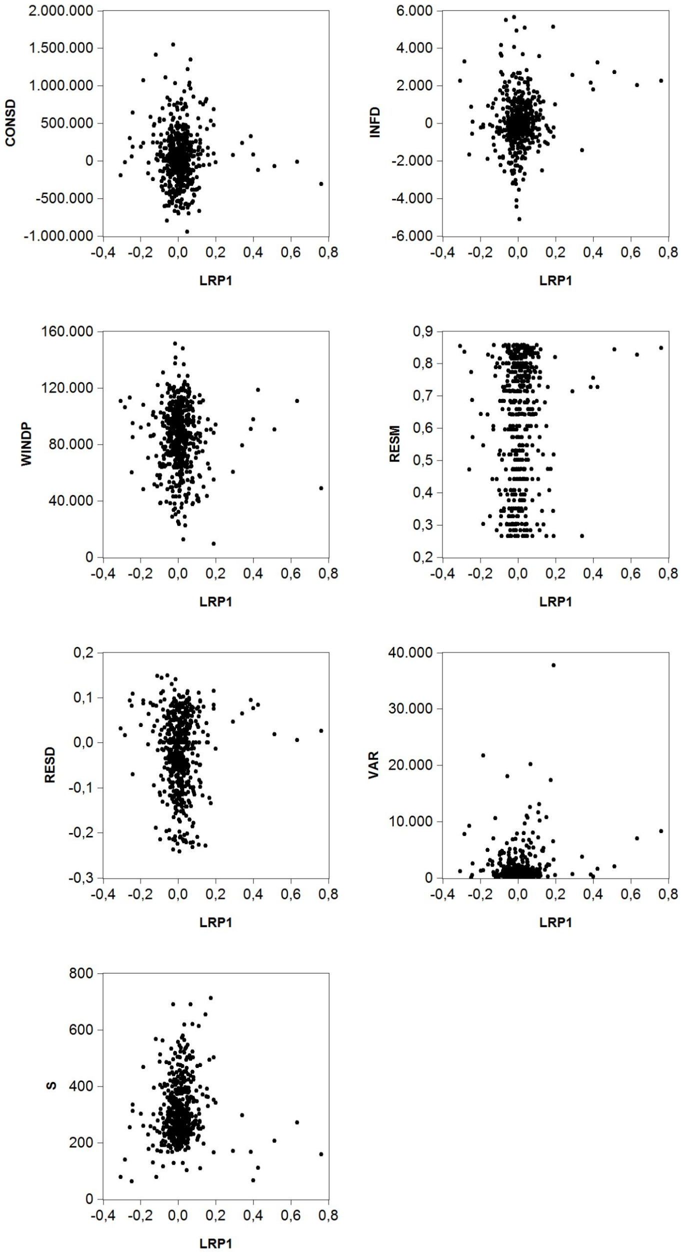

Figure H1: The figures plot the observations of each explanatory variable in Model 1 against the dependent variable, LRP1, for the period 2004-2013.

I Multicollinearity

Table I1: The table shows the correlation measures between the explanatory variables in the regression model. Due to the unknown distributions of the variables, it is not straightforward to interpret these measures, cf. Section G.1

	CONSD	INFD	WINDP	RESM	RESD	VAR	S
CONSD	1						
INFD	-0.301	1					
WINDP	-0.076	0.105	1				
RESM	-0.037	-0.003	0.024	1			
RESD	0.005	0.334	0.014	-0.102	1		
VAR	0.377	0.037	0.070	-0.035	0.047	1	
S	0.266	-0.342	0.027	0.029	*-0.605*	0.249	1

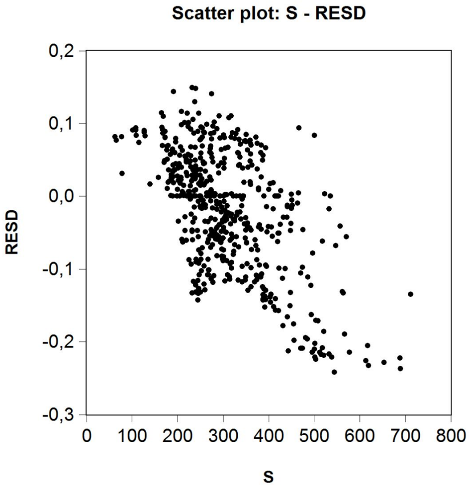

Figure I1: The figure plots the observations on the deviation in reservoir level from the long term average (1995-2013), given as a fraction of 100, and the spot price, given in NOK/MWh.

J Residual plots

J.1 Plot for LRP1

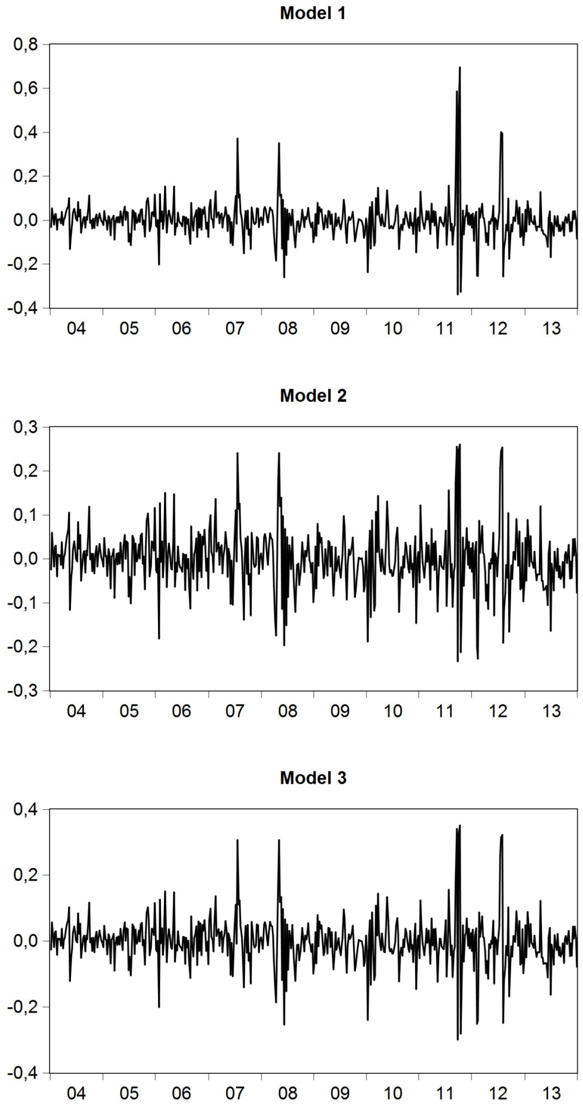

Figure J1: The figures plots the residuals from regression on LRP1 using Model 1, Model 2 and Model 3, respectively.

J.2 Plot for LRP4

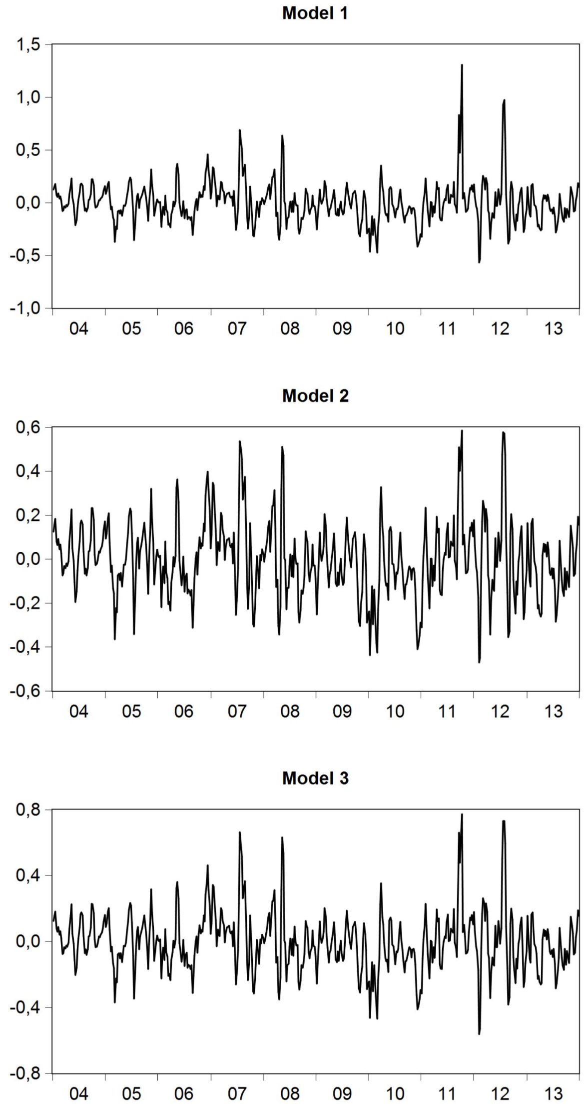

Figure J2: The figures plots the residuals from regression on LRP4 using Model 1, Model 2 and Model 3, respectively.

K Simple linear regression

Table K1: The table provides the results from simple linear regression on each of the explanatory variables in Model 1, 2 and 3 for all holding periods. ***, **, and * indicate significance of the variable at a 1%, 5% and 10% level, respectively, based on Newey-West heteroskedasticity and autocorrelation consistent covariance matrix estimator. An empty cell reflects a non-significant variable, although the regression is valid. The ”n/a” notation reflects a rejected F-test, i.e. the regression is invalid.

		CONSD	**INFD**	**WINDP**	**RESM**	**RESD**	**VAR**	**S**
M1	LRP1	n/a	**	n/a		n/a	**	n/a
	LRP2	n/a	**	n/a		n/a	n/a	n/a
	LRP3	n/a	*	n/a		n/a	n/a	n/a
	LRP4	n/a		n/a		n/a	n/a	
M2	LRP1	n/a	*	n/a	n/a	n/a	**	*
	LRP2	n/a	*	n/a		n/a		
	LRP3	n/a	n/a	n/a	*	n/a	n/a	
	LRP4	n/a		n/a		n/a	n/a	
M3	LRP1	n/a	*	n/a	n/a	n/a	**	
	LRP2	n/a	*	n/a		n/a		
	LRP3	n/a	*	n/a		n/a	n/a	
	LRP4	n/a		n/a		n/a	n/a	