Modelling and predicting the Distribution of Risk Premia in Mid-Term Electricity Futures

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Problem description

Modelling the risk premium in electricity futures using OLS and quantile regression frameworks. The goal is to create a model capable of explaining the variation in forward premia for mid-term futures traded on the Nord Pool power exchange as a function of key economic and physical conditions and to look at how the effects have changed over time, and if the market shows signs of maturing.

Preface

This paper is written as a master thesis for the course *TIØ 4900 - Master Thesis. Financial Engineering* at the Norwegian University of Science and Technology (NTNU) during the spring of 2015. The course is part of the master program *Industrial Economics and Technology Management* and is mandatory for student choosing the *Financial Engineering* specialization. The thesis will investigate the forward premia in the Nordic electricity market using various regression models in the vein of previous research conducted on the forward premium in electricity markets. The paper has been written in LaTeX. The empirical analysis has been performed using the R statistical programming language (R Core Team, 2014).

I would like to thank my supervisors Peter Molnar and Eirik Haugom for their advise and guidance in writing this thesis.

Abstract

This thesis examines risk premia in mid-term electricity futures traded in the Nordic electricity market Nord Pool using a time series of 8 years worth of data. Using OLS and quantile regression the relationship between the forward premium and several economic and physical conditions are examined. The reservoir levels and the basis are found to have a significant relationship with the forward premium both in the OLS and the quantile regression models. The volatility of the spot price is found to have negative effects on forward premia below the median and a positive effect on forward premia above the median, indicating that the effect of volatility on forward premia is highly dependent on the quantile being modelled. The OLS coefficient for volatility is very close to zero indicating that the effect on the mean is not significant. The effects of all the considered variables are considerably larger in the tails indicating that their impact may be larger than estimated in the OLS model, though the results are uncertain.

Evidence is also found to support the notion that market efficiency is increasing as forward premia have decreased over time. Parameters are less significant when analyzing only the most recent data. In addition forward premia have decreased and open interest in the futures has increased in the last portion of the data sample. This suggests that speculative interest has increased and investors have gained experience.

Sammendrag

I denne oppgaven analyseres risikopremien i månedslange elektrisitets futures handlet i det nordiske kraftmarkedet i perioden 2005−2014. Ved hjelp av OLS og kvantil regresjon blir sammenhengen mellom risikopremien og en rekke nøkkelvariabler av økonomisk og fysisk art undersøkt. Både OLS-modellen og kvantil regresjon modellen viser at fyllingsgraden i vannmagasinene og basisen har en signifikant effekt på risikopremien. I tillegg viser kvantil regresjonen at volatiliteten til spot prisen har en signifikant negativ effekt på risikopremien for kvantilene under medianen og en positiv effekt over medianen. OLS koeffisienten for volatiliteten er svært nærme null og det tyder på at effekten på gjennomsnittet er svært liten. Ved hjelp av kvantil regresjon vises det og at effektene for de aller fleste av de vurderte variablene er høyere i halene. Det er knyttet en del usikkerhet til disse resultatene, men det tyder på at effekten er sterkere for ekstreme risikopremier.

Videre har tidsserien blitt delt i to for å se om risikopremien har endret seg over tid. Det viser seg at risikopremien er blitt lavere mens likviditeten har økt i de siste 4 årene sammenlignet med de 4 første. I tillegg er signifikansen til de forklarende variablene betraktelig lavere i periode to. Dette tyder på at markedet er blitt mer effisient over tid ettersom spekulativ interesse har økt og investorer har tilegnet seg erfaring.

Contents

1. Introduction

The behaviour of commodity prices and their financial derivatives has been an important area of economic and financial study for a long time. Many of the commodities that are currently traded in the world are necessary for our survival. Foodstuffs, metals, minerals and other raw materials as well as electricity are all commodities necessary to sustain the modern way of life.

An important function of financial markets has always been the allocation of risk to those investors willing to bear them. Finding good models to describe and predict price behaviour in these markets is therefore an important task so market participants can know when and how large risks they are taking.

With the deregulation of electricity markets around the world an important commodity is now traded on regional exchanges, both directly and through derivatives. These exchanges mirror traditional financial markets trading in stocks and securities. Most of the traditional models used to describe the behaviour of financial assets is however not usable to describe electricity markets. Electricity features some important differences to other commodities and financial assets. It is not storable in economically significant quantities and demand and to a lesser degree supply are highly dependent on the weather and have a large impact on the price causing larger volatility than for most other assets and a larger possibility of upward price spikes (Weron, 2008).

This behaviour underlines the importance of good hedging strategies and the availability of derivatives. In practice one of the most important hedging tools for electricity firms are forwards and futures, which enables them to fix their price at some point in the future. The relationship between the forward or futures price and the spot price has been the subject of much research. The earliest works can be traced back to the no-arbitrage approaches presented in Keynes (1930) and Kaldor (1939). As electricity is not storable the classical approach of no-arbitrage pricing is not generally viable for describing the relationship for electricity and its derivatives as they typically rely on hedging strategies that involve holding the underlying asset for some period of time, which is not possible with electricity (Bessembinder and Lemmon, 2002).

The alternative approach is based on equilibrium models where the difference between the forward price and spot price is described using a risk premium (or forward premium[1]) (Fama and French, 1987). In this thesis the focus of study will be the forward premium which is the negative of the risk premium as defined by Weron and Zator (2014). The

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[1]The language on risk and forward premia is not wholly consistent in the literature, with the risk premium and forward premium being defined the same way in some papers and different in others, see Weron and Zator (2014) for a more detailed look at this.

study of risk premia in electricity futures have largely used the definition for the forward premium as the object of study and this thesis chooses the same approach. The approach of utilising the risk premium to describe the relationship between the forward and spot price has been an object of several recent empirical studies on electricity futures (Botterud et al. (2010), Lucia and Torró (2011) and Weron and Zator (2014) being the most important ones on the Nordic power market).

Risk premia in futures and forward in electricity markets have mainly been researched in two main respects. The analysis of whether there exists significant premia and what market and physical conditions have an impact on the observed premia. Equilibrium considerations have been used to predict what effect certain changes in the market conditions will have on the risk premia, by focusing on how they are likely to change supply and demand for futures relative to one another (Bessembinder and Lemmon, 2002).

No consensus has yet been reached on whether or not mature electricity markets should exhibit risk premia or which factors impact the size and sign of the risk premium. An important reason is the differences in supply and demand characteristics between the various regional electricity markets that have been studied. In addition to this most electricity markets are still relatively young and researchers have just recently gotten access to relatively long and stable time series. Some of the more influential early works, such as Bessembinder and Lemmon (2002), Longstaff and Wang (2004) and Villaplana (2003) suffer under a lack of data, in addition to the fact that the market likely has changed over the last 10 to 12 years. As the markets are relatively young an important question yet to be answered is whether the observed risk premia represent a market price of risk or if they represent market inefficiencies (Weron and Zator, 2014).

The Nordic electricity market has been a relatively popular object of study owing to it being amongst the first deregulated electricity markets in the world (Bye and Hope, 2005). The large proportion of hydro electricity in the Nordic electricity market has even led to some studies where the hydro reservoirs are used as a proxy for storing electricity (see for instance Botterud et al. (2010)). The Nordic electricity market shows lower volatility and lower prices than other electricity markets, probably due to the large proportion of flexible hydro electricity production.

Botterud et al. (2002), Lucia and Torró (2011) and Weron and Zator (2014) all find evidence of risk premia in futures in the Nordic electricity market. These papers also use regression methods to describe the relationship between the observed risk premia and market conditions, which will also be the focus of this thesis.

The research available thus far has mostly focused on short-term contracts , primarily day-ahead futures (Bessembinder and Lemmon (2002), Longstaff and Wang (2004)) and weekly contracts (Lucia and Torró (2011), Botterud et al. (2010)). Mork (2006) did some analysis on the forward premium for futures with a delivery period of one month, but

the dataset is old and analysis of more recent data is lacking. This thesis will therefore focus on 1 month futures of which there are no recent studies on the risk premium in the Nordic electricity market.

This thesis will analyze models that can describe and predict forward premia in 1-month futures based on important physical and economic characteristics of the Nordic electricity market. The thesis will extend the literature on electricity futures by considering an 8 year long recent time series on spot and mid-term futures contract prices traded on Nord Pool between 2005 and 2013. Specifically it will look at the relationship between the risk premium in mid-term futures and various physical and economical underlying variables. This work follows in the footsteps of among others Botterud et al. (2010) and Weron and Zator (2014). The empirical analysis will include variables that have been studied earlier, such as the reservoir levels (Botterud et al., 2010) and volatility (Bessembinder and Lemmon, 2002) of the spot price as well as variables that have not been studied extensively. The goal is to develop a model that can describe the relationship between the forward premium, the demand for futures, temperature, the volatility of the spot price, reservoir levels, overall market risk as expressed by the VIX index and the basis.

The thesis will also analyze the evolution of the Nordic electricity market over time. Electricity markets are fairly young still and speculative interest in these markets has likely been increasing. By splitting the sample in two any changes in the market that has occurred over the 8 years considered can be quantified and studied. As noted by Mork (2006) one would assume that risk premia decrease and speculative participation increases over time as market participants gain experience and the understanding of the market mechanisms increases. Using the most recent data available enables an analysis of how market efficiency and investor experience impact the forward premia found in Nordic electricity futures.

Using quantile regression as well as OLS regression the effects of the mentioned variables will be examined both for the mean and across all quantiles. Quantile regression models have so far been unexplored in the area of risk premia and this method will enable analysis of how the effects of the variables changes based on which quantile of the forward one wishes to model. A quantile regression model will give a more realistic model for the highest and lowest premia and will give market participants a better understanding of where the forward premia is likely to be. The quantile regression models will enable the worst and best possible outcomes to be predicted based on the same data where an OLS model would give an indication of the expected average forward premium based on market conditions. Market participants will be more interested in the tail effects as extreme forward premia will have a larger impact on their profitability. The quantile regression framework also enables analysis of trends in the variables relationship to the forward premium depending on the quantile modelled.

The rest of the thesis is organized as follows. Chapter 2 will look at the defining charac-

teristics of electricity markets and electricity as a traded commodity. Chapter 3 will go through the literature on the risk premium in futures and forwards focusing especially on electricity futures traded in the Nordic area. Chapter 4 will go through methodology and data selection. Then in chapter 5 the results of the empirical analysis will be discussed before chapter 6 concludes.

2.   Electricity markets

In this chapter the defining characteristics of electricity markets will be explored. First the trend of deregulation that has happened in the electricity sector over the last twenty or so years will be discussed, focusing on the Nordic electricity market. Then the current organisation of the Nordic electricity market will be presented. We will then discuss some of the defining characteristics of electricity as a commodity and their implications, before discussing some of the central issues when modelling the spot price of electricity. As will be seen the literature on electricity as a commodity is relatively young as deregulated electricity markets have only existed for a relatively short amount of time compared to other financial commodity markets.

2.1   Deregulation of electricity markets

The deregulation of electricity markets is a relatively new development. The earliest deregulations started around the beginning of the 1990s. Before that electricity production and transmission was dominated by large vertically integrated entities, usually controlled by governments. Arguments of economies of scales and the need to secure efficient supply were used in favour of the regulated nature of the markets (Weron et al., 2004).

Eventually deregulation processes were started several places around the world at about the same. Microeconomic theory would argue that the introduction of competition to a market should decrease prices and increase the socioeconomic profit to society. Another important argument in favour of deregulation was investor behaviour (Bye and Hope, 2005). The incentives in the Norwegian electricity market led to overinvestment and a large amount of excess capacity (Bye and Hope, 2005).

The current Nordic electricity market Nord Pool traces its roots back to the Norwegian electricity market. Bye and Hope (2005) go through the background for the deregulation of the Norwegian electricity market and the experiences that can be drawn from it. There were three forms of inefficiency that were present in the Norwegian market before the deregulation. Inefficiencies in production and production capacity due to the way prices were set, inefficiencies in the transmission and distribution of the power and inefficiencies in the market. Inefficiencies in the market were shown by different consumer groups paying different prices for electricity (Bye and Hope, 2005). The deregulation led to lower prices and prices between consumer groups became more equal. Investment both in transmission and production capacity fell and the return on capital increased. Regionally the market concentrated due to transmission constraints, and although no evidence for

abuse of market power was found opportunities for the abuse of market power has certainly appeared (Bye and Hope, 2005).

With the deregulation both a physical power exchange and a market for financial derivatives on electricity was created. As electricity became an exchange traded commodity participants in the electricity sector became more exposed to price risks. The main purpose of derivatives market is typically to supply instruments firms and investors can use to hedge their risks, something that was needed as power firms faced a price set by supply and demand rather than political decree as was the case in Norway before the deregulation started (Bye and Hope, 2005).

The deregulation of the Norwegian electricity market started in 1991 where Statnett Marked set up the first electricity pool in Norway. By 1996 all Norwegian consumers had free choice of electricity suppliers and Statnett Marked was succeeded by Nord Pool as a joint electricity exchange for the Norwegian and Swedish electricity markets. In 1997 clearing of standardised financially settled futures are introduced and two years later in 1999 Nord Pool introduced trading and clearing of standardised options.

As these markets are fairly new both researchers and market participants did not have experience or knowledge of how these markets would function. Electricity has some characteristics that separate it from other commodities meaning that pricing theory typically applied to commodities might not be appropriate. In addition energy firms would not need as much financial expertise to trade in the electricity market before the deregulation, leading to a lack of experience with these activities. Although Nord Pool has had some form of spot market even before the deregulation, which has likely made it more successful than other markets as participants faced a less steep learning curve (Bye and Hope, 2005).

Since 1999 the market has been gradually increased as new countries join Nord Pool. Currently Nord Pool operates the electricity market in Norway, Denmark, Sweden, Finland, Estonia, Latvia and Lithuania.

2.2 The Nordic electricity market

The Nordic electricity market will now be discussed, both the physical markets for electricity and the market for financial derivatives using the Nord Pool spot price as the underlying asset.

2.2.1 The physical electricity market

The Nordic physical electricity market is operated by Nord Pool Spot ASA. At present it runs a combined day-ahead spot market (Elspot) (NordPool, 2014a) and an intraday market covering the same area to ensure balance in the grid (Elbas) (NordPool, 2014b). Trading in the day-ahead market closes at 12.00 the preceding day. Trading in Elbas takes place until one hour before delivery.

Market participants in the Elspot market place orders to buy or sell electricity for every hour of the next day. Nord Pool's algorithm then generates the system price by aggregating the orders. The system price does not take transmission constraints into account. This will likely lead to congestion and to alleviate this the market is divided into several price areas with different prices based on the supply and demand in the given area. The bidding areas are divided by country and then further divided within each country based on the decision of the total system operator in each country (NordPool, 2014c)[1].

The Nord Pool system price is first generated on a per hour basis as demand usually follows a predictable pattern within a 24 hour period. Demand is highest during working hours as businesses contribute significantly to demand and lower in the evening and at night. The daily spot price is then generated by taking the arithmetic average of all 24 hours of the day. This daily spot price is then used as the underlying asset for the traded financial derivatives.

Trading on Elspot and Elbas requires physical delivery of the electricity that is traded. Therefore trade in these markets is dominated by electricity generating companies and utilities. Within the Nord Pool area there are more than 370 electricity producing companies and more than 370 utilities selling electricity to end-users.

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[1]For instance Norway is divided into 5 price areas whereas all of Denmark is in the same price area

2.2.2   Financial derivatives market

In addition to the physical markets there is a financial market for trading derivatives based on the Nord Pool prices. The financial market is currently operated by Nasdaq Commodities Europe. Nasdaq offer trading of futures, options and area price differentials based on the system and area prices in the Nord Pool area. The financial market used to be a subsidiary of Nord Pool, but in 2008 it was spun off into a separate entity and sold to Nasdaq.

Nasdaq Commodities offer a variety of derivatives based on the system and area prices within the area covered by the physical Nord Pool markets. The derivatives offered include options, futures, forwards and contracts for differences (CFDs). CFDs are used to hedge price area risk. The futures and forward contracts offered are used by participants in the physical electricity markets to hedge their price risk as well as speculative investors looking to make a profit.

Nasdaq offer two different types of futures contracts on the Nord Pool system price, "normal" futures and deffered settlement (DS) futures. The difference between them is the sizes of the delivery periods and how the mark-to-market amount during the trading period is settled. The normal futures are marked-to-market every day during the trading period and the change in price will be credited or debited the buyer or seller of the futures every day (NasdaqOMXEurope, 2014a). The deferred settlement future will just accumulate the prices and the difference between the price of the futures when it was bought and the final futures price will be settled at the beginning of the delivery period (NasdaqOMXEurope, 2014b). The futures offered on Nasdaq OMX have times to maturity varying from 1 day up to several years. The contracts also specify the size of the time period for the delivery. All futures contracts available are cash-settled with no physical delivery expected. Bye and Hope (2005) indicate that the volume in the derivatives is about five times the volume of physical trade and that the ratio has been increasing since 2003. This is not surprising as the high prices caused by the cold winter and low amount of precipitation that winter would likely increase demand for risk hedging instruments.

2.3 Defining characteristics of electricity as a commodity

The most important characteristic of electricity as a commodity is that is is not storable in any economically meaningful quantity. Although fuel or water in a hydro electricity reservoir can be stored and used to create electricity at a later point in time there is a constraint on the amount of electricity that can be generated at any point in time. The implication of this feature is that no-arbitrage pricing approach for forwards cannot be used to price electricity forwards. These approaches rely on buying a commodity at the spot price to store it and sell it at a point in time in the future. This means that there is no reason to believe electricity forward prices follow a cost-of-carry relationship.

Another limitation to the trading of electricity is the restrictions on transportation of electricity. Any closed power system needs to be in balance between supply and demand and the transportation capacity is capped by the transmission grid. This means that no-arbitrage approaches for comparing prices geographically will not be successful. An investor cannot easily buy electricity in one electricity market and move it to another to sell there. Essentially the spot price is determined by local conditions that impact supply and demand curves within a geographically delimited area (Douglas and Popova, 2008).

Electricity is used by both industrial customers as well as private households and corporations. In the short-term demand is very inelastic as consumers do not directly see the cost of electricity as it is consumed. Consumers of electricity will not have real-time pricing information and will use electricity for the services they deem necessary. This can be space heating, lightning, cooking, electronics etc.

In addition to this there are recurring patterns in the demand for electricity. Demand usually follow predictable fluctuations within a day, within a week and within a year. Within a day demand is highest during working hours as businesses contribute to the peak load with off peak hours being during the evening and night. The biggest variations are the seasonal ones and the specific pattern the demand follows changes between electricity markets. Peak demand within a year is usually connected to the temperature. In the American PJM market peak demand occurs on hot days were demand for air-conditioning is particularly high. Heating here is predominantly covered by other sources than electricity. In the Nord Pool area peak demand occurs on the coldest days. Here space heating is a large driver of electricity demand.

Supply in electricity markets is restricted by the available generation capacity. Typical geographically delimited energy markets have a mix of generation capacity from various sources including hydro, coal, gas, wind and nuclear.[2] The various sources of electricity

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[2]For   instance   http://www.nordpoolspot.com/How-does-it-work/The-market-members/

have different marginal costs and vary in how easily their output can be changed. Hydro power features very low operating costs and can very easily vary the output electricity by just turning a valve to change the flow of water over the turbine. Whereas for nuclear power plants changing the output is a time consuming and expensive process. These features mean that the supply curve in a electricity market typically has several jumps in the available capacity at any given price point. And especially as demand increases to its peak over a year the marginal cost of electricity can get extremely high. Some production methods also feature variation in available output. Notably hydro, wind and solar power which are all dependent on weather conditions to be able to produce power.

Together these features impact the spot price distribution and evolution to a large degree. Electricity spot prices typically follow seasonal variation on the yearly, weekly and daily level (Weron, 2008), caused by the seasonal variations in supply and demand of electricity. In Nord Pool the behaviour is generally high prices during the cold parts of the year and lower prices during summer, as demand is highest during the winter. It is not just the price that varies with the seasons, but also the variance of the spot price. One possible explanation is that the variance of the temperature also displays a seasonal variation with larger variance in the temperature in some parts of the year than others (Weron, 2008).

Another important feature of the electricity spot price are price spikes. Infrequently the electricity spot price will show large upward swings in price, that typically do not persist (Weron, 2008). This means the electricity spot price to be more volatile than most other high volatility commodities. This is caused by the combination of no storage and limited transmission capacity as well as very inelastic demand in the short term. These jumps in the spot price are generally not persistent and tend to be caused by unexpected changes in supply or demand, such as extremely cold weather, power plant outages or other unpredictable events. These jumps are typically manifested by time series of spot prices exhibiting high right skewness and high kurtosis indicating that the possibility of large upward changes in price are more likely than for the Gaussian normal distribution.

`Producers/` shows the typical mix of generation capacity within the area covered by Nord Pool.

2.4 Modelling the spot price of electricity

The features of electricity as a commodity discussed in the previous section need to be captured in any model meant to describe the evolution of spot prices. Typically the time series of prices for a financial asset are modelled with the use of stochastic processes (Mcdonald, 2014). These processes are usually based on Brownian motion which is a process that is continuous and evolves in continuous time (Mcdonald, 2014). The base Brownian motion process is a random walk process and is therefore not particularly useful to represent the price of an asset as most financial assets do not follow random walk processes.

Generally stochastic processes used to model the behaviour of asset prices feature a drift term and a volatility term as a bare minimum. The drift term can be a constant or variable and indicates the general trend of the asset price. The volatility term is used together with a stochastic process to generate movements in the price for every increment in time (Mcdonald, 2014).

The electricity spot price typically features some measure of mean reversion, meaning that prices will tend to converge back towards some mean level. Although prices are seasonal large fluctuations from the expected seasonal variation tend to be short-lived, as they are usually caused by unexpected and short-lived events that impact supply or demand. The modelling of spot price time series has gotten attention by Weron et al. (2004) and Villaplana (2003). Villaplana (2003) use data from the PJM market to test their model empirically while Weron et al. (2004) focus on the Nordic electricity market.

An important part of understanding the behaviour of electricity prices is the stack of possible generation capacity, which is typically ranked in terms of marginal cost. A stylized supply curve is seen in figure 2.1 showing marginal costs plotted against the generation capacity (Weron et al., 2004). The large portions with low marginal cost typically represents hydro and nuclear power, then coal and combined heat and power units follow with gas power plants typically having the largest marginal costs. By looking at this figure it is obvious that demand shocks when demand is already quite low will not have a large impact on the spot price, but even small demand shocks that happen when demand is high can lead to very large changes in price. This contributes significantly to the high right skewness typically exhibited by the electricity spot price.

There are three main features of electricity prices any spot price model needs to take into account, mean-reversion, seasonal fluctuations and jumps (Weron et al., 2004). All three of these features are influenced by electricity not being storable and how important supply and demand is for the price setting. Jumps are typically caused by extraordinary conditions and as soon as conditions return to the ordinary the price will revert to the mean expected from looking at supply and demand (Weron et al., 2004). Taking this
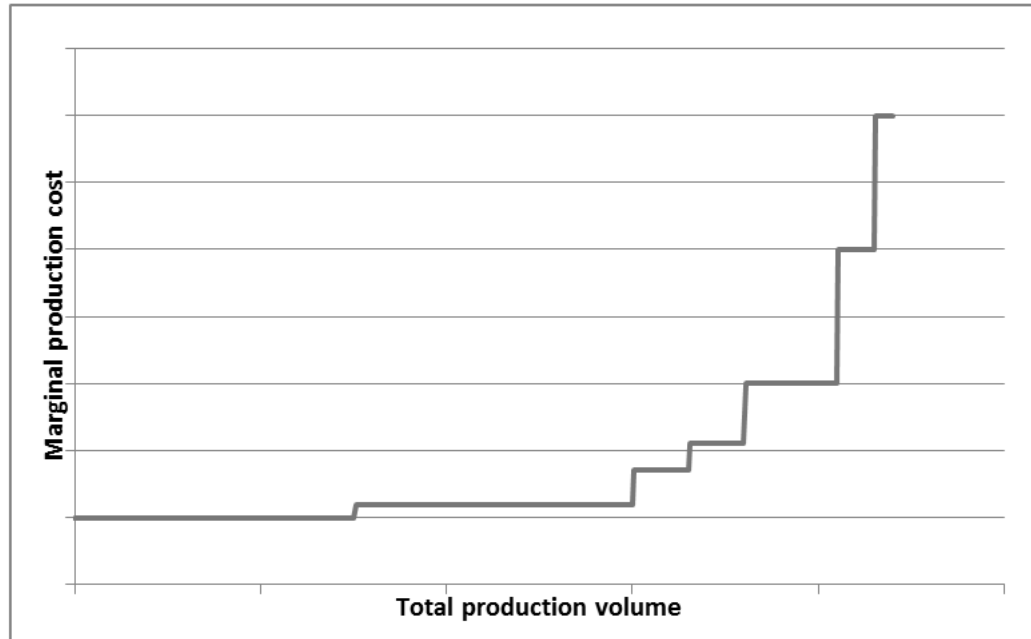
Figure 2.1: Typical supply curve in an electricity market

into consideration Weron et al. (2004) suggest a jump-diffusion model to describe the behaviour of the spot price over time. The empirical analysis suggests that their model is a good fit for modelling the spot price of electricity in the Nordic market.

As we will see modelling the spot price and the expected spot price directly is one way that can be used to calculate the ex ante risk premia.

3.   Risk and forward premia in electricity markets

In this chapter the theory and research on futures prices and their relationship to the spot price will be looked at. We will first briefly present the general theory on the pricing of futues. Then the difference between forward and risk premia will be addressed before delving into the theory on risk and forward premia which is established as the most accurate approach for analyzing the relationship between forward prices and spot prices for electricity. We will then look at findings from various electricity markets around the world before focusing on research conducted on the Nordic electricity market as in this thesis.

3.1   The pricing of futures

Traditionally there have been two main approaches to the pricing of forwards and futures (see for instance Hirshleifer (1990) or Fama and French (1987)). One line of reasoning is based on no-arbitrage assumptions and the possibility of creating a replicating portfolio to the forward. If no-arbitrage conditions hold the replicating portfolio should have the same value as the forward contract. Using this a relationship between the forward price and the spot price is relatively easily obtainable.

The second approach used to model forward prices is based on equilibrium considerations. These models generally focus on the forward premium, the difference between the forward price and the expected spot price. In an equilibrium model the forward premium represents the compensation for holding price or demand risk for a given commodity. Classically as in works by Keynes and Hicks (as referenced in Hirshleifer (1990)) the assumption is that the forward premium should be negative due to the demand for short positions in forwards created by producers of a commodity who are looking to hedge their risks. Hirshleifer (1990) finds that the optimal hedging positions, and thus the hedging pressure on the forward price varies depending on whether demand is elastic or inelastic. This implies that the forward premia can be positive, zero or negative depending on the economic conditions of the market one wishes to model. One important note about the models considered in the paper is that it assumes that some amount of consumers do not participate in the futures market. For electricity futures this will propably not hold as both producers and "consumers", for the most part utilities, will face price risks and thus have demand for futures contracts.

The theory of normal backwardation has generally been used to describe forward premia

in futures markets (Mork, 2006). According to this forward premia depend on the risk preferences of investors wishing to hedge their positions and speculators. If a market is in backwardation futures prices are below the spot price and sellers pay a premium to hedge their prices at a point in the future. As there is a premium on average speculators will have an incentive to buy futures (Mork, 2006). The opposite situation is contango where buyers have to pay a premium to fix their price in the future. The sign and size of the forward premium depend on the relative demand for hedges between buyers and sellers of a given commodity.

Hirshleifer (1989) go through several determinants of futures risk premia for commodities in general. Here the effects of several factors are analysed as they impact either the hedging premium or the general stock market premium. Under the assumptions of the capital asset pricing model (CAPM) a risky security will have a risk premium consisting of a part proportional to its covariance with other traded assets and a term proportional to its covariance with non-diversifiable risks. Participants in commodity markets, such as producers and whole-sale buyers will likely not hold diversified portfolios within any one commodity. This will affect the demand for futures used to hedge the price risk of participants in commodity markets. This change in demand will in turn influence the risk premium and cause it to deviate from the pure CAPM prediction. Hirshleifer (1989) present this starting point and improves on older models to include more realistic market assumptions. Specifically harvest costs and barriers to entry into the futures market are included as factors impacting the commodity futures risk premium. The determinants considered to have significant non-zero effects on the futures risk premia through hedging pressure are harvest costs, demand and supply variability and the correlation of demand and production output. All of these conditions exist in electricity markets to some degree. Harvest costs can be likened to the marginal production costs of electricity and as has already been argued demand and supply variability has a very high impact on prices in electricity markets.

3.2 Risk premium versus forward premium

In the literature on electricity futures the terminology on the risk premium is not wholly consistent. The forward premium as defined in equation 3.2 below is used in the majority of studies including Daskalakis and Markellos (2009), Longstaff and Wang (2004) and Lucia and Torró (2011). There does seem to be some terminological confusion as Weron and Zator (2014) notes that different researchers have used the forward premium and the risk premium interchangeably as terms to describe the premium defined in equation 3.2. In this thesis the forward premium will be used as the measure of the relationship between spot and forward prices as it is the most widespread measure in the literature.

There is also some differences in how exactly the forward premium is defined. As is often the case with financial data presenting the premium as a relative value rather than an absolute value is preferable. The two most popular definitions are the percentage and logarithmic definitions of the forward premium as in equation 3.6 and 3.7. Haugom et al. (2014) argues that the logarithmic forward premium is most suited for OLS regression purposes. The logarithmic definition is used in Haugom et al. (2014), Botterud et al. (2010) whereas the percentage definition of the forward premium is used by Daskalakis and Markellos (2009) and Longstaff and Wang (2004). In this thesis both definitions will be used to analyze whether the choice of definition has an impact on the considered regression models or not.

In the following when referring to the forward and risk premia the terminology is the same as that used by Weron (2008) (see section 3.3 for mathematical definitions of the forward and risk premium).

3.3   Defining the risk premium

The risk premium $RP(t,T)$ for futures is defined as the difference between the expected spot price $E_t[S(T)]$ and the futures price $F(t,T)$. This is the so called ex ante risk premium. Where t is the time the future is bought and T is the time of maturity for the future contract. Weron and Zator (2014) uses the risk premium, but also notes that some papers use the forward premium and some papers use the forward premium while calling it the risk premium. In the following the forward premium will be defined rigorously. The forward premium is the negative of the risk premium and will be the focus of this thesis.

$$RP(t,T) = E_t[S(T)] - F(t,T) \tag{3.1}$$

The ex ante forward premium $FP(t,T)$ for a futures contract is the difference between the futures price $F(t,T)$ and the expected spot price $E_t[S(T)]$. The relationship between the futures price the expected spot price and the forward premium can be expressed as in equation 3.2 (Lucia and Torró, 2011).

Another important measure is the basis presented in equation 3.3. This is the difference between the forward price F(t,T) at some point in time t for delivery at time T and the spot price S(t) at time t (Lucia and Torró, 2011)

$$F(t,T) = E_t[S(T)] + FP(t,T) \tag{3.2}$$

$$B(t,T) = F(t,T) - S(t) \tag{3.3}$$

The problem with the ex ante premium is that the expected spot price is not readily available. The spot price is dependent on factors that are outside human control and impossible to know perfectly, particularly the weather. To use this premium in an empirical analysis some form of model for the expected spot price needs to be developed. This presents a difficult econometric problem, that has been tackled by amongst others Villaplana (2003) and Weron et al. (2004). Two main ways to analyze the forward premium has been used, either a model for the expected spot price is used, or one can choose to analyze the ex post forward premium in stead. Not having to rely on making assumptions on how to model the expected spot price makes the ex post forward premium an attractive option (Lucia and Torró, 2011).

The ex post forward premium is defined as the difference between the futures price $F(t,T$ and the spot price at maturity $S(T)$. This has the advantage for statistical analysis that the spot price at maturity will be readily available from time series of spot and future prices. This makes the ex post forward premium attractive for any time series analysis on the forward premia. With these definitions the ex post forward premium can

be decomposed into the ex ante forward premium and a forecast error. Under standard assumptions that the forecast errors are random noise evidence of a non-zero ex post forward premium will also be evidence of a non-zero ex ante forward premium. Due to these properties most studies choose to analyze the ex post forward premium (See Weron and Zator (2014) for a review). The ex post and ex ante forward premia can be related with the forward price, the expected spot price and the actual spot price as in equation 3.4 below. An important point made in Haugom and Ullrich (2012) is that deregulated electricity markets are relatively young and as such the assumption that the forecast errors are random noise may not be correct. In such a case a non-zero ex post forward premium is not necessarily evidence of a non-zero ex ante premium. Analyzing the ex post premium will still be preferable to analyzing the ex ante premium however as the difficulties in accurately modelling the expected spot price are at least as big.

$$F(t,T) - S(T) = FP(t,T) + E_t[S(T)] - S(T) \tag{3.4}$$

Using this equation the ex post forward premium is given as the ex ante or expected forward premium plus any unexpected variations in the spot price, and they can be related as in equation 3.5. The percentage forward premium and the logarithmic forward premia are also defined in equations 3.6 and 3.7.

$$F(t,T) - S(t) = FP(t,T) + E_t[S(T) - S(t)] \tag{3.5}$$

$$PFP(t,T) = \frac{F(t,T) - S(T)}{F(t,T)} \tag{3.6}$$

$$logFP(t,T) = ln(F(t,T)) - ln(S(T)) \tag{3.7}$$

Most studies agree that the forward premium should not be expressed in absolute terms, as the right skewness observed in electricity prices means that the premium in absolute value is heavily influenced by large outliers (see Daskalakis and Markellos (2009) and Longstaff and Wang (2004)). Haugom et al. (2014) however chooses to use a logarithmic forward premium arguing that it is more suited for OLS regression purposes. There is no consensus on whether defining the forward premium logarithmically or as a percentage is the best way. As such in this thesis both definitions of the forward premium will be analysed to see if there are any significant differences.

3.4   The forward premium in Electricity futures

In this section the research on forward premia in electricity futures will be presented. First we will look at the research on the existence of the forward premium. We will then look at research attempting to explain the forward premium before looking finally at the large amount of research conducted in the Nordic electricity market.

3.4.1   The existence of the forward premium in electricity futures

The seminal work on the forward premium in electricity futures is found in Bessembinder and Lemmon (2002). The paper develops an equilibrium model to explain the forward premium in the American PJM market[1] under assumption that the price is determined by power producers and retailers, without input from speculative investors. The model is based on the assumption that power producers are net short in forwards to guarantee a certain price for some amount of their production capacity, whereas utilities providing electricity to end-users are net long in the forward to hedge the risk of price spikes. These assumptions mean that as the spot price distribution skewness increases, demand for forwards will increase from the utilities. All other things being equal this will increase the price of forwards as whoever is going short on these forwards would want a compensation, in this case a larger forward premium. Next it is assumed that the variance of the spot price has a negative relation to the forward premium. This is caused when the expected spot price is below the retail price, in which case an increase in spot price variance will reduce the downside risk of utilities. Thus their demand for forward contracts should fall reducing the price of forwards and the forward premium (see also Douglas and Popova (2008) for a take on the Bessembinder and Lemmon (2002) assumptions). The model features several simplifying assumptions about the electricity market to create a solvable equilibrium price model for futures. The paper focuses mostly on exploring the biasedness of the forward price as a predictor of the subsequent spot price. The paper features some limited empirical evidence and finds evidence of significant forward premia during the summer period. This is the period with highest demand for electricity and thus the most skewed distribution of prices as extreme prices caused by adverse market conditions are more probable. The paper also finds significant relationships between spot price skewness and variance and the observed forward premia.

Longstaff and Wang (2004) test the implications of the model presented in Bessembinder and Lemmon (2002) more thoroughly and also present some statistical analysis of the observed ex post risk premia found in hourly spot and day-ahead forward prices in the

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[1]PJM is a regional transmission operator and an electricity market operator in eastern USA, for more info see `http://www.pjm.com/about-pjm/who-we-are.aspx`

Pennsylvania, New Jersey and Maryland (PJM) electricity market in the United States. Although the dataset is limited to two years the paper finds evidence of significant forward premia in the hourly prices, and that the forward premium varies significantly depending on the time of year and the time of day. The paper also compares the observed forward premia to time-varying risk measures such as the conditional volatility of electricity demand, spot prices and total revenue and examines the relative volatility of forward and spot prices. The paper finds evidence that the forward premium is positively related with the mentioned risk measures. The empirical analysis also shows that the forward price has less volatility than the observed spot price which suggests that electricity forwards exhibit significant forward premia.

Villaplana (2003) also analyse data from the PJM market. The goal here being predominantly to find a process to adequately model the time series of spot prices. Specifically a jump-diffusion approach with two factors is used to capture the dynamics of the spot price. The connection to the seasonal pattern of the forward premium is captured through seasonality in the probability of jumps. In periods where the probability of jumps in the spot price is close to zero the forward premium should be small and mostly explained by the variance in the spot price. In periods where there is a significant probability of price jumps this should drive demand for futures up and also the forward premium. A higher probability of price jumps implies more positive skewness over the period as the possibility of large prices increase. This supports the Bessembinder and Lemmon (2002) model and Villaplana (2003) reaches the same conclusion as Bessembinder and Lemmon (2002). Namely that spot price skewness and variance drives the forward premia in this market.

Haugom and Ullrich (2012) revisits the forward premia found on the PJM market using a more recent dataset. Both Bessembinder and Lemmon (2002) and Longstaff and Wang (2004) found evidence of significant forward premia in the day-ahead market. Haugom and Ullrich (2012) repeat the analysis conducted by Longstaff and Wang (2004) using the most recent dataset available at the time. The paper uses the logarithmic definition of the forward premium. By using a rolling window of 365 days and recursive estimation with a dataset from 2001 to 2011 the model from Bessembinder and Lemmon (2002) is estimated and an evolution of the impact of skewness and variance on the forward premium is calculated. For the first years of the sample evidence is found in favour of the Bessembinder and Lemmon (2002) model. The regression explains about 60 % of the variation in the data and parameters for both skewness and variance are significant and with the predicted sign. Over time the model performs significantly worse, with the coefficients changing signs and the confidence bands generally including zero. This indicates that the model presented in Bessembinder and Lemmon (2002) cannot explain the behaviour of the forward price in the PJM market at present.

Going further Haugom and Ullrich (2012) use a rolling window and recursive estimation on the unbiased forward rate hypothesis (UFH), which is a simple regression model where

the spot price is related to the forward price, a constant and an error term as in equation 3.8. Here S_{t+1} is the spot price in period t+1, $F_{t,t+1}$ is the forward price observed at time t for delivery in period t+1 and ϵ_{t+1} is an error term. Under the null hypothesis the errors should have mean 0 and be serially uncorrelated and $\alpha = 0$ and $\beta = 1$. This indicates that the market is efficient. Here the forward price is an unbiased predictor of the spot price and the forward premium should be zero. Testing the UFH on the dataset indicates that the forward price has evolved into an unbiased predictor for the spot price. The forecast for the spot price is not significantly increased by including other information. The conclusion seems to be that market participants have increased their experience and the PJM market has matured to the point where it does not exhibit forward premia on average.

$$S_{t+1} = \alpha + \beta F_{t,t+1} + \epsilon_{t+1} \tag{3.8}$$

Diko et al. (2006) investigate three European electricity markets[2] for the presence of a risk premium in day-ahead electricity futures. Analyzing the spot and futures prices a significant risk premium is found for peak hours for all three markets. For off-peak hours only EEX shows a significant short term risk premium. Using a multi factor model the paper finds support for the Bessembinder and Lemmon (2002) model in the peak hour forward premia. The paper also finds in agreement with Haugom and Ullrich (2012) that the forward premia changes over time, and specifically that it decreases in absolute value as market maturity increases. An important innovation in the paper is the extension of the analysis from short term day-ahead forwards to longer time horizons. Significant risk premia are found in all time horizons considered in the paper. As time to maturity increases the risk premia decrease as the impact on the premium of skewness is less important and the impact on the risk premia from variability in the spot price becomes more important.

3.4.2 Explaining the risk premium

The differences in generation mix between the PJM market and Nord Pool call into question whether the results obtained from analyzing the PJM market are directly applicable to time series from Nord Pool. The main difference is the amount of available hydro power, which is markedly higher on Nord Pool (Botterud et al., 2010). As discussed in the previous chapter electricity prices are influenced mainly by local supply and demand conditions and it is uncertain to what degree findings in one electricity market are generalisable.

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[2]The German EEX market, France's Powernext and the Dutch APX

Douglas and Popova (2008) look at the potential effects of power producers opportunities to store gas on the model proposed in Bessembinder and Lemmon (2002). In America gas companies have access to a network of depleted wells that can be used for storage of natural gas. This system is analogous to a hydro dominated system where water can be stored in reservoirs. The theory presented in the article is that the cost of fuel represents the larger part of the marginal cost of electricity and that gas is often the marginal fuel. Gas power plants are relatively (compared to for instance nuclear or coal power plants) cheap to start up and to have their output changed. Essentially this means that gas inventories and supply of natural gas will impact the distribution of electricity prices, specifically the skewness of the spot price, as storage opportunities will likely impact the size of possible price spikes. Douglas and Popova (2008) then develop a regression model to describe the forward premium using the variance and skewness of the spot price as well as variables that impact demand for gas for heating and the available gas in storage. The empirical analysis supports the intuition that gas storage levels should have a negative impact on the forward premium by decreasing the spot price skewness. Higher gas storage levels will mean that the potentially available electricity is higher, which would lead to a smaller impact from demand shocks and thus a lower premium according to the Bessembinder and Lemmon (2002) model. The differences between the Nordic and American electricity market are however obvious in the discussion. In the market considered by Douglas and Popova (2008) low temperatures do not affect electricity demand by much, as gas is primarily used for space heating, whereas very high temperatures drive electricity demand as air conditioning predominantly runs on electricity. This is in stark contrast to the Nordic electricity market where a large amount of electricity is used for space heating and the peak demand over a year is always on the coldest days. The main findings in the article are however of prime interest. That storage opportunities of the resources used to create electricity have a significant impact on forward premia. The Nordic electricity market has a large share of hydro power with reservoirs. Water can be stored in reservoirs and it is therefore likely that the reservoir level and weather conditions that impact the reservoir levels will have an impact on the forward premium.

Bunn and Chen (2013) go through a large portion of the literature on risk premia in electricity futures and notes that a consensus on the existence and explanation of risk premia in electricity futures has not been reached. One reason being that a large part of the literature has focused on using the statistical features of the spot price, mainly the skewness and volatility to model the risk premia. In their analysis of the British electricity market the find evidence that risk premium includes risk premia in the underlying fuel, which in Britain is gas. In addition supply and demand shocks are found to have a significant effect. Bunn and Chen (2013) also find significant differences between day-ahead and 1-month futures, where day-ahead forwards reflect the operational aspects of the electricity market and month-ahead forwards are based on fundamental expectations. Lastly the point is made that differences between electricity markets in supply and demand characteristics are likely to yield differences in statistical behaviour. They argue that methodological insights are likely generalisable, whereas specific results might not be.

Looking to the future the point is made that a changing energy mix with more renewables will likely change how electricity markets function and have impacts both on the forward price and volatility. As renewables have high investment costs and very low operating costs forward prices will have to lie above marginal costs and the highly variable nature of generation from solar and wind power is likely to increase volatility (Bunn and Chen, 2013).

Daskalakis and Markellos (2009) analyze data from Nord Pool, EEX and PowerNext to determine what effect emission allowance prices in the EU have on the forward premia. The paper analyzes the percentage forward premia as defined in equation 3.6. Analysis is performed on day-ahead futures for the base load where significant negative forward premia are found in all three markets.

Using OLS regression with robust standard errors and emission allowances and lagged hits of the forward premia as the only explanatory variables Daskalakis and Markellos (2009) find evidence that strongly support the hypothesis of emission allowance prices having an impact on the forward premia. The results are consistent across all three markets for the significance of the emission allowances. By splitting the emission returns into a two variables, one for positive and one for negative the effects of varying signs for the emission allowance price is studied. Both high and low returns on the emission allowance have a positive impact on forward premia, with negative returns having the largest.

3.4.3   The forward premium in the Nordic electricity market

The Bessembinder and Lemmon (2002) model was developed to describe the PJM market in the US. As has already been mentioned there are important structural differences between PJM and Nord Pool that impact both demand and supply for electricity, and thus has a large impact on prices. This will likely have ramifications for the forward premium as well.

One of the first papers to analyze empirical evidence on risk premia in the Nordic electricity market is Botterud et al. (2002). Using a data set of observations between 1996 and 2001 and contracts with 1, 2, 26 and 52 weeks to delivery they find significant and positive risk premia with a magnitude that increases as the length of the holding period increases. Botterud et al. (2002) also try to find a relationship between deviations from normal reservoir levels and the risk premium. This is only done through visual inspection of graphical plots of the reservoir deviation, spot and futures prices, and the risk premium, and the results are preliminary at best.

Botterud et al. (2010) makes the case that several of the assumptions in the Bessembinder and Lemmon (2002) model are not fulfilled in the Nord Pool market. The assumption

that each producer faces a convex cost function does not hold for a system with a large amount of hydro power. Hydro power has very low actual production costs and scheduling decisions are based on the so called water value which is the opportunity cost of production now versus deferring production. Secondly a fixed retail price for load serving entities cannot be assumed for Nord Pool where there is a large amount of competing utilities with different contract specifications given to consumers. It is also likely that there is significant speculative participation in the Nordic electricity market where the Bessembinder and Lemmon (2002) model assumes no speculators participate.

3.5   Regression models for the forward premium

Several papers have suggested various regression models to explain the forward and risk premia found in futures traded in the Nordic electricity market. Here their findings and methodology will be presented.

Weron (2008) continue the work from Weron et al. (2004) where a model for the behaviour of the spot price is proposed. In addition Asian style options and futures are analysed to look at the market price of risk, a term used to describe the compensation to investors for holding some asset in stochastic differential equations that describe spot price dynamics (Weron and Zator, 2014). The paper finds evidence of a negative market price of risk in the Nordic market. This is the same result as found in Bessembinder and Lemmon (2002) and Botterud et al. (2002). The negative market price of risk might indicate that buyers of electricity, such as utilities have a higher demand for futures for hedging purposes than producers of electricity. Weron (2008) also find that the price of risk increases with time to maturity.

Mork (2006) look at one month and one block[3] futures contracts in the period from 1997-2004. Three hypotheses are put forward and examined in the paper. That risk premia were present in the Nordic market from 1997-2004, that risk premia were smaller in the period 2000-2002 due to higher speculative interest and that after the supply shock in 2002-2003 the risk premia were changed substantially due to a change in hedging behaviour on the consumer side. Evidence is found that supports the hypothesis of positive forward premia that increase with the time to maturity for the entire period. When looking at the sub-periods Mork (2006) find that there were significant risk premia in the period leading up to 2000. From 2000-2002 a large amount of international speculators participated in the market and in this period risk premia were not statistically significant from zero. Surprisingly perhaps for the period after these market participants left the data does not give evidence of a risk premium significantly different from zero between 2002-2004. Possible explanations are large price swings giving errors in the observed premia or that Nordic participants in the electricity market increased their speculative activity following 2002. The analysis does not support the hypothesis that premia have increased due to increased hedging demand in the post 2003 period, but the data sample is limited and further research is necessary to conclude one way or the other.

Redl et al. (2009) analyse year-ahead forwards traded on Nord Pool and the central European market EEX. The paper finds evidence of significant ex-post risk premia in the Nordic market. A regression model is estimated with spot price skewness and variance as explanatory variables separately for peak load and base load situations. For EEX

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[3]Before 2003 "blocks" were the standard size of mid-term futures listed on Nord Pool. The delivery period were usually 4 weeks, with the 5 weeks occasionally. One year was split into 13 blocks. In 2003 they were replaced by month futures.

skewness is found to be significant for base loads and variance is found to be significant in peak loads. For the Nord Pool data none of the coefficients are significant. Redl et al. (2009) explain this with the higher percentage of hydro power available in the Nord Pool area which gives some possibilities to defer production, and avoid or lessen price spikes. The models are extended with indices for nuclear and hydro power generation and total consumption in the two markets. For Nord Pool the coefficients are not significant, although they do show the expected sings. The lack of significance here likely has the same cause as earlier, namely the high proportion of hydro power with large reservoirs available. The analysis from the Nordic market does not give support to the implications of the Bessembinder and Lemmon (2002) model in the Nordic market. A significant relationship between the risk premium and the skewness and variance of the spot price is not found.

Botterud et al. (2010) analyze 11 years of data from Nord Pool from 1996 to 2006. The paper uses both the risk premium and the convenience yield and the theory of storage to analyze the relationship between the forward and spot price. The argument being made that the high amount of hydro power with reservoirs give producers the ability to store water as a proxy for storing electricity. Producers can produce electricity now and sell on the spot market or save the water and sell the electricity forward. Assuming that both prices are known and that there is no risk of overflow both options are risk-free and must yield the same return (Botterud et al., 2010). The data shows evidence of a convenience yield that follows a very seasonal pattern with a positive yield in the first half of the year and negative yield in the second half. A possible explanation for the observed behaviour is the nature of inflows to hydro power reservoirs (Botterud et al., 2010). Typically the inflow is low during the winter and therefore having water is worth more. During the autumn reservoirs typically experience high inflows and the risk of spillage means that having full reservoirs is less attractive leading to a negative yield.

The regression model in Botterud et al. (2010) includes reservoir levels, deviation from average inflow, deviation from average electricity consumption, spot price, spot price skewness and spot price variance as explanatory variables. The paper estimates regression models with the same explanatory variables used to explain the convenience yield and the risk premia encountered in the data. The overall explanatory power of the models is fairly low and they conclude that the market is young and that fundamentals do not determine the risk premium by themselves (Botterud et al., 2010). They point to the possibility of large amounts of noise present in the price data as shown in Koekebakker and Ollmar (2005). The paper does find significant relationships between the deviations from average inflows and consumption and the risk premium as well as between the spot price level and the risk premium.

Lucia and Torró (2011) repeat the study from Botterud et al. (2010) using futures with a one week delivery period and time to maturity varying from one to four weeks. The paper analyzes the spot price before and after the extreme period between 2002 and 2003

and find that the spot price behaviour has changed. Following the supply shock the spot price is higher on average and has higher volatility than before 2003.

To examine the forward premia Lucia and Torró (2011) estimates a VAR model where the basis, lagged hits of the forward premia and deviations from average reservoir level are used as explanatory variables. The analysis indicates that reservoir levels below average have a significant impact on the forward premium, where decreases in reservoir level lead to an increase in the forward premium. The model also gives evidence supporting the idea that the forward premia exhibited in the Nord Pool market vary over time. The forward premium on Nord Pool is found to be positive during the autumn and winter, and zero during the spring and summer. This agrees with the model of Bessembinder and Lemmon (2002), as in the Nordic market skewness is much higher during the winter months.

The Bessembinder and Lemmon (2002) model is tested by Lucia and Torró (2011) both before and after the supply shock in 2002-2003. Lucia and Torró (2011) find evidence supporting the model in the first half of the sample, but the sample from 2003 and onwads does not support the implications of the model, that the forward premium can be related only to the variance and skewness of the spot price. The evidence on the post-shock period also seems to indicate that the seasonal nature of the forward premia have lessened and that market conditions in general have tightened.

Weron and Zator (2014) represent the most comprehensive recent study of forward premia on the Nordic electricity market. Using a time series with 13 years worth of data the paper revisits the findings and the model from Botterud et al. (2010). The analysis focuses on futures with a week-long delivery period and time to maturity varying from 1 to 6 weeks. When re-estimating the model from Botterud et al. (2010) for the longer dataset the findings confirm the result from Botterud et al. (2010). Weron and Zator (2014) does however argue that the use of OLS regression in Botterud et al. (2010) likely suffers from some methodological deficiencies. The potential issues are simultaneity, correlated measurement errors and seasonality. The specific issues in Botterud et al. (2010) that cause this is the inclusion of the spot price as an explanatory variable, which is likely to cause simultaneity, the use of realised consumption and inflow is likely to have measurements errors that are correlated with the spot price, lastly the spot price and reservoir levels both show strongly seasonal patterns that need to be accounted for.

Based on these considerations the model from Botterud et al. (2010) is extended with a variable representing the deviation from average reservoir level and omitting the spot price as an explanatory variable. The model has fairly low explanatory power with R^2 in the range of $0.04 - 0.08$ (Weron and Zator, 2014). The evidence is also very weak on the coefficient for the reservoir level, with only one of the maturities showing a slightly significant coefficient for the deviation from average reservoir level. The relationship is found to be positive between the risk premium and the deviation from average reservoir level. This is the opposite of the results from Botterud et al. (2010) where the relationship

between the risk premium and the reservoir level is found to be negative. Weron and Zator (2014) cannot find evidence supporting the storage cost theory from Botterud et al. (2010), but neither does the analysis contradict it. Weron and Zator (2014) conclude that the significant findings in Botterud et al. (2010) are caused by the deficiencies in their methods, particularly that the inclusion of the reservoir level straight up is problematic due to its seasonal nature.

To improve the regression models for the risk premium GARCH residuals are to re-estimate the risk premia and the convenience yield models from Botterud et al. (2010) (Weron and Zator, 2014). The results remain the same with a definite positive relationship between the risk premium and the reservoir levels. For the convenience yield the same results are found, but with much less significance compared to the original analysis in Botterud et al. (2010). The economic impact of changes in the reservoir levels are also found to be significant, with a change in reservoir level of 10 % leading to changes in the risk premium that are about the size of the average risk premium. The conclusions drawn are that there exists a significant and positive relationship between the risk premium and deviations from average reservoir levels.

4.   Methodology and Data

In this chapter the empirical methods and models used will be presented along with the dataset used in the empirical analysis. The regression model analyzed in the thesis will be presented first and then the dataset used to estimate the model will be presented.

4.1   Methodology

In this section the regression model analysed in this thesis will be presented. The variables used in the model will be explained shortly a long with some predictions on the effects of the variables considered based on equilibrium considerations of the forward market.

4.1.1   Model specification

To explain the variation in the forward premium a multiple linear regression model is suggested. The model is defined below in equation 4.1.

$$FP_i^p = \beta_0 + \beta_1 OI_{LOW,i} + \beta_2 OI_{HIGH,i} + \beta_3 T_i + \beta_4 RV_i + \beta_5 RESD_i + \beta_6 VIX_i + \beta_7 B_i + \beta_8 FP_{i-1}^p + \epsilon_i$$
$$(4.1)$$

Here FP_i^p is the ex post forward premium on day i, $OI_{LOW,i}$ is the deviation from the mean open interest if it is below average, $OI_{HIGH,i}$ Is the deviation from open interest when above average, T_i is the temperature, RV_i is the realized volatility, $RESD_i$ is the deviation from average reservoir levels and VIX_i is the level of the CBOE Volatility Index (VIX)[1]. ϵ_i represents an error term assumed uncorrelated with information at time i. The subscript i indicates day i which corresponds to the time t at which the future is bought in equation 3.2.

The coefficients of the various variables can be predicted based on how they are likely to affect the demand for futures and forwards. A positive forward premium implies that people holding long positions in forwards on average have to pay a premium. This implies that firms that buy electricity, such as utilities, pay a premium to hedge their price risk. This means that factors that increases the risk of high prices should have a positive impact on the forward premium and factors that increase the chance of low prices would have a negative impact on the forward premium.

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[1]VIX is a volatility index based on the S & P 500 stock index. It is viewed as one of the key markers on market-wide volatility expectations, see `http://www.cboe.com/micro/VIX/vixintro.aspx`

The two open interest variables function as indicators of demand for futures. The variables are constructed to show the deviation from average open interest, with one variable for above average open interest and one for below average (See equations 4.2 and 4.3 below for the mathematical definitions). When demand for futures is above average, which means the OI_{HIGH} is positive, the forward premium should increase as more people want to buy futures contracts. This indicates that β_2 should have a positive sign. For low open interest the opposite is true. As the open interest deviates below the average demand for futures is low and investors wanting to go short in the futures will likely have to pay a premium. As OI_{LOW} is defined as the open interest minus average open interest it is a negative number. This indicates that the coefficient should be positive. As OI_{LOW} becomes more negative the forward premium should decrease indicating that β_1 should have a positive sign.

The temperature variable is hard to predict the sign of. As temperatures decrease one would assume that the risk of high prices increases and demand from consumers of electricity for futures increases. This should give a negative coefficient β_3 as lower temperatures increase the forward premium.

The volatility of the spot price has been used as an explanatory variable in several studies all the way back to Bessembinder and Lemmon (2002). Here the assumption is that the variance should have a negative relation to the forward premium. Following from this β_4 should be negative.

Deviation from average reservoir levels has been used in Lucia and Torró (2011) and reservoir levels was used by Botterud et al. (2010) as explanatory variables in their regression models. Deviations from average reservoir levels are chosen rather than reservoir levels themselves to avoid using a variable with strong seasonal patterns (Weron and Zator, 2014). $RESD_i$ shows the effects of the variable supply on the price of electricity. If reservoir levels are lower than average the chance of price spikes increases and the demand for futures should increase. This should lead to an increase in the forward premium. As lower than average reservoir levels would give a negative number and higher than average a positive one the coefficient β_5 should be negative.

The VIX index is included to see if there is any correlation between forward premia in electricity markets and the overall market risk. The effect of market risk on the relative hedging preferences of electricity producers and consumers is not obvious, and it is uncertain if there even is an effect. As such no predictions are made for β_6

The basis is the difference between the futures price and the spot price today. The basis contains information both about the expected premium and the expected spot price (Lucia and Torró, 2011). The basis should therefore have a positive relationship to the forward premium with β_7 being positive.

Variable	Predicted sign
OI_{LOW}	Positive
OI_{HIGH}	Positive
T_i	Negative
RV_i	Negative
$RESD_i$	Negative
VIX_i	Unknown
B_i	Positive
FP_{i-1}^p	Positive

Table 4.1: The predicted signs of the coefficients in the regression model

The included lagged hit of the variable should have a positive sign as the forward premium will likely show autocorrelation. Thus we would expect β_8 to be positive.

The predicted signs are summarized in table 4.1.

As discussed earlier there is some disagreements among academics on how the forward premium should be calculated when used in regression models. Papers have used the absolute value, a logarithmic forward premium and the forward premium as a percentage. In this paper both the logarithmic and percentage forward premia are analysed, to see if results are consistent and find out whether the choice of forward premia has an impact. There should be no reason to cause the coefficients to assume different signs between the two definitions of the forward premia.

The explanatory variables are chosen based on intuitions about what might influence the risk attitudes, specifically the demand for price hedges, of participants in the Nordic electricity futures markets. Some of the variables have been the studied before, such as the reservoir level in Botterud et al. (2010) and the volatility of the spot price in amongst others Bessembinder and Lemmon (2002). How the variables are constructed and some preliminary discussion on why they were chosen is presented below in section 4.2.

The model specification in equation 4.1 includes one lagged hit of the forward premium. The model is estimated both with and without this lagged hit. Without a lagged hit the assumptions on the error term ϵ of OLS regression may not be fulfilled, as it will likely exhibit autocorrelation. To account for this the model is estimated both with normal OLS error assumptions and with heteroskedastic and autocorrelation robust standard errors.

4.1.2   Model implementation

The model has been implemented in the R statistical programming language (R Core Team, 2014). The OLS implementation was fitted using the standard lm() function for fitting linear models (see Appendix A for the code used to implement the models). The base version of R does not include functions for estimating quantile regression models. To implement a quantile regression framework the package quantreg was used (Koenker, 2015). The package is developed by Roger Koenker and contains several functions to estimate and analyze quantile regression models. In addition the R package stargazer was used to export regression results into LaTeX tables (Hlavac, 2014).

4.2   Data

Using the correct data sample and time series is key to achieve good empirical results in any quantitative study. In this section the dataset used in this thesis will be presented. The sources and any potential shortcomings of the variables or the data they are constructed from will be presented.

The time series of spot and futures prices used in the empirical analysis consists of daily system spot prices and daily prices for 1 month DS futures traded on Nasdaq OMX Europe. The dataset was obtained from Montel[2] through their excel import functions.

As expected the spot prices show high seasonal variation where the prices are highest during the winter months. The futures prices follow a very similar pattern as can be seen in figure 4.1. Figure 4.1 also clearly shows the infrequent upward spikes in the spot price that are typical in time series of electricity prices. The prices are highest during the winter. The peaks for the spot price are quite a bit larger than the peaks for the futures price. This is also as expected as the spot price is more heavily influenced by short-term events with large ramifications such as exceptionally cold weather. In general the time series of spot and futures prices seem to behave very similarly to what one would expect. Large upward price spikes are generally found in electricity prices when market conditions are particularly bad. This effect is more pronounced for electricity than for any other commodity due to the fact that electricity cannot be stored.

The time series of spot prices and futures consist of 2174 daily observations of the system spot price and the futures price between 1st of December 2005 and september 2014. Using this data the average spot price for every month of the dataset was calculated. As the futures used in this study are 1-month futures they are for 1 unit of electricity delivered every day of the delivery period. This means that forward premium is found by taking the difference between the futures price and the average spot price during the delivery period. Using the definitions from section 3.3 both the logarithmic and percentage forward premia were calculated.

For reservoir levels the deviation from the daily mean is used. The effects of reservoir levels has been studied in several papers including Lucia and Torró (2011), Botterud et al. (2010) and Weron and Zator (2014). Following the arguments from Weron and Zator (2014) the deviation from average reservoir level is chosen as the explanatory variable. Only the reservoir levels in Norway is used, as they were the only ones that were publicly available. The error from omitting reservoir levels from other countries in the Nord Pool area is likely not very impactful as Norway has about 65 % of the hydro power within the

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[2]Montel is a provider of market information for European electricity markets, including historical data, analysis etc. For more information see `http:\\www.montel.no`
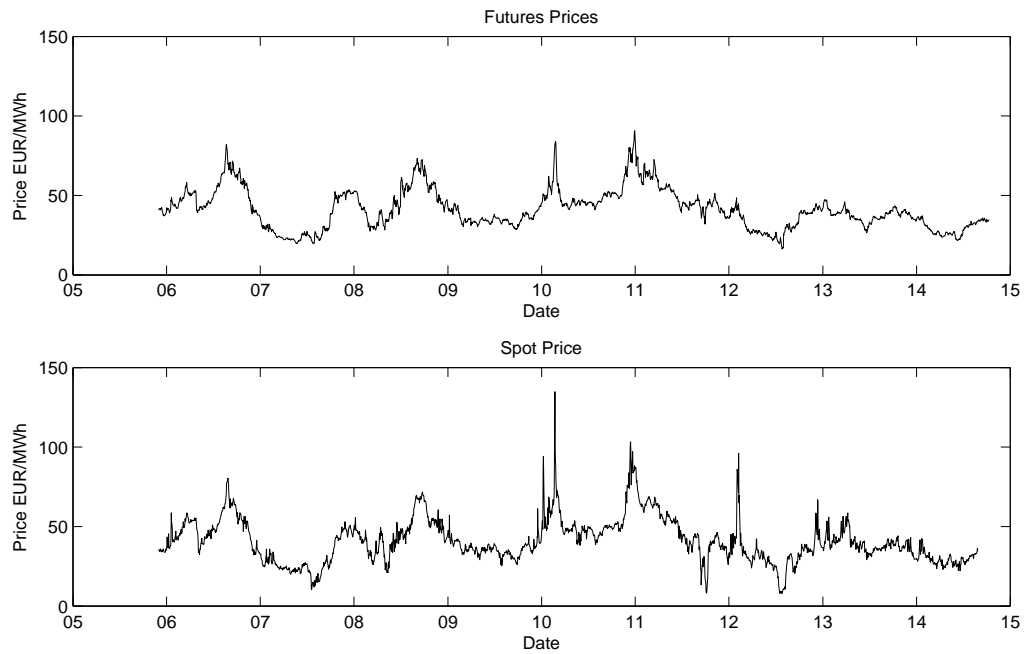
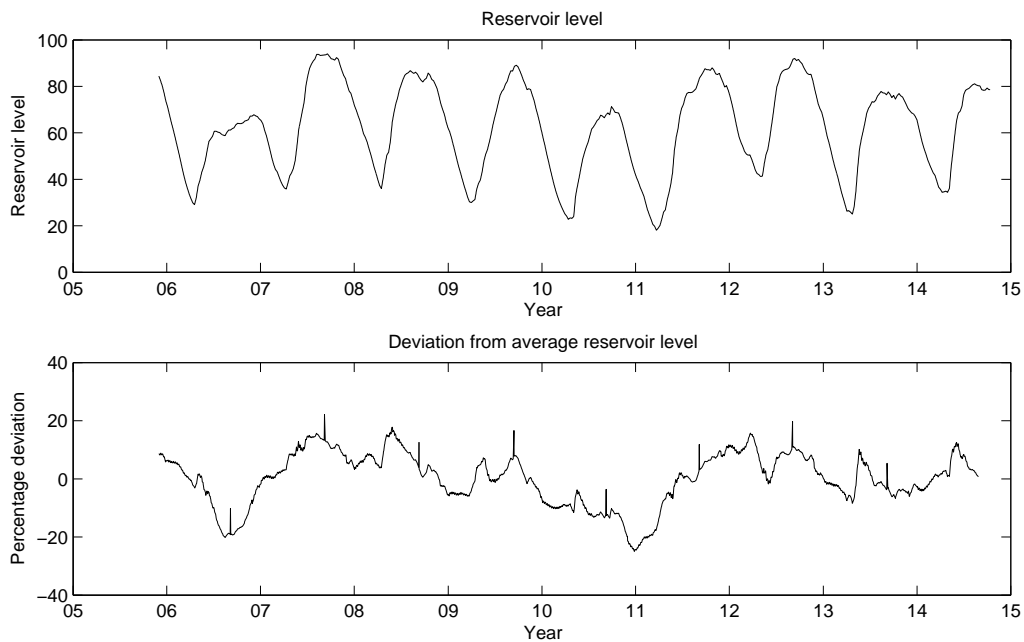Figure 4.1: 1-month futures and spot prices

Figure 4.2: Reservoir levels and deviation from average reservoir levels throughout the period

Nord Pool area.[3] The data for the reservoir levels was obtained from the Norwegian Water Resources and Energy Directorate. They provide weekly aggregated reservoir levels for all hydro power reservoirs in Norway.[4] As the data is for weekly reservoir levels some amount of transformation is needed to fit the daily values for the spot and futures prices. Assuming that the weekly levels are the levels at the beginning of the week and the first week of the year begins at the 1st of January the weekly values were transformed to daily values using linear interpolation. This transformation is not perfect, but it should be very close to the actual reservoir level on the given day. Using the obtained daily values the deviation from the average reservoir level at any given day was calculated. The reservoir level and deviations from the average level is presented graphically in figure 4.2. The reservoir levels follow a strong seasonal pattern as expected. The inflows generally stop during winter and the reservoirs are tapped down until the snow stars melting and they start refilling. The deviations from average reservoir levels show no obvious seasonal patterns, which is what motivated the choice of deviation from the mean as the explanatory variable.

The temperature variable used has been created by using Norwegian weather data only.[5]. The variable was constructed by taking the measurement station closest to the largest population center in every Norwegian county (fylke) and averaging the observations for each day. There are some obvious weaknesses in this approach as the Nordic electricity market is far larger than Norway. In addition the weighting coefficients are hard to estimate accurately, as the population density varies heavily between measurement points. An intuition is that there should be some correlation between temperatures in Norway and the rest of the Nordic region, and that the average temperature in Norway at least to some level reflects the temperature in the entire Nord Pool area.

Open interest for the futures contract was part of the data set obtained from Montel. The variable was split into two, one for levels of open interest above the average and one for open interest below average. The intuition behind this is that low levels of open interest for a futures contract is more likely to influence the forward premium than high levels. The variables are defined as the deviation from average open interest. The high open interest variable is set to zero if the open interest is below average and the low open interest variable is set to zero if open interest is above average. The mathematical definitions used are shown in equations 4.2 and 4.3.

$$OI_{LOW,i} = OI_i - OI_{average} \tag{4.2}$$

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[3]Norwegian hydro power has a mean annual production of about 131,4 TWh, see `http://www.nve.no/no/Energi1/Fornybar-energi/Vannkraft/`. The total amount of hydro power in the Nord Pool area is about 200 TWh as can be seen from `http://www.nordpoolspot.com/How-does-it-work/The-market-members/Producers/`

[4]The data was obtained from the url: `http://vannmagasinfylling.nve.no/Default.aspx?ViewType=AllYearsTable&Omr=NO`

[5]Data was collected from the Norwegian Meteorological Institute, which offers a wide range of climate data free of charge through their service at `http://www.eklima.met.no`

$$OI_{HIGH,i} = OI_i - OI_{average} \tag{4.3}$$

Data for volatility was obtained from Peter Molnar. The data was calculated and used by Birkelund and Opdal (2013) in their project thesis to create an index for the implied volatility. In the dataset used in the paper the series of realised and implied volatilities had different lengths. The IV dataset only contains 1407 daily observations and only runs until 2011. The RV dataset runs all the way until September 2013. Due to the increased length of the time series for realized volatility and the assumption that the realised and implied volatility should be highly correlated the realised volatility is used in the model. Including the realised volatility necessitates discarding about one year of data for all the other variables. With the RV the total observations on forward premia and explanatory variables reduces to 1953. This still corresponds to a period of just under 8 years and should be sufficient to get some general insights into the performance of the model.

The VIX index was obtained through Montel's data retrieval tools. As it is a traded index that measures the volatility of the stock market no manipulation of the sampled data was necessary. The effect of overall market risk on the forward premia in electricity futures has not been studied previously. The VIX is therefore included to see if the overall market risk impacts the relative risk aversions of electricity market participants.

The basis was constructed simply using the definition, see equation 3.3 and the time series of forward data and spot prices. Here we follow Lucia and Torró (2011) in including the basis in the regression model.

5.   Results

In this section the results of the empirical analysis will be presented. The first section contains some preliminary graphical analysis as well as descriptive statistics for both the time series of prices and the forward premia. The following sections look at the results from implementing the model with OLS regression and quantile regression frameworks.

5.1   Preliminary analysis

In this section we will use graphical evidence and descriptive statistics to look at the spot and futures prices and the forward prices, to see if these methods will offer any insights into the behaviour of the prices. Using the definition of the forward premium as developed in section 3.3 both the logarithmic and percentage forward premia were calculated.

5.1.1   Graphical analysis

Figure 5.1.1 shows the result from plotting the percentage and forward premia. The visualisation of the data does not give any obvious insights about the distribution of forward premia. The forward premium does seem to be on average larger during the winter than the summer, although the largest negative forward premia coincide with the largest spikes in spot price which usually happen in the winter months. This is because of the definition of the forward premium. Likely these large price spikes represent severe, unexpected changes in the factors influencing the spot price.

Figure 5.1.1 also shows that the choice of definition of the forward premium yields very different time series. Even though both definitions lead to levels that are comparable the evolution of the forward premium is quite different between the two. Most notably the percentage forward premium seems to exhibit a larger variance than the logarithmic forward premium over the entire period.

The forward premium does not exhibit any obvious seasonality patterns, whereas both the spot and forward prices do exhibit the expected seasonality patterns. In the Nordic area the price is generally highest during the winter as demand is highest when the weather is cold.
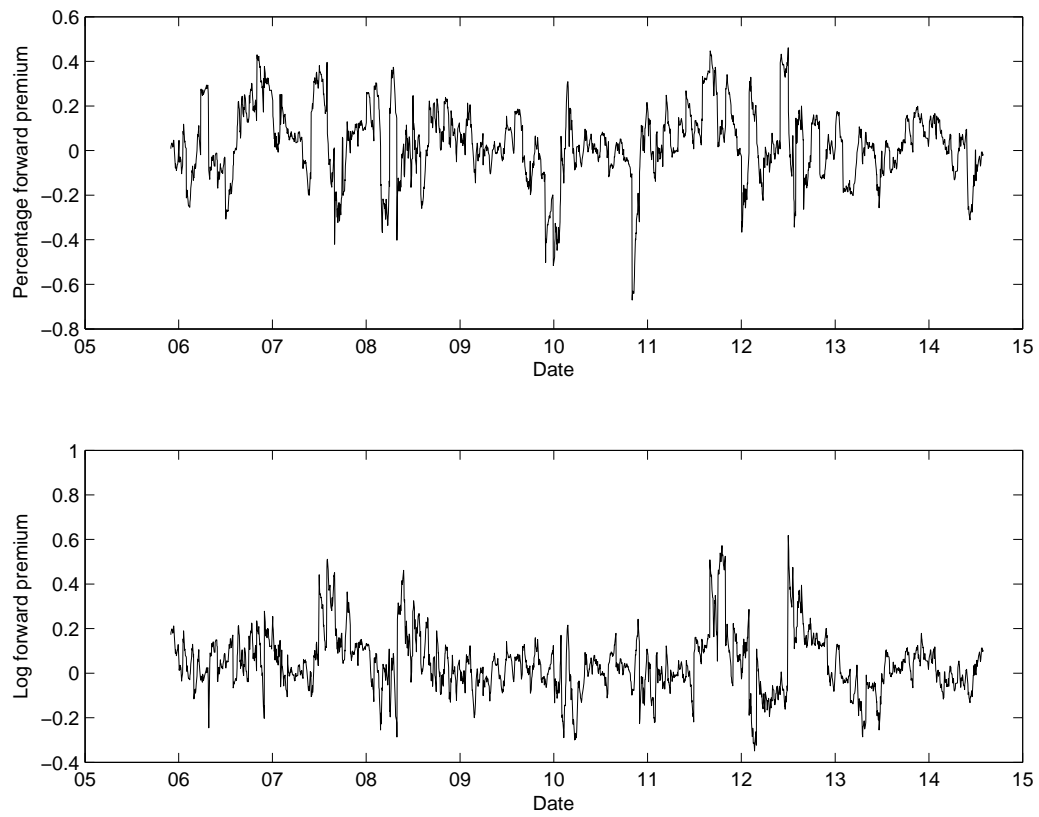
Figure 5.1: Log and percentage forward premia

5.1.2   Descriptive statistics

Table 5.1 shows a summary of descriptive statistics for the spot price, futures prices and the forward premia. The spot price shows the expected statistical features, which is high skewness and high excess kurtosis. This indicates that the distribution of spot prices is quite peaked and that the right tail of the distribution is fatter than the left tail. In short it is more likely to experience high prices that deviate far from the mean than low prices that deviate far from the mean and extreme observations are more likely than they are in the Gaussian normal distribution.

The futures price is on average larger than the spot price. Both the mean and median futures prices are larger than their counterparts for the spot price. This indicates that the forward premium is positive on average for the entire sample. The futures price also exhibits positive skewness and excess kurtosis, although the excess kurtosis is substantially smaller for the futures than the spot price. This can also bee seen from figure 4.1 where the spot price peaks are much higher than the peaks for the forward price. This is caused by extreme market conditions that were not predictable and as such could not be reflected in the futures price. The effect of non-storability further increases the chance of extreme price peaks for the spot price. The highest spot price in the sample is more than 3 times the mean spot price for the entire sample. These price swings represent huge potential losses for utilities and end-users of electricity.

As could be seen from graphing the futures and spot prices the volatility is is higher for spot prices than for futures, but the difference is not very large.

The absolute value forward premium exhibits very high volatility. The maximum and minimum values are both an order of magnitude bigger than the mean and median forward premium. Both the negative and positive peaks for the forward premium are in the range of 20 to 30 Euro per MWh. Which is very large, especially when compared to the lowest spot prices which are far lower. These characteristics together with the very high excess kurtosis exhibited by the forward premium indicate that the distribution of forward premia has quite fat tails. The skewness of the forward premia is negative indicating a fatter left tail than the right tail.

When looking at the statistics for the percentage and log forward premium some differences emerge. Both definitions show that the forward premium is positive on average. The medians are very similar, whereas the mean log forward premium is substantially higher than the mean percentage forward premium. The volatilities are very similar between the two definitions. The biggest differences are between the skewness and kurtosis of the distribution of forward premia, as well as the max and min values. The logarithmic definition yields values that are shifted more positively compared to the percentage forward premia. The percentage definition of the forward premium yields a distribution with negative skewness, which indicates a fatter left tail. The logarithmic definition how-

Statistics	Spot Price	1-month futures	AbsFP	PFP	LogFP
Mean	39.65	41.24	1.57	0.0304	0.044
Median	37.56	39.88	1.12	0.0303	0.0318
Max	134.80	90.77	25.92	0.4608	0.6177
Min	5.79	16.25	-32.68	-0.6704	-0.3488
Standard Deviation	13.61	12.40	7.12	0.162	0.133
Skewness	0.811	0.703	-0.27	-0.312	0.751
Excess Kurtosis	1.781	0.444	2.36	0.963	1.924

Table 5.1: Summary of descriptive statistics for the spot price, futures price and forward premium

ever has quite high positive skewness with a fat right tail. Interestingly this means the skewness changes for the logarithmic definition compared to the absolute value forward premia, which have negative skewness. The logarithmic definition also gives a distribution with substantially higher kurtosis. This was also indicated by looking at the relationship between means and medians for the two definitions. For the logarithmic forward premium the mean is higher than the median which indicates that the distribution has a fatter right tail.

5.2   OLS Regression

In this section the results from the OLS estimation of the regression model will be showed and discussed. For clarity the section has been divided into four subsections one for the base model excluding the lagged hit and using normal errors, one where various methods of dealing with the autocorrelation are tested and two sections where the sample is divided in two to look at whether market maturity has increased over time and what effects this has on the forward premium.

5.2.1   Regression results

The results from the regressions run on both log and percentage forward premia is summarized in table 5.2. The overall explanatory power of both models is quite low and only about 4 % of the variation in the forward premia is explained by the models. This is about the same level of explanatory power found by the model from Botterud et al. (2010) when analyzed in Weron and Zator (2014). The overall performance of the model is fairly bad as it does not explain any significant amount of the variation in the sample.

The Durbin-Watson statistics for both definitions of the forward premium is close to zero which indicates large positive autocorrelation in the residuals. The highly autocorrelated residuals also indicate that the model does not capture the autocorrelated behaviour of the forward premium itself. The autocorrelation in the daily forward premia are caused by its definition, the same average monthly spot price is subtracted for one month worth of forward prices.

Table 5.2 shows that all parameters are significant at the 1 % level except the basis, deviation from average reservoir level and open interest higher than average. The differences between the logarithmic and percentage forward premium models are quite small. The same explanatory variables are significant for both definitions and the coefficients are very similar across the board. Most importantly perhaps both definitions show the same effects (i.e. the negative or positive influence on the forward premium) for all the considered explanatory variables.

Looking at the signs of the coefficients most of the coefficients behave as predicted. The coefficients that do not follow their predicted signs are β_1 for low open interest, β_3 for the temperature and β_4 for the realized volatility. Considering the overall explanatory power of the model and the high level of autocorrelation exhibited by the residuals no firm conclusions can be taken from these deviations.

That deviation from average reservoir level and the basis are not significant in the re-

	PFP	LogFP
	(1)	(2)
OI.LOW	−0.00017***	−0.00020***
	(0.00006)	(0.00006)
OI.HIGH	0.00005*	0.00006*
	(0.00003)	(0.00003)
Temperature	0.00317***	0.00314***
	(0.00059)	(0.00062)
RV	0.09402***	0.10738***
	(0.02112)	(0.02224)
RESD	−0.00026	−0.00024
	(0.00041)	(0.00043)
VIX	0.00115***	0.00102***
	(0.00036)	(0.00038)
Basis	0.00045	0.00069
	(0.00064)	(0.00067)
Constant	−0.06257***	−0.05111***
	(0.01275)	(0.01342)
Observations	1,953	1,953
R^2	0.03805	0.03798
Adjusted R^2	0.03459	0.03452
Residual Std. Error (df = 1945)	0.16391	0.17254
F Statistic (df = 7; 1945)	10.99100***	10.96931***

Notes:	***Significant at the 1 percent level.
	**Significant at the 5 percent level.
	*Significant at the 10 percent level.

Table 5.2: Regression results from the OLS regression

gression analysis is quite unexpected, as they have been found to be significant in several earlier studies of the Nordic electricity market. Weron and Zator (2014), Lucia and Torró (2011) and Botterud et al. (2010) all find significant effects from the reservoir levels on the forward premium. Lucia and Torró (2011) also finds significant effects from the basis on the forward premium.

Considering the high auto-correlation in the residuals the assumptions inherent in standard OLS regression do not hold for the model. In total this indicates that the base version of the model is not a good fit for modelling forward premia in the Nordic electricity. The lack of significance in the coefficients that have been found to be significant before also indicates that the model is not a good fit for the Nordic electricity market.

5.2.2 Accounting for autocorrelation

To account for the large degree of autocorrelation in the residuals two different methods are considered. The first is to include 1 lagged hit of the explanatory variable. This approach is not ideal as the lagged hit will not be available to market participants as information to base decisions on, but it can be taken as a proxy for the expectations on the forward premium. Another approach is to use robust standard errors that can account for both autocorrelation and heteroskedasticity in the error terms. The model will be re-estimated with robust HAC standard errors, as in Daskalakis and Markellos (2009), and with robust HAC standard errors and 1 lagged hit of the forward premium.

Table 5.3 show the results from the OLS estimation using robust HAC standard errors. The significance of the terms has changed dramatically compared to when using normal errors. With robust errors none of the coefficients are significant at the 1 % level. The only coefficient that is significant at the 5 % level is the realised volatility. This seems to support the notion from Bessembinder and Lemmon (2002) and others of the effect of the spot price volatility on the forward premium. The coefficients remain the same including the coefficients with surprising signs. And R^2 is still very low showing that the model has very poor explanatory power. In summary it seems that the model still features very obvious deficiencies and that just using robust standard errors does not yield a model with satisfactory performance.

Table 5.4 show a summary of the regression results for the model including 1 lagged hit of the explanatory variable using both percentage and logarithmic definitions of the forward premia. As can be seen this dramatically improves the overall performance of the model. R^2 is now above 0.9 for both definitions of the forward premium, which indicates that the model can explain more than 90 % of the variation in the data. Perhaps more importantly the Durbin-Watson test statistic is now very close to 2 for both definitions. This indicates that the residuals do not exhibit any autocorrelation.

| | PFP | LogFP |
	(1)	(2)
OI.LOW	−0.00017	−0.00020
	(0.00015)	(0.00016)
OI.HIGH	0.00005	0.00006
	(0.00006)	(0.00007)
Temperature	0.00317	0.00314
	(0.00237)	(0.00250)
RV	0.09402**	0.10738**
	(0.04734)	(0.05091)
RESD	−0.00026	−0.00024
	(0.00175)	(0.00181)
VIX	0.00115	0.00102
	(0.00104)	(0.00119)
Basis	0.00045	0.00069
	(0.00232)	(0.00259)
Constant	−0.06257*	−0.05111
	(0.01275)	(0.03712)
Observations	1,953	1,953
R^2	0.03805	0.03798
Adjusted R^2	0.03459	0.03452
Residual Std. Error (df = 1945)	0.16391	0.17254
F Statistic (df = 7; 1945)	10.99100***	10.96931***

Notes:	***Significant at the 1 percent level.
	**Significant at the 5 percent level.
	*Significant at the 10 percent level.

Table 5.3: Regression results from the OLS regression with robust standard errors

	PFP	LogFP
	(1)	(2)
OI.LOW	−0.00001	−0.00002
	(0.00002)	(0.00002)
OI.HIGH	0.00001	0.00001
	(0.00001)	(0.00001)
Temperature	−0.00016	−0.00018
	(0.00019)	(0.00019)
RV	0.00083	−0.00166
	(0.00793)	(0.00850)
RESD	−0.00026*	−0.00027*
	(0.00014)	(0.00015)
VIX	−0.00000	−0.00000
	(0.00009)	(0.00010)
Basis	0.00083***	0.00086**
	(0.00030)	(0.00034)
PFP.lags	0.94889***	
	(0.00781)	
LFP.lags		0.95174***
		(0.00781)
Constant	0.00055	0.00175
	(0.00386)	(0.00400)
Observations	1,953	1,953
R²	0.90188	0.90728
Adjusted R²	0.90147	0.90690
Residual Std. Error (df = 1944)	0.05236	0.05358
F Statistic (df = 8; 1944)	2,233.47200***	2,377.84900***
Durbin-Watson Statistic	1.9924	1.9422

Notes:	***Significant at the 1 percent level.
	**Significant at the 5 percent level.
	*Significant at the 10 percent level.

Table 5.4: Regression results from the OLS regression including 1 lagged hit

For the logarithmic forward premium the basis and the included lagged hit are the only explanatory variables that are significant at a 5 % level. This is in stark contrast to the model excluding lagged hits where the the basis were not found to be significant at a 5 % level. The deviation from average reservoir level is found to be significant at the 10 % level. In light of the increased explanatory power and overall statistical performance exhibited by this model it is likely that the effect observed here is more significant than the results found in the model without a lagged hit. Deviation from average reservoir levels and the basis are the explanatory variables in this model supported by the most research. It is therefore not surprising to find that they are the only variables to stay significant.

For the percentage forward premium the deviation from average reservoir level is significant at the 10 % level. For this definition only the basis and the included lag are found to be significant. The explanatory power of the percentage forward premium model is also slightly lower than for the logarithmic forward premium, although the difference is very small.

These findings corroborate earlier results from the literature where reservoir levels and the basis have been found to have significant effects on the forward premium (as in Lucia and Torró (2011)). The coefficients now all show the predicted signs except for β_1 for low open interest. The coefficient for low open interest is very close to zero and not significant however, so this is likely because open interest does not impact forward premia in the Nordic electricity market. The estimated model now shows coefficients that agree with findings by other researchers and that agree with equilibrium considerations and the predictions based on these.

Overall the results indicate that the model performance is increased in all aspects by adding a lagged hit of the forward premium and using robust standard errors. In the further analysis focus will therefore be on the model with an included lagged hit of the forward premium.

5.2.3   Increased market maturity

In this section we will split the sample in two and analyse the differences. One indicator of market maturity can be the open interest in futures contract. Higher open interest indicates that more investors participate and that the market will function more efficiently. First the regression results for the open interest will be analysed and we will look at whether or not open interest and the forward premia have changed over time. Then the sample used to estimate the regression model will be split in two at the halfway point and the model will be re-estimated for each sub period to see whether or not the effects of the explanatory variables change over time.

As several papers have noted forward premia in electricity markets decrease as market maturity increases. In this vein investigating whether the Nordic electricity market shows signs of maturing, and what effects this has on the forward premia and what influences them will be very interesting. For the entire sample results support the findings of Lucia and Torró (2011), Weron and Zator (2014) and Botterud et al. (2010) that reservoir levels and the basis have a significant impact on the forward premium. It can now be analyzed whether this behaviour has changed over time or not.

One interesting result from the regression models considered so far is for low open interest. As this variable is always a negative number the negative coefficient indicates that low open interest increases the forward premium. Essentially this would mean that the price to hedge forward for utilities or other buyers of electricity would increase as demand for the hedge decreases, which is counter-intuitive and in disagreement with equilibrium arguments about the forward premium. Although the coefficient is insignificant on would expect to see the predicted sign. One possible explanation for this is that the market efficiency has increased over time as has been found in several studies for instance Botterud et al. (2010) and Diko et al. (2006). As the market matures, one would expect the open interest to increase and the forward premium to decrease. If overall participation in the market has increased we would assume that there are more observations of below average open interest in the first half of the sample. If this has coincided with a general increase of market maturity and thus a decrease in forward premium this would serve to explain the sign of the coefficient.

To test this the total sample of forward premia and corresponding open interest was split into two, one from 1st December 2005 to 31rd of March 2010 and the other subsample from 31rd of March 2010 to 31st of July 2014. By calculating the means for the open interest and the forward premium in both sub periods we find as in table 5.5 that the forward premium is higher and the open interest is lower in the first period compared to the second. Following this it is likely that the open interest deviation in this time period and model shows the effect of the market maturing, rather than open interest driving the forward premium. Especially considering the definitions used in this thesis where a larger amount of observations above the whole sample average for open interest will happen in the latter part and a larger amount of low open interest observations happens before the halfway point.

If the market had shown signs of being relatively mature for a longer period of time, i.e. the forward premium did not show significant differences in the two sub-periods, these results might have been more interesting. The most likely interpretation is however that the open interest does not directly influence the forward premium, but rather functions in this scenario as an indicator of market maturity.

	Open interest	Log FP	PFP
1.12.2005–31.3.2010	214.1	0.0335	0.0558
1.4.2010–31.7.2014	297	0.0273	0.0330

Table 5.5: Means for the open interest and forward premia for the two sub periods

5.2.4   Re-estimating the regression for two sub-periods

Taking this analysis further the entire data sample has been divided in two and the OLS regression model has been estimated for both halves of the data. The first subsample runs from the 1st of December 2005 until the 23rd of October 2009. The second subsample runs from the 24th of October 2009 until the 31st of July 2013. This will show if there are any significant changes in the effects of the variables. The results from the newest part of the sample will be of particular interest as there is significantly less research based on data after 2009. It has already been shown that the forward premia show sign of declining with time, but changes in the effects of the considered variables have not previously received much attention.

Table 5.6 presents the regression results for estimating the model separately for the two periods. We see that the overall explanatory power of the model estimated for the last part of the sample is slightly better than for the first half of the sample, and this is valid for both definitions of the forward premium.

Generally the two definitions yield models that are similar in terms of the size and sign of the coefficients. The only major difference is that the high open interest coefficient is negative in the first period for the percentage definition and positive for the logarithmic definition of the forward premium. As both estimates are not statistically significant this does not seem to indicate any meaningful differences between the definitions of the forward premium.

Looking at the coefficients in the two different sub-periods yield some very interesting changes. The included lagged hit has not changed much and remains significant at a 1 % level in both periods. For the other coefficients the changes are quite large. Both the basis and the deviation from average reservoir level are significant at the 1 % level for the period from 2005 to 2009, for both models but not significant at any level for the period from 2009 to 2013. The coefficient estimates for these are also reduced by an order of magnitude for the model estimated for the second sub-period in both models. That both the basis and reservoir deviation have a smaller and less significant impact over time seem to indicate that market efficiency has increased and that the results of Botterud et al. (2010) and Lucia and Torró (2011) might not be correct in describing the current behaviour of the forward premium in the Nordic electricity market.

Some of the more interesting results for the logarithmic forward premia are for low open interest, realised volatility and temperature. The coefficients for all of these variables change sign between the sub periods. Open interest has a positive coefficient for the first period and a negative coefficient for the second period. Realised volatility and temperature go from negative to positive. The temperature variable is significant at the 10 % level for the first subsample. The realised volatility doesn't just change sign, it also increases in absolute value. Although the low significance of the coefficient estimate indicates that the results might not be meaningful the fact that increased volatility has opposite effects on the forward premia between the two periods is surprising and not the predicted behaviour as in Bessembinder and Lemmon (2002).

For the second period there are only two variables with coefficients that are significant. The lagged forward premium is still significant at the 1 % level. For both definitions of the forward premium the high open interest variable is found to be significant at the 5 % level for the second period. This seems to follow from the intuition in for example Bessembinder and Lemmon (2002) that futures demand for hedging purposes causes a pressure that increases the cost of hedging. For both models the results indicate that the forward premium increases as open interest increases. Surprisingly the high open interest variable changes coefficient for the percentage forward premium model. In the first period the coefficient is found to be negative. This is not what would be expected as high demand for futures would be expected to increase the forward premium rather than decrease it.

The results indicate clearly that market efficiency has increased over time. The explanatory power of the physical and economic variables considered in this thesis clearly have a smaller impact on the forward premium in the second period. The deviation from average reservoir level and the basis are not significant for the second period, contrary to findings using older data, both in this thesis and in other research. The sign of the coefficient for the realised volatility has changed sign between the two periods for both definitions of the forward premium. The coefficients are not significant however and it is unclear if this represents any changes in the market or not.

The coefficients are all significantly smaller in the second period except for the VIX indicating that the economic effect on the forward premium is significantly smaller as well. For instance are the coefficients for the basis and the deviation from average reservoir level which are significant in the first period reduced by an order of magnitude in the second period. The evidence do seem to indicate that the market has matured over time and that forward premia on average are decreasing in the Nordic electricity market.

The results indicate that the models developed by Lucia and Torró (2011) and Botterud et al. (2010) might not be good fits for the current behaviour of the market. Both the impact of the basis and the deviation from average reservoir levels has lessened over time and their coefficients in this model are no longer significant when the model is estimated

using data from 2009-2013.

	PFP		LogFP	
	2005-2009	2009-2013	2005-2009	2009-2013
OI.LOW	0.00002	−0.00003	0.00002	−0.00003
	(0.00002)	(0.00003)	(0.00003)	(0.00003)
OI.HIGH	−0.00000	0.00003**	0.00000	0.00003*
	(0.00003)	(0.00001)	(0.00003)	(0.00001)
Temperature	−0.00053*	0.00014	−0.00055*	0.00007
	(0.00027)	(0.00028)	(0.00029)	(0.00027)
RV	−0.00662	0.01489	−0.00768	0.00814
	(0.00864)	(0.01434)	(0.00919)	(0.01448)
RESD	−0.00062***	−0.00008	−0.00065***	−0.00008
	(0.00021)	(0.00019)	(0.00024)	(0.00019)
VIX	0.00003	0.00018	0.00003	0.00026
	(0.00011)	(0.00036)	(0.00012)	(0.00031)
Basis	0.00228***	0.00024	0.00244***	0.00021
	(0.00052)	(0.00034)	(0.00055)	(0.00038)
PFP.lags	0.93927***	0.95007***		
	(0.01216)	(0.01115)		
LFP.lags			0.94269***	0.95224***
			(0.01202)	(0.01229)
Constant	0.00914	−0.01251**	0.00890	−0.01162*
	(0.00597)	(0.00633)	(0.00643)	(0.00658)
Observations	976	977	976	977
R^2	0.89306	0.90929	0.89981	0.91444
Adjusted R^2	0.89217	0.90854	0.89898	0.91374

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5.6: Regression results for both definitions with for the sample split in two

5.3   Quantile Regression

In this section the results found when implementing the model in a quantile regression framework are presented. The model was implemented in the R statistical programming language using the quantreg package (R Core Team (2014) Koenker (2015)). The quantile regression model was solved for quantiles from 0.01 to 0.99 with increments of 0.01. Using this the coefficients and confidence bands for the coefficients were plotted together with the OLS estimates and confidence bands for the OLS estimates. In the next subsection the results will be presented and analysed for both definitions of the forward premium. The second subsection here will present the results when the quantile regression model was re-estimated for the two sub-periods presented. This will enable a more thorough look at the changes over time.

5.3.1   Regression results

For the percentage risk premia figure 5.2 present the results from estimating the model for all quantiles. The black dotted line presents the coefficient estimates from the quantile regression plotted versus the quantiles. The gray shaded area indicates the confidence bands for the coefficient estimates. The OLS results are also plotted with the solid red line representing the OLS coefficient estimate and the dashed red lines indicating the upper and lower bounds of the confidence intervals.

Figure 5.3 presentes the result from estimating the model for the logarithmic risk premium definition, with the figure showing the same measures as figure 5.2 does for the percentage definition.

Now the general trend shown by figure 5.2 is that the effects close to the mean are fairly small. The confidence bands for both the median estimates and the means include zero for all variables except the included lagged hit, the basis and the deviation from average reservoir level. This seems to follow the results from the OLS estimation where these are the only variables with significant coefficients. Considering the low amount of significant variables found in the OLS estimation this seems to indicate that the effect of the other considered variables are zero on the mean. Figure 5.3 show that the case is more or less the same for the logarithmic forward premium. By looking at the tail effects and changes we can see that the effects are not constant across all quantiles for any of the considered variables.

The coefficient for low open interest is very close to zero over nearly all quantiles, and the results are nearly identical for the two definitions of the forward premium.. The extreme left tail shows a slightly positive coefficient and the extreme right tail shows a

slightly negative coefficient. The confidence bands do include zero in both tails so the possibility that low open interest does not impact the forward premium cannot be ruled out. That the left tail coefficient is positive is as predicted. When the forward premium is low a decrease in open interest should indicate lower demand and decrease the forward premium. The right tail coefficient is however a bit surprising as open interest seems to have a negative relationship with the forward premium in the right tail, that is when forward premia are high.

The results for high open interest seem very inconclusive. The confidence bands in both tails cover zero and as such cannot guarantee a non-zero effect. There does seem to be a slight trend towards an increasing coefficient with increasing quantiles. From the 30 % quantile and down and the 70 % quantile and up the coefficient seems to be slightly negative (positive for the upper tail). The coefficient is extremely small in any case on the order of $5 * 10^-4$ or smaller. The coefficients and confidence bands are once again almost identical for both definitions of the forward premium. The right tail seems to give a slightly larger coefficient for the logarithmic definition of the forward premium, but it is still well within the confidence intervals. The left tail has an extremely wide confidence band, especially at the 1-2 % quantiles, indicating that the results are highly uncertain. The mean and median coefficients are extremely close to zero, so the most likely interpretation is that high open interest does not impact forward premia.

The coefficient for the temperature also indicate an effect close to zero over the majority of quantiles. The results are almost identical between the two definitions of the forward premium. The tails do show some negative coefficients above 80 % and below 20 % indicating that the temperature has a negative effect on the forward premia in these ranges. The extreme right tail however has a very wide confidence band centered on zero while the extreme left tail does show some tendency for a positive coefficient, but the confidence band is once again very wide, particularly for the logarithmic definition of the forward premium. The results seem to indicate that the temperature variable considered here only has a limited explanatory power for the 5 - 15 % and 80 - 95 % parts of the quantile distribution.

The coefficient for the realised volatility differs in its behaviour compared to the other coefficients. Where all the other coefficients except the included lag are close to zero and almost constant over the majority of quantiles and show some deviations in the tail the coefficient for realised volatility shows a very clear trend in changing influence on the forward premium. At the median the coefficient is close to zero and this is true for the OLS estimate as well. Outside of that the coefficient changes from negative in the left tail to positive in the right tail. The change in the coefficient is almost linear. Interestingly in the extreme right tail the effect seems to lessen as the coefficient gets closer to zero. Overall the results indicate that the realised volatility has a negative relation with the forward premium in the lower tails. This can be interpreted as that when the forward premium should be low based on other factors influencing it a large volatility

will decrease the forward premium. Essentially at the lower tail increasing volatility will increase hedging costs for producers of power, for the positive tail the opposite will be true with increasing volatility increasing the hedging costs of utilities. The results are once again almost identical between the two definitions of the forward premium. The size of the coefficients indicate that the economic impact of the realized volatility is very significant in the tails with the estimates lying between -0.1 and 0.1.

The deviation from average reservoir level shows a very clear trend. Around the mean and towards the lower quantiles the coefficient is very slightly negative indicating that positive deviation from the average reservoir level decreases the forward premium and negative deviation increase the forward premium. The effect increases in the lower tail, whereas in the higher tail the coefficient becomes positive. As the higher tail models the largest forward premia it is surprising that the coefficient becomes positive. This would indicate that the largest forward premia are increased by a positive deviation from average reservoir level, which would indicate a surplus of water. Positive deviation should reduce the risk of price spikes and should therefore theoretically decrease the forward premium as the demand for hedging from consumers decrease. The confidence band does include zero and even negative values in the right tail so the possibility of a zero or negative coefficient cannot be ruled out.

The curve for the coefficient for VIX follows the same general trend as the open interest variables. The coefficient is close to zero for all but the 5 % quantile tails. The left tail is positive, whereas the left tail is slightly negative, but with very uncertain estimates as the wide confidence bands show.. This indicates that the effect is likely very small. This is the same result as found in the OLS estimation and as the figure shows the OLS estimate for the coefficient is so close to zero as to be indistinguishable.

Looking at the basis the graphs are almost identical between the two definitions of the forward premia. The coefficient is positive across nearly all quantiles. The confidence bands are markedly wider in the tails than in the middle of the distribution, indicating a larger degree of uncertainty for the tail estimates. The top tail does not seem to show any change in effect compared to the middle part with coefficients lying along the same line. For the low quantile (5 %) tail the coefficient estimate changes sign and becomes negative. The confidence band covers a very large area in this tail and neither a zero or a positive coefficient can be rejected. The general trend indicates that the result from the OLS estimation are likely valid across all quantiles as the plot of coefficients is close to constant across quantiles.

The lagged variable shows slightly different behaviour between the two definitions of the forward premium. The percentage definition has the highest coefficient in the left tail and then shows slightly decreasing coefficients as the quantile increases. The logarithmic definition has the opposite behaviour with the peak in the right tail and increasing coefficient from the low quantile toward the highest. Both definitions show a lower coefficient

in the extreme tails however. This seems to indicate a higher explanatory power for the physical and economic conditions in the tails than in the middle. Another interpretation is that the extreme tails for the forward premia are caused by sudden events that are not predictable. In this model the lagged hit will include all relevant information that market participants have available at time t. As the extremes in spot price or futures price happen because of unpredictable events (outages, extreme weather etc.) the most extreme forward premia are likely caused by the same unpredictable events. In these cases the variables that describe the physical environment or statistical behaviour of spot price will have a larger impact on the forward premia than the forward premia from the day before which does not contain information about the unpredictable event.

The realised volatility results are very interesting indicating that there are significant non-zero effect both on negative and positive forward premia, but that these effects seem to roughly average out to a zero impact on the mean. This effect has not received much earlier study. It seems likely that the relationship between the volatility and the forward premium depends on the spot or forward price at time t. One intuition would be that if the spot price is already high an increase in volatility will likely impact the demand for long futures from utilities more than the demand for short futures from power producers, with the opposite being true for low spot prices. This would give an informal explanation for the shape of the coefficient curve. Both tables 5.2 and 5.3 indicate strongly that the effect of the realised volatility changes significantly across quantiles.

The results from the quantile regression seems to corroborate the results from the OLS estimation of the model for the most part. The coefficients that are found to be significant using OLS estimation also show significant non-zero coefficients for the majority of quantiles. The results also indicate that the market and physical variables considered have higher impact on extreme forward premia and that the lagged hit is less useful in predicting extreme forward premia. The basis is found to have a significant positive effect on the forward premium over the majority of quantiles. The same result is found for the deviation from average reservoir level, with the coefficient being negative in this case.

The included lag remains the variable considered with the largest economic impact, with a coefficient between 0.9 and 1 across almost all quantiles. The decrease of the coefficient of the forward premium in the tails indicate that the extreme forward premia are not easily predictable and are likely caused by changes in the other fundamental variables. The magnitude of the coefficients increases in the tails for all the considered variables apart from the lagged hit indicating that this could be the case. The tail estimates have a large degree of uncertainty for all of the considered variables which means that the sign and size of the coefficients cannot be taken as clear evidence of the tail effects of the variables on the forward premium. The results indicate also that the effects of open interest and the VIX index is likely zero or very close to zero both for the mean and across quantiles. Evidence on the basis and the deviation from average reservoir levels show significant effects across all quantiles that are consistent with the OLS results.
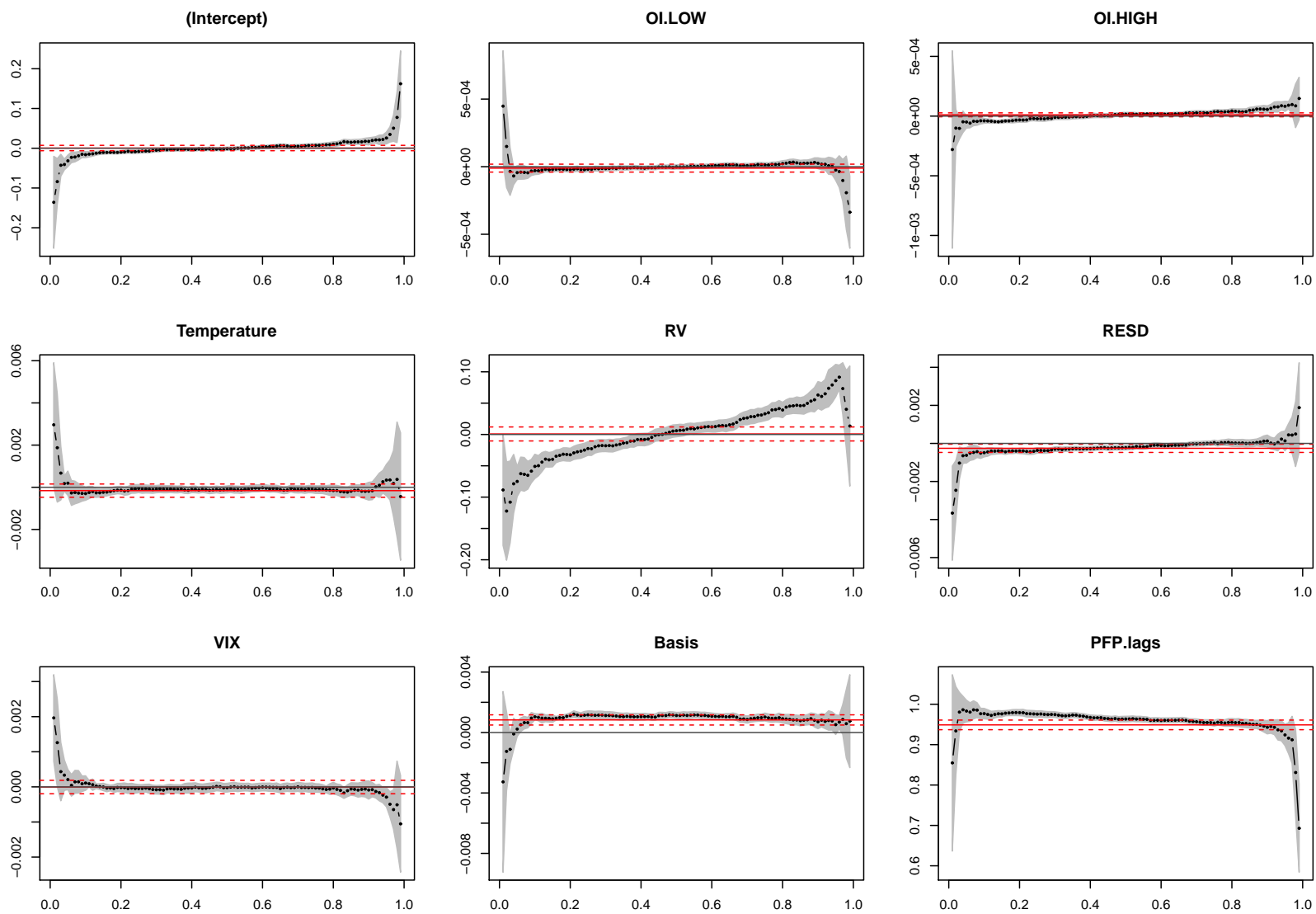
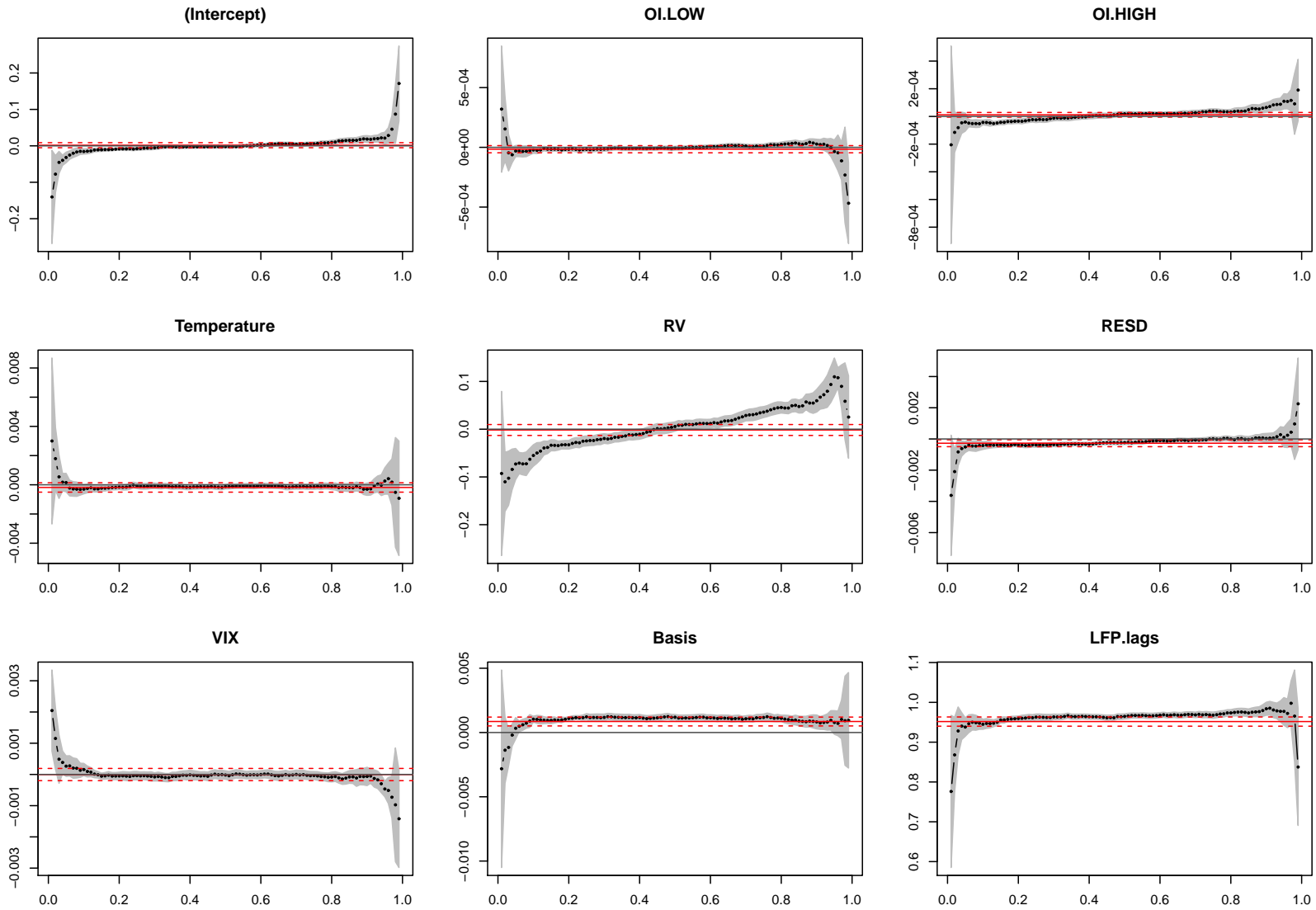Figure 5.2: Coefficients plotted per quantile for the percentage forward premium.

Figure 5.3: Coefficients plotted per quantile for the logarithmic forward premium.

5.3.2   Re-estimation of the model for two sub-periods

In this section we will take a look at the results from re-estimating the model for the two sub-periods to analyze whether the market shows any signs of maturing over time. Only results for the logarithmic forward premium will be shown and discussed, as the percentage forward premium shows the same overall trends and results the figures have been omitted from this section. The results for the percentage definition can be found in appendix B.

The results from the estimation of the quantile regression model for the two sub-periods are shown in figures 5.4 and 5.5. As the figures show the behaviour has clearly changed over time.

For the first period the open interest variables have coefficients very close to zero over most quantiles. The low open interest does show some small positive coefficients in both tails. The positive coefficients are as expected and that the effects of low interest are more substantial in the tails is in agreement with the hypothesis that physical and market conditions have a larger impact on extreme forward premia. In the second period the graph of the coefficient looks more like the results for the entire data sample. The right tail now has a slightly negative coefficient, but the confidence bands include zero in both tails. Here the quantile regression results strongly suggest that the effect is close to zero across all quantiles.

The high open interest coefficient is close to zero for all quantiles for the first period. The graph heavily indicates that high open interest has zero impact on the forward premium in the first period, with confidence bands including zero across all quantiles. For the second period the coefficient shows behaviour similar to the results from estimating the model for the entire sample. The left tail is slightly negative and the right tail is slightly positive. While the coefficient is close to zero the confidence do not include zero for the 30 % right tail. In the left tail the confidence bands include zero indicating that a non-zero impact can not be ruled out for forward premia below the median.

The temperature coefficient shows very different results for the first period compared to the OLS results. The OLS coefficient is negative with confidence bands that do not include zero. The quantile regression shows a coefficient and a confidence band closer to zero for all quantiles but the lowest 20 %. The left tail shows a negative trend in the coefficient. Negative is the predicted sign of the coefficient for the temperature in this model, but surprisingly the effect seems to be zero in the right tail, indicating that the temperature has very little impact on high forward premia. The impact is larger on negative forward premia, perhaps indicating that the temperature is more likely to affect forward premia by increasing the spot price more than expected, which would cause negative forward premia. The second period shows a very different picture for the temperature. While the impact seems to be zero over the majority of quantiles both of

the tails now show positive coefficients. The right tail does not provide any conclusive evidence as the confidence bands are very wide. The lower tail does show some indication of a positive relationship between the forward premia and the temperature, although the estimate is highly uncertain here as well. This is directly opposite the results for the first period and the predicted behaviour. The OLS estimate is very close to zero indicating that the effects of the temperature in the second period is very small. The effect of temperature on forward premia in the Nordic market seems to have decreased markedly over time., and the most likely conclusion is that the effect is not significant in the period 2009-2013.

The realised volatility coefficient shows some interesting difference between the two periods. In the first period the coefficient seems to show similar behaviour to the model when estimated for the entire sample. The coefficient is negative below the median and positive above. The changes seem to be roughly similar in size as well with the coefficient varying from about -0.1 to 0.1. In the second period the same general picture emerges with the coefficient changing from negative to positive depending on the tail. The median coefficient changes and is slightly positive in the second period. The tails also show markedly larger coefficients in the second period with the largest values being at around ± 0.2. The extreme tails in both periods have coefficients with confidence intervals that include zero indicating that a non-zero effect in the 3-4 % quantile tails cannot be ruled out. Interestingly the mean effect seems to be very close to zero, whereas the effects away from the mean are quite large as the realised volatility shows the second largest coefficient after the included lagged hit. The results here are analogous to the results when estimating the model for the entire period, with a larger tail effect in the second period compared to the first period indicating that the impact of the volatility has increased over time.

The reservoir deviation shows a clear trend of a negative coefficient in the first period. The coefficient is negative over all but the top 5% quantiles. The coefficient is close to zero from the median to the 5% quantile. The top 5% quantiles show a positive coefficient, but the confidence band is extremely wide giving little significance to the result. The overall negative coefficient in the first period agrees with the predictions on the effects of deviations from the reservoir levels on the forward premium and the results from the OLS estimation. In the second period the graph is very similar. The main difference being that the coefficients are slightly closer to zero indicating that the effects on the forward premium have lessened with time. The right tail coefficients are slightly more positive, but the confidence bands remain very wide indicating that non-zero coefficients cannot be ruled out. Taking the evidence from the OLS estimation together with this indicates that the effect of reservoir levels on forward premia has decreased significantly over time.

The effect of the VIX index on the forward premium is very close to zero everywhere but the tails in the first period. The left tail shows some positive coefficients and the right extreme tail shows some negative coefficients, but these results are not significant. In the second period the results do not support the idea of non-zero effects over any of

the quantiles. The coefficient is very close to zero with extremely uncertain results in the tails. The mean and median regression coefficients are both virtually zero in both periods indicating that the overall market risk does not influence the forward premium for futures on Nord Pool. The possibility remains that the overall market risk has had some small impact on extreme forward premia before 2009, but no clear evidence supporting this notion is found.

The basis is the variable that shows perhaps the biggest difference in behaviour between the two periods. In the first period the coefficient is significantly positive over all considered quantiles. The quantile regression results are quite close to the OLS regression estimate. The top 10 % quantile does show some upward deviation from the OLS estimate, but for the rest of the quantiles the quantile regression estimate of the coefficient is very close to the OLS estimate. In the second period the quantile regression results give a lower coefficient, although it is still positive. The OLS estimate is also significantly reduced, but the quantile regression line indicates generally larger coefficients over most quantiles. Interestingly the tail behaviour seems to have changed with the coefficient estimates in both tails indicating a negative coefficient. The confidence bands do not indicate that the results in the extreme tails are significant however. The results here agree with the prediction that the basis should have a positive effect on the forward premium. In the first period the results strongly support the notion that the effect is positive across all quantiles, whereas the second period does not support this as strongly with both tails indicating negative coefficients with a large degree of uncertainty. The results also clearly support the notion that the effects of the basis on the forward premium has decreased over time and it is uncertain whether non-zero effects in the second period are significant.

For the lagged hits the results seem close to identical between the two periods The coefficient is between 0.9 and 1 for most quantiles. In the tails the coefficient estimates decrease substantially. The quantile regression estimate lies above the OLS estimate of the coefficient across all quantiles both in the second and first sub period. In the second period the right tail increases towards 1 where as in the first period the plot of quantile regression coefficients is more or less constant. This seems to indicate that the autocorrelation is higher in the second period, particularly that a large forward premium is more likely to be followed by a large forward premium than a low forward premium has of being followed by a low forward premium.

In general the first period shows more significant effects from most of the considered variables over the entire range of quantiles. The results in the extreme tails seem to be highly uncertain for all considered variables with very large confidence bands, which is as expected as the number of variables has been halved leading to fewer extreme observations to base the extreme tail estimates on. The analysis does not give conclusive evidence of the effects of the variables considered on the most extreme tails. The basis, the realised volatility, the deviation from average reservoir level and the included lag seem to have significant non-zero effects on the forward premium in the first period. The basis has
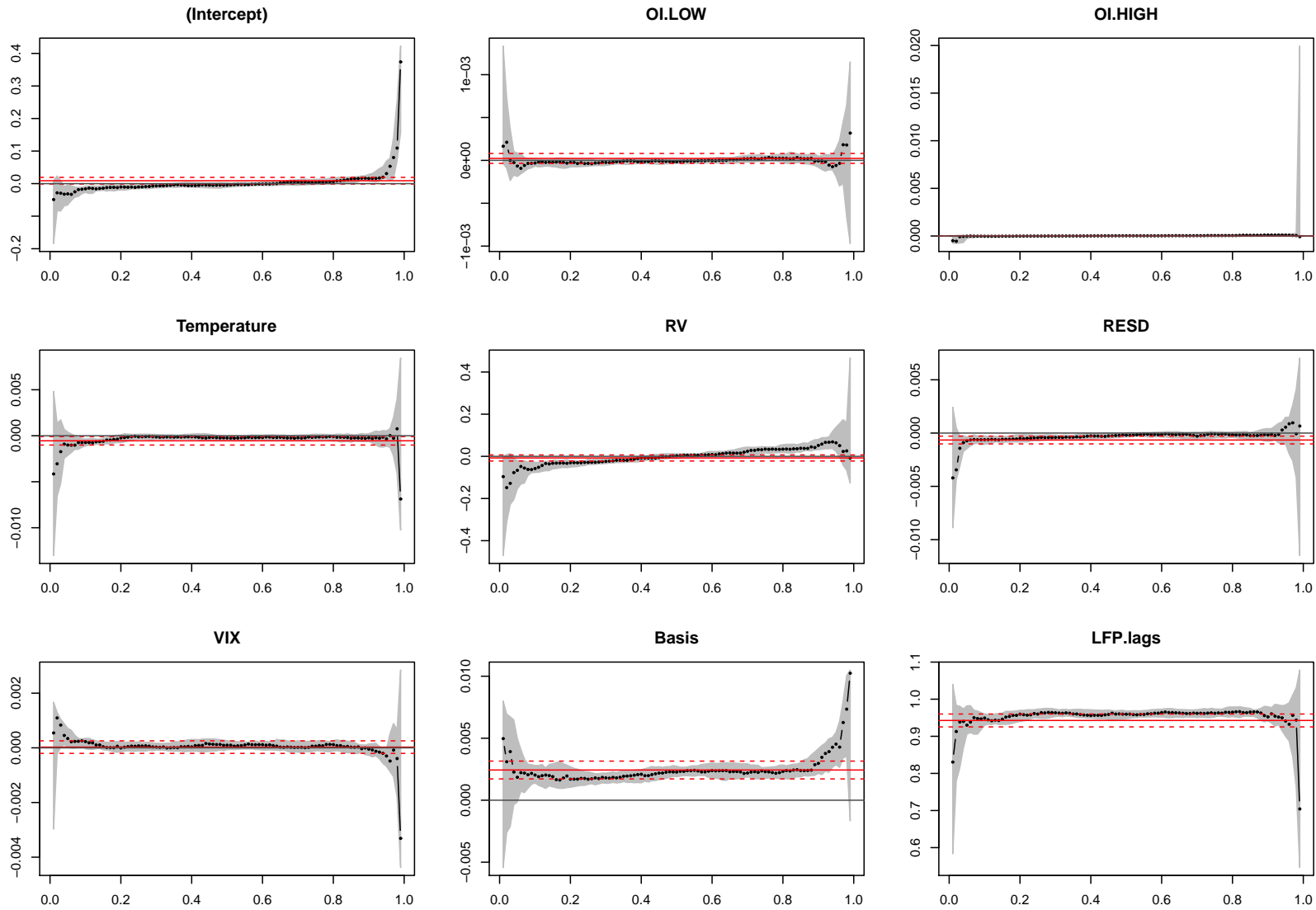
Figure 5.4: Coefficients plotted per quantile for the logarithmic forward premium for the first sub-period
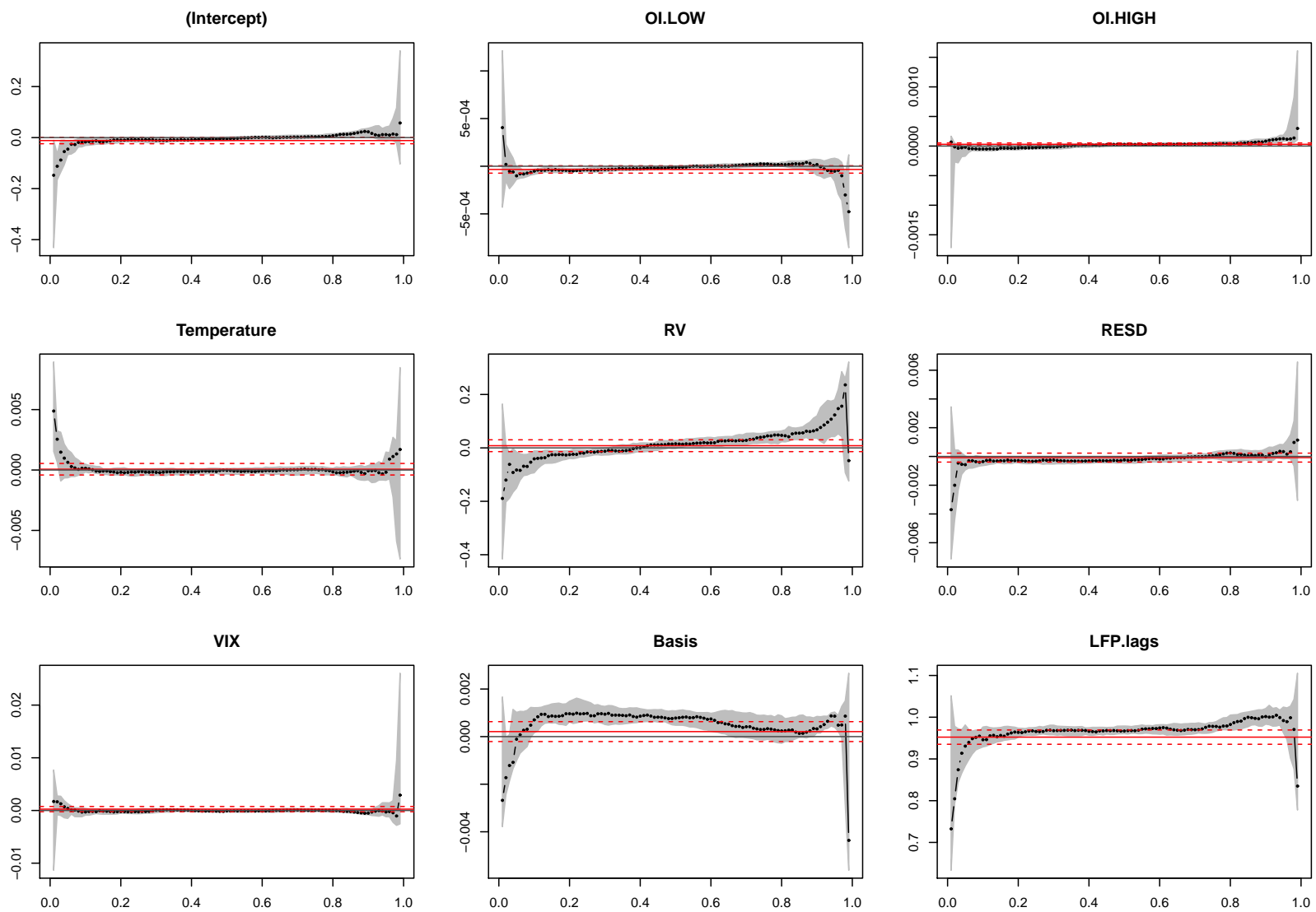
Figure 5.5: Coefficients plotted per quantile for the logarithmic forward premium for the second sub-period

a very clear positive coefficient. The realised volatility varies from positive to negative depending on quantile. The deviation from average reservoir level indicates a negative relationship between the deviation and the forward premium. The rest of the variables have smaller, but still noticeable, effects on the forward premium in the first period.

In the second period the coefficient estimates are lower across all quantiles for all the variables except the lagged hit of the forward premium and the realized volatility. The general behaviour of the variables has not changed. Importantly it seems that a larger degree of explanation is found in the lagged hit of the forward premium compared to the first period. This agrees with the findings from the OLS estimation where the variables outside the lagged hit were considerably less significant for the second period.

The results indicate that market conditions are changing over time. The effects of the explanatory variables considered outside the lagged hit have a smaller economic impact in the second period. The basis and the deviation from average reservoir level still show some explanatory power in the second period with positive and negative coefficients respectively over most quantiles. The lagged hit seems to have the same behaviour in both periods with decreased economic significance in the extreme tails, although the second period estimation give significantly larger coefficients between the median and the extreme right tail. The tail effects of the realised volatility seems to have increased significantly for the second period indicating that the volatility of the spot price might be one of the driving factors of extreme forward premia in recent times.

The forward premia in the Nordic market have decreased over time. Together with the decreases in the magnitude of the coefficients considered here this seems to indicate more efficient market conditions. Open interest has increased which indicates greater liquidity in the futures market and may also indicate a larger degree of speculative investment, although there is no data available to analyze whether this is the case or not. An increase in speculative interest would likely have the effect of driving forward premia down on average as the competition between investors wanting to collect the forward premia increases.

6. Conclusion

In this chapter the conclusions drawn from the empirical analysis will be summarized and then some avenues for further research based on the findings in this thesis will be suggested.

Empirical analysis

The time series of spot and futures prices analyzed in this thesis show the expected behaviour of electricity prices with large positive kurtosis and skewness indicating the relatively high probability of positive price spikes and fat tails. The forward premia are found to be positive on average with no immediately obvious seasonal patterns. The results agree with the majority of research which have found forward premia in the Nordic electricity market to be positive on average (Lucia and Torró, 2011).

In the empirical analysis several regression models for explaining the forward premium in electricity futures on the Nord Pool power exchange have been analysed. Using both OLS estimation and quantile regression to look at the effects on the mean and across varying quantiles. The data has also been analyzed to look for evidence of changing market conditions over time and whether the market shows signs of increasing efficiency.

The OLS results from the base model shows very poor performance. This seems to agree with the ideas in Weron and Zator (2014) that OLS regression has some deficiencies when applied to the forward premium. The choice of variables will likely have mitigated some of the potential pitfalls mentioned by Weron and Zator (2014), but the overall performance of the model is still unsatisfactory when lagged hits of the forward premium are excluded. The explanatory power is low and the residuals show clear signs of being autocorrelated. The estimation finds significant effects on the forward premium from the temperature, low open interest, realized volatility and VIX using normal errors. In addition several of the variables show coefficients with the opposite sign of what was predicted based on equilibrium considerations. Considering that the autocorrelation in the residuals is very high the results here cannot be considered meaningful. With robust standard errors only the realized volatility remains significant, with the opposite of the expected sign which seems to support the notion that the model does not adequately describe the forward premium in the Nordic electricity market.

The inclusion of 1 lagged hit of the forward premium drastically improves the overall performance of the model. The overall explanatory power is changed from between 3-4 %

to 90 % of the variation observed in the forward premia. For the model estimation with an included lagged there are some small differences between the estimation for the logarithmic and the percentage forward premium. The percentage forward premium shows a positive relationship between volatility and the forward premium and the logarithmic forward premium shows a negative relation, none of these coefficients are significant however, so their impact is likely small.

Including a lagged hit leads to three variables having coefficients that are significant at the 10 % level or better. The deviation from average reservoir level, the basis and the included lag are all significant. The coefficients also have the predicted signs with the basis and the included lag having positive coefficients and the deviation from reservoir level showing a negative coefficient. These results support the findings of Lucia and Torró (2011) and Weron and Zator (2014) with respect to both the significance of the coefficients and the sign and thus their effect on the forward premium. The other variables are mostly very close to zero and insignificant suggesting that they do not impact the forward premium in the Nordic market.

By splitting the sample into two periods the data shows evidence of a decreasing forward premium with time. Open interest has increased indicating that market liquidity has increased and that speculative investment possibly has increased. This would serve to explain the decrease in the forward premium (Mork (2006) notes that increased speculative interest should decrease forward premia).

By re-estimating the model for the two sub-periods the economic impact of all coefficients is significantly smaller in the second period with coefficients on an order of magnitude lower for several of the variables. In the first period both temperature, deviation from average reservoir level and the basis are found to be significant, with temperature and deviation from average reservoir level having negative coefficients and the basis and the lag having positive coefficients. The OLS estimation indicates that market conditions are changing and that deviation from average reservoir level and the basis have significantly less impact on the forward premia now than before 2009. The results for the period before 2009 seems to support the findings from other studies on the forward premia in the same period such as Botterud et al. (2010) and Lucia and Torró (2011). This thesis does not however answer the question of whether the observed premia in this period reflect a market price of risk or market inefficiencies. The analysis does suggest that earlier forward premia have included atleast a component related to market inefficiencies as the forward premia are decreasing with time. Only high open interest is found to be significant in the second period outside of the included lag indicating that the model cannot adequately describe current behaviour in the Nordic market. This also seems to indicate that the findings in Lucia and Torró (2011), Botterud et al. (2010) and Weron and Zator (2014) on the significance of reservoir levels on the forward premium might no longer be valid for the Nordic market.

The quantile regression estimation of the model largely shows the same picture as the OLS estimation. Important results are the fact that the lags have a smaller coefficient in the tails whereas the rest of the variables have coefficients that generally increase in the tails indicating a larger degree of explanatory power from the fundamental variables on extreme forward premia. The volatility of the spot price influences the spot price with opposite signs below and above the median. This is likely related to the spot price level as higher spot prices are likely to increase the forward premia as an increase in variance will increase the risk of large positive spikes increases demand for futures from utilities (Bessembinder and Lemmon, 2002) with the opposite effect when the spot price is low where increased variance will increase the risk for producers more than the risks for utilities.

The deviation from average reservoir level and the basis remain the variables with significant non-zero coefficients with respectively a negative and a positive relationship to the forward premium across most quantiles.

The analysis presented here show no meaningful differences between the logarithmic and percentage definitions of the forward premium. In fact the only significant difference is the distribution of the forward premia with the percentage definition showing negative skewness whereas the logarithmic definition features positive skewness. This seems largely a result of the percentage definition giving smaller premia on average with the minimum, maximum and mean lying below the same measures for the logarithmic definition.

Re-estimating the quantile regression model for the two sub-periods show the same picture as the OLS regression. The impact of all variables considered is smaller in the second period except the lagged hit. The extreme tail results are more uncertain as the dataset is smaller. The quantile regression results indicate a small negative coefficient in the lower tail for the temperature. The realised volatility shows the same changing relationship in both periods with a negative coefficient in quantiles below the median and a positive coefficient in quantiles above the median. The impact of the realized volatility seems to have increased with larger coefficients in the second period.

The effects from the basis and deviation from average reservoir levels has decreased in the second period. Temperature, open interest and VIX show results that indicate that they do not currently influence forward premia in the Nordic market.

The results in total support the results from Lucia and Torró (2011) and Botterud et al. (2010) for the equivalent time period. It seems however that the behaviour has changed over time and that reservoir levels and the basis do not significantly explain forward premia currently. This conclusion is based on a relatively small dataset however and the results would have to be confirmed by further research as data becomes available.

IT also seems likely that volatility has a significant impact on forward premia, but that

this impact is not constant across quantiles and the effect is likely based on the relative levels of spot and futures prices, as this will impact how changes in variance have an effect on the downside risk of investors in electricity markets.

Further Work

There are several avenues to extend the analysis performed in this thesis. Two approaches stand out as particularly interesting. Further exploring the changes that have happened over time to the forward premium in the Nordic electricity market in general and looking deeper into the quantile behaviour of the forward premium.

This thesis strongly suggest that market conditions are changing in the Nordic electricity market and that the market efficiency seems to increase. Looking into any changes in the financial market in terms of investors or underlying conditions that have change is highly interesting. Using more recent time series to re-examine the findings on day-ahead futures to see if the changes are manifest there as well would be interesting. Weron and Zator (2014) has already presented a recent study on weekly futures, but the paper does not specifically analyze the newest data and their sample ends in 2010. Especially data between 2010 and 2015 has seen very little attention by researchers so far.

As this paper presents a quantile regression model one possible extension is into the territory of Value-at-Risk estimation. A quantile regression model gives the possibility to directly model the conditional quantiles of a distribution of returns, which is what has been done for long positions in electricity futures in this paper. This will give access to better risk assessment for energy firms. Comparing the efficacy of a quantile regression framework with the more popular general VaR approaches such as GARCH models would be particularly interesting.

In addition to this the effect of volatility on the forward premium varies greatly across quantiles. Seeing if this behaviour is consistent across various sizes of futures contracts would be highly interesting and yield new insights into the relationship between forward premia and the spot price volatility. IT would also be highly interesting to see if this changing behaviour with respect to the quantile being modelled can be found in other electricity markets than the Nordic.

A. R code

OLS regression

Normal standard errors

```
LRPdata <- read.csv2("LRPnolag.csv")
PRPdata <- read.csv2("PRPnolags.csv")

attach(PRPdata)

PRPmodel <- lm(PRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis,
data = PRPdata)


detach(PRPdata)
attach(LRPdata)
LRPmodel1 <- lm(LogRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis,
data = LRPdata)

detach(LRPdata)

dwtLRP <- car::dwt(LRPmodel1)
dwtPRP <- car::dwt(PRPmodel)
```

With robust standard errors

```
LRPdata <- read.csv2("LRP.csv")
PRPdata <- read.csv2("PRP.csv")

library("lmtest")
library("sandwich")

attach(PRPdata)

PRPmodel <- lm(PRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+PRP.lags,
data = PRPdata)
```

```
detach(PRPdata)
attach(LRPdata)
LRPmodel1 <- lm(LogRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+LRP.lags,
data = LRPdata)

detach(LRPdata)


coeftest(PRPmodel,vcov = vcovHAC)
coeftest(LRPmodel1,vcov = vcovHAC)
dwtLRP <- car::dwt(LRPmodel1)
dwtPRP <- car::dwt(PRPmodel)
```

Two sub-periods

```
LRPdata1 <- read.csv2("LRP1av2.csv")
LRPdata2 <- read.csv2("LRP2av2.csv")
PRPdata1 <- read.csv2("PRP1av2.csv")
PRPdata2 <- read.csv2("PRP2av2.csv")


attach(PRPdata1)

PRPmodel1 <- lm(PRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+PRP.lags, data = PRPd

detach(PRPdata1)

attach(PRPdata2)

PRPmodel2 <- lm(PRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+PRP.lags, data = PRPd

detach(PRPdata2)
attach(LRPdata1)
LRPmodel1 <- lm(LogRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+LRP.lags, data = LR

detach(LRPdata1)
```

```
attach(LRPdata2)
LRPmodel2 <- lm(LogRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+LRP.lags, data = LRPdata

detach(LRPdata2)
LRPsummary1 <- summary.lm(LRPmodel1)
PRPsummary1 <- summary.lm(PRPmodel1)
LRPsummary2 <- summary.lm(LRPmodel2)
PRPsummary2 <- summary.lm(PRPmodel2)
```

Quantile Regression

The entire sample

```
LRPdata <- read.csv2("LRP.csv")
PRPdata <- read.csv2("PRP.csv")

quantiles <- seq(0.01,0.99,by=0.01)
attach(PRPdata)

PRPmodel <- quantreg::rq(PRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+PRP.lags,
tau =quantiles, data = PRPdata)


detach(PRPdata)
attach(LRPdata)
LRPmodel1 <- quantreg::rq(LogRP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+LRP.lags,
tau = quantiles, data = LRPdata)

detach(LRPdata)
LRPsummary <- quantreg::summary.rqs(LRPmodel1)
PRPsummary <- quantreg::summary.rqs(PRPmodel)

quantreg::plot.summary.rqs(PRPsummary, ols = TRUE)
dev.copy(postscript,'PRP.eps')
dev.off()
quantreg::plot.summary.rqs(LRPsummary, ols = TRUE)
dev.copy(postscript,'lrp.eps')
dev.off()
```

Two sub-periods

```
LRPdata1 <- read.csv2("LRP1av2.csv")
LRPdata2 <- read.csv2("LRP2av2.csv")
PRPdata1 <- read.csv2("PRP1av2.csv")
PRPdata2 <- read.csv2("PRP2av2.csv")

quantiles <- seq(0.01,0.99,by=0.01)

attach(PRPdata1)

PRPmodel1 <- quantreg::rq(PFP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+PFP.lags,ta

detach(PRPdata1)

attach(PRPdata2)

PRPmodel2 <- quantreg::rq(PFP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+PFP.lags,ta

detach(PRPdata2)
attach(LRPdata1)
LRPmodel1 <- quantreg::rq(LogFP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+LFP.lags,

detach(LRPdata1)
attach(LRPdata2)
LRPmodel2 <- quantreg::rq(LogFP~OI.LOW+OI.HIGH+Temperature+RV+RESD+VIX+Basis+LFP.lags,

detach(LRPdata2)

LRPsummary1 <- quantreg::summary.rqs(LRPmodel1)
PRPsummary1 <- quantreg::summary.rqs(PRPmodel1)
LRPsummary2 <- quantreg::summary.rqs(LRPmodel2)
PRPsummary2 <- quantreg::summary.rqs(PRPmodel2)

quantreg::plot.summary.rqs(LRPsummary1, ols = TRUE)
dev.copy(postscript,'lrp1av2.eps')
dev.off()
quantreg::plot.summary.rqs(PRPsummary2, ols = TRUE)
dev.copy(postscript,'PRP2av2.eps')
dev.off()
quantreg::plot.summary.rqs(LRPsummary2, ols = TRUE)
```

```
dev.copy(postscript,'lrp2av2.eps')
dev.off()
quantreg::plot.summary.rqs(PRPsummary1, parm = c(1,2,4,5,6,7,8,9), ols = TRUE)
dev.copy(postscript,'PRP1av2.eps')
dev.off()
```

B. Quantile Regression results for the two sub-periods

Here are the results for re-estimation of the quantile regression model using percentage forward premia for the two sub-periods. The high open interest plot had to be omitted for the first period due to essentially unbounded confidence levels. Figure B.1 shows the first period and table B.2 shows the second period.
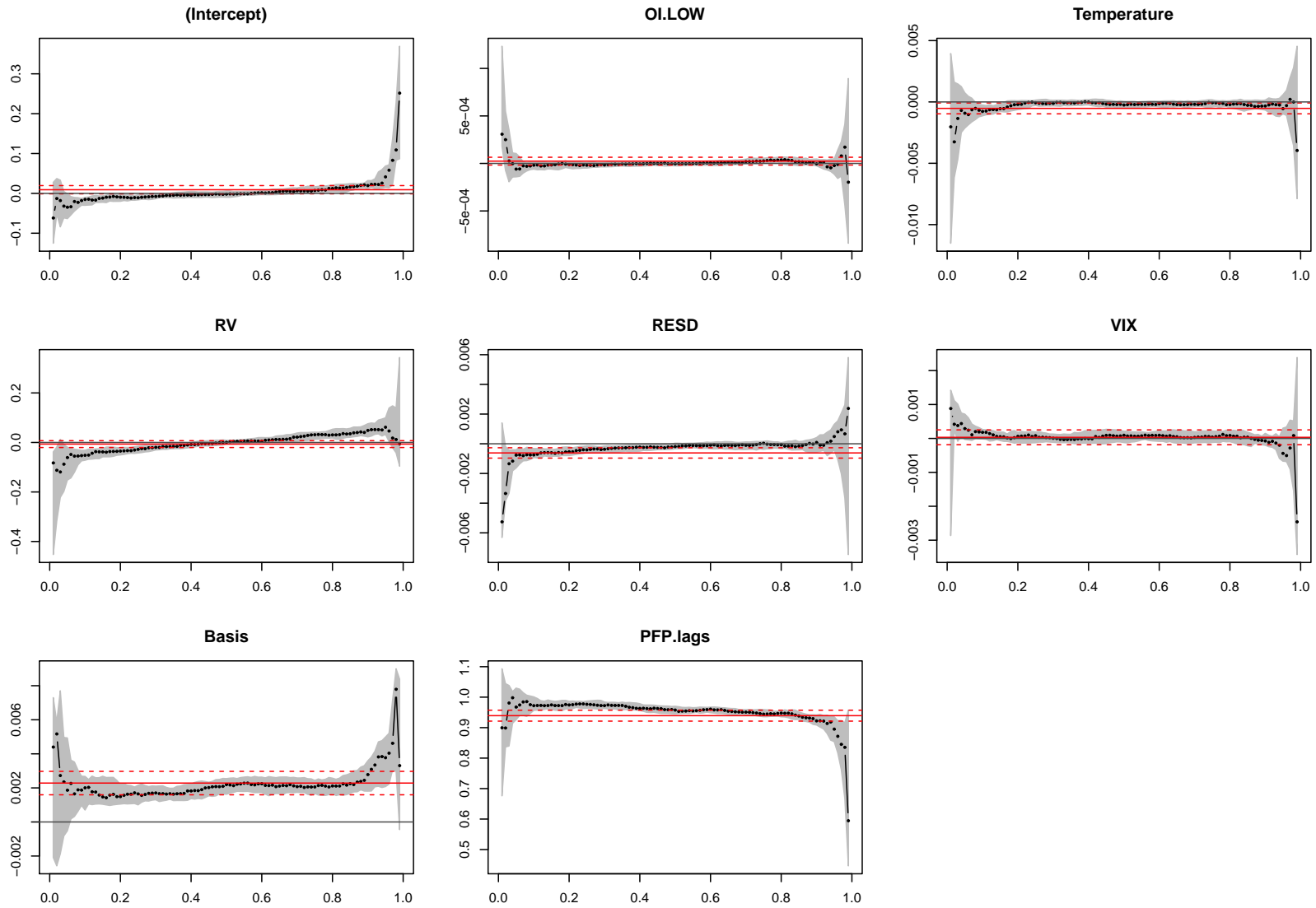
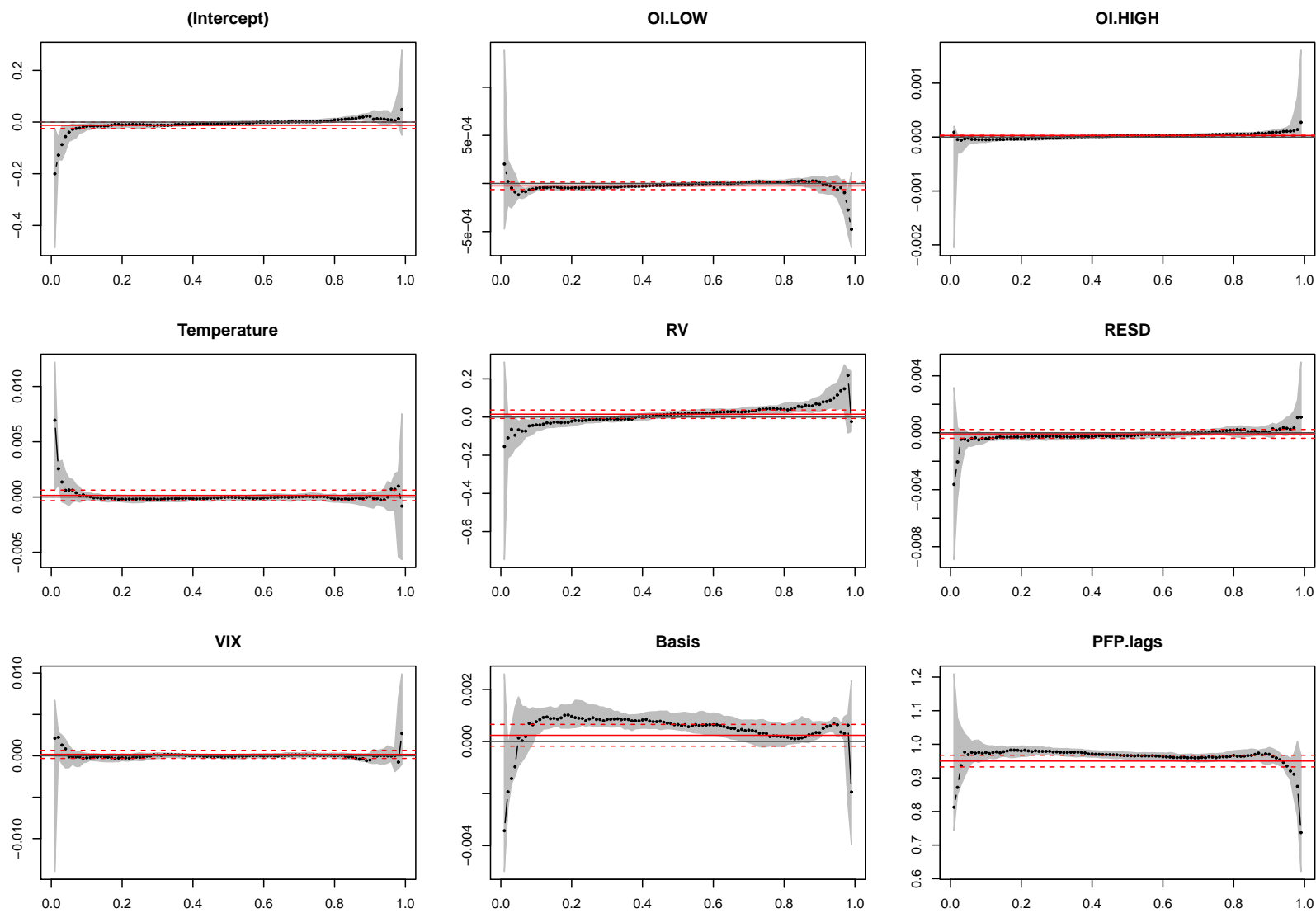Figure B.1: Coefficients plotted per quantile for the percentage forward premium for the first sub-period

Figure B.2: Coefficients plotted per quantile for the percentage forward premium for the second sub-period

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