Aalto University
School of Business

Futures Pricing in the Nordic Electricity Market

Finance

Master's thesis

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Abstract of master's thesis

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Abstract

This master's thesis examines the behavior of electricity spot and futures prices and the futures premium in the Nordic electricity market. The objective of the study is to identify, whether a nonzero futures premium exists in the Nordic electricity market, and to gauge its economic significance and the factors affecting its behavior. Furthermore, the forecasting ability of electricity futures over the future spot price is examined, and finally the existence of arbitrage opportunities is tested by constructing synthetic futures and comparing their prices with actual futures prices.

The data in this study consists of daily electricity spot prices in the Nord Pool power exchange for years 2000 – 2011, and electricity futures price data for weekly, monthly, quarterly and yearly contracts during the same period. The price data is complemented by coal price data and Nordic level data on water reservoir levels and electricity demand, which are the variables used to examine the behavior of electricity prices and the futures premium.

The results show that the futures premium in the Nordic electricity market is nonzero and positive for the time period 2000 - 2011, generally increasing with contract maturity. The futures premium exhibits very high variation, but on average the relative futures premium ranges from being close to zero with weekly futures to levels above 20 percent for yearly futures.

The OLS regression analyses show that deviations from historical water reservoir levels have an inverse relationship with electricity spot and futures prices so that above average water reservoir levels have a negative impact on electricity prices, and vice versa. Coal price and the overall electricity demand exhibit a positive relationship with electricity prices, and the influence of all these physical factors diminishes with the futures' time to maturity, being the strongest for shorter maturity futures and weak or inexistent for futures with longer maturities.

On the contrary, deviations from historical water reservoir levels indicate a positive relationship with the futures premium, this relationship being negative for coal price and electricity demand.

Furthermore, consistent with the expectations theory, electricity futures seem to possess strong explanatory power over the future spot price in the Nordic electricity market, whereas no evidence of time-varying risk premiums is found.

Finally, the comparison of synthetic futures prices to actual futures prices reveals that with yearly futures the mean relative price difference is close to zero, indicating that no opportunities for arbitrage exist, but for quarterly and monthly futures the price difference is different from zero on average, reaching a maximum mean value of 2.0% for 1-month contracts. This indicates that opportunities for risk-free profits may exist for arbitrageurs using synthetic futures to mimic the actual futures contracts. These arbitrage opportunities continue to prevail when transaction costs are at levels below two percent of the futures price, although their economic significance is low.

Keywords Nord Pool, electricity, futures pricing, basis, futures premium

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Abstract of master's thesis

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Tiivistelmä

Tämä pro gradu-tutkielma tarkastelee sähkön spot- ja futuurihintojen sekä futuuripreemion käyttäytymistä Pohjoismaiden yhteisillä sähkömarkkinoilla. Tutkielman tavoitteena on tutkia, onko futuuripreemio Pohjoismaisilla sähkömarkkinoilla positiivinen, sekä mitata sen taloudellista merkittävyyttä ja sen käyttäytymiseen vaikuttavia tekijöitä. Lisäksi tutkielmassa tarkastellaan sähköfutuurisopimusten kykyä ennustaa tulevaisuuden sähkön spot-hintoja. Lopuksi tutkin, onko synteettisiä futuurisopimuksia rakentamalla mahdollista saavuttaa riskittömiä arbitraasituottoja.

Tutkimuksessa käytetty havaintoaineisto koostuu päivittäisistä sähkön spot-hinnoista Pohjoismaisessa Nord Pool-sähköpörssissä vuosilta 2000 – 2011 sekä viikko-, kuukausi-, kvartaali- ja vuosifutuurien päivittäisistä hintahavainnoista samalla aikavälillä. Lisäksi käytän tietoja hiilen päivittäisestä hinnasta sekä vesivarantotasojen ja sähkön kysynnän määrästä selittävinä muuttujina tutkiessani sähkön hintojen sekä futuuripreemion käyttäytymistä.

Tulokset osoittavat, että futuuripreemio Pohjoismaisilla sähkömarkkinoilla on positiivinen aikavälillä 2000 – 2011, kasvaen futuurisopimusten maturiteetin kasvaessa. Futuuripreemio vaihtelee voimakkaasti, keskimääräisen suhteellisen futuuripreemion ollessa lähellä nollaa viikkofutuureilla ja jopa yli 20 prosentin tasolla vuosifutuureiden osalta.

OLS-regressioanalyysit osoittavat, että poikkeamat historiallisista vesivarantotasoista ovat käänteisesti sidoksissa sähkön hintoihin, ja hiilen hinta ja sähkön kysyntä ovat positiivisesti sidoksissa sähkön hintoihin. Näiden fyysisten tekijöiden vaikutukset sähkön hintoihin pienenevät futuurisopimusten maturiteetin kasvaessa, ollen suurimmillaan lyhyiden futuurisopimusten kohdalla ja pienimmillään tai jopa olemattomia pitkän maturiteetin futuurisopimusten osalta.

Poikkeamilla historiallisista vesivarantotasoista on positiivinen suhde futuuripreemioon, tämän suhteen ollessa negatiivinen hiilen hinnan ja sähkön kysynnän kohdalla.

Odotusteorian mukaisesti sähköfutuureilla vaikuttaisi olevan kyky selittää sähkön spot-hintaa tulevaisuudessa, kun taas tukea ajassa muuttuvien riskipreemioiden olemassaololle ei löydy.

Lopuksi, synteettisten ja todellisten futuurisopimusten hintojen vertailu näyttää, että näiden keskimääräinen suhteellinen hintaero on lähellä nollaa vuosifutuurien kohdalla, osoittaen että arbitraasimahdollisuuksia ei ilmene. Kvartaali- ja kuukausifutuurien kohdalla hintaero ei keskimäärin ole nolla, saavuttaen maksimikeskiarvon 2.0% yhden kuukauden futuurisopimuksilla. Tämä osoittaa, että mahdollisuuksia riskittömiin tuottoihin esiintyy rakentamalla synteettisiä futuurisopimuksia replikoimaan todellisia futuureja. Nämä tuottomahdollisuudet ilmenevät edelleen myös transaktiokustannukset huomioiden, mikäli transaktiokustannukset ovat alle 2.0%:a futuurisopimuksen hinnasta, vaikkakin näiden riskittömien tuottojen taloudellinen merkittävyys on alhainen.

Avainsanat Nord Pool, sähköfutuurien hinnoittelu, futuuripreemio

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1. INTRODUCTION

1.1. Background and motivation

The deregulation of power markets, both in the Nordics and around the world, has brought increased transparency into the electricity market operation, allowing a larger audience to observe electricity prices and their developments. This has supported the development of financial markets for electricity, and also attracted the attention of power producers and wholesalers, speculators, consumers and regulators (see, for example, Lucia and Schwartz, 2002; and Redl et. al, 2009). In addition to balancing the supply and demand for electricity, the power markets also provide electricity suppliers and consumers a means of hedging against the highly volatile electricity prices. Electricity futures and forward markets thus serve an important role in the management and allocation of risks associated to the physical market prices (see, for example, Bessembinder and Lemmon, 2002; Botterud et al. 2010; and Lucia and Torro, 2011). Furthermore, electricity prices are extremely volatile, which makes hedging against price volatility very important for the market participants. Therefore it is important to examine electricity financial markets to provide information and develop understanding about their functioning and efficiency, and the inherent information borne by the electricity prices.

The Nordic Power Exchange, Nord Pool, was the first market in the world for trading power, and today it is also the world's largest market of its kind, providing a leading marketplace for buying and selling power in the Nordic region (Nord Pool [a]). Thus, Nord Pool provides an unmatched environment for examining the development of a power market and its pricing dynamics.

Furthermore, the special characteristics of electricity as a non-storable commodity – at least economically[1] – bring upon distinctive challenges that do not support using the traditional futures pricing models when valuing electricity futures and forwards contracts. Bessembinder and Lemmon (2002) present an equilibrium model for electricity forwards pricing, arguing that because electricity spot prices are volatile and since power cannot be economically stored, familiar arbitrage-based methods are not applicable for pricing electricity derivative contracts. Therefore it is important to empirically test and evaluate the models developed for pricing these

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[1] Electricity can be stored to some – relatively small – extent by filling hydropower reservoirs or charging batteries. See Bessembinder and Lemmon (2002), Botterud et al. (2002), Mork (2006) and Huisman and Kilic (2012) for further discussion on electricity storability.

financial instruments and to provide further evidence on the relationship between the spot and futures prices, the factors affecting this relationship, and their implications.

The previous research on the futures pricing in the Nordic electricity markets is relatively recent, dating back to the early 2000's, due to the fact that the electricity market in the region is also rather young as it began its operation in the 1990's. The previous literature seems to be rather unambiguous about the existence of the nonzero futures premiums in the Nordic electricity market, but a large share of the previous literature has questioned the market's maturity, and called for further testing to see whether the Nordic electricity market characteristics have evolved over time and whether the market has become more mature. Furthermore, the research on the fundamental factors influencing the electricity spot and futures prices has focused on the role of water reservoir levels in the Nordic power market, but the role of coal-fired power generation has received surprisingly little attention. Hence, it appears that there is ample of room for further research on the characteristics and behavior of the Nordic electricity market, and my aim is to contribute to this research, as specified in the next section.

1.2. Research question and contribution

Building on the previous literature on the Nordic electricity market characteristics, I further examine the existence and the nature of futures premiums in the Nordic electricity market. If a nonzero futures premium exists, it is of particular importance to analyze its characteristics, economic significance and the factors affecting these elements. Moreover, I also test the pricing efficiency in the electricity futures market by comparing the market prices of long-maturity electricity futures to the prices of synthetic futures consisting of shorter-maturity contracts.

Drawing these elements together, the research question of this thesis can be formulated as a combination of three sub-questions:

1) *Does a nonzero futures premium exist in the Nordic electricity market?*
2) *If a nonzero futures premium exists,*
    a. *what is its economic significance?*
    b. *what factors affect its behavior?*
3) *Does the Nordic electricity futures market present opportunities for arbitrage?*

The contribution of this thesis to the existing literature is two-fold: First, the role of marginal electricity production cost in determining electricity prices has received little attention in the academic literature on the Nordic electricity market. This gap in the literature is notable, given that there seems to be a widespread view amongst the practitioners in the market that the cost of coal-fired power stations plays an important role in determining the electricity price in the Nordic market. Furthermore, the relationship between the futures premium and the marginal production cost, for which I use coal price as a proxy, has not been previously examined in the literature. My research contribution thus lies in examining the influence of coal price on electricity prices and the futures premium in the Nordic electricity market.

Second, I further develop the findings from the previous literature by testing the influence of water reservoir levels and the overall electricity demand on electricity spot and futures prices and the futures premium by using a longer sample period and a more comprehensive set of futures and forward contracts than the previous studies. Similarly, I analyze the relationship between real and synthetic futures prices with a more comprehensive set of futures contracts and during a longer and more recent time-period. These analyses extend the previous literature and also shed some light on whether the market has become more mature over time – a question raised in the previous research – and whether the market dynamics have changed over time.

Thus, my contribution to the existing literature can be summarized as first introducing a new variable – coal price, serving as a proxy for the marginal cost of producing electricity – into the discussion about the factors affecting the futures premium in the Nordic electricity market. Second, I provide new information about the relationship between coal price and electricity futures prices using a wider range of futures and forward contracts, and third, I validate and further test the previous research on the Nordic electricity market’s behavior.

1.3. Research scope and limitations

The focus of this thesis is in the behavior of electricity spot and futures prices in the Nord Pool electricity market and in the factors affecting the behavior of these prices. A number of fundamental factors closely linked to electricity prices – such as water reservoir levels, electricity supply and demand, temperature and coal price are touched upon – but the scope of this thesis is restricted to examining their relationship with electricity prices, and thus a detailed analysis of the behavior of these factors is not in the scope of this study.

Furthermore, the scope of this thesis with regards to the electricity financial markets is limited to the Nord Pool daily system price as the spot price, and to weekly-, monthly-, quarterly- and yearly futures contracts in the financial market. Hence, examination of hourly prices and intraday trading in the Elbas market, as well as the more complex financial products such as area prices, contracts for difference, or options contracts, are limited outside the scope of this thesis.

An important limitation in this study is also presented by the data: As the Nord Pool data proved to be too costly to be accessed directly, the data on electricity spot and futures prices together with the water reservoir and electricity demand data was received from the Economics department at Aalto University School of Business. This does not present severe handicaps to the analyses performed in the thesis, but the unavailability of the data on trading volumes and bid-ask -spreads limits the possibilities for further analyzing the market dynamics.

1.4. Main findings

The results in this thesis show that the basis – i.e. the futures premium – is, on average, nonzero and positive in the Nordic electricity market, ranging from 1.96% to 21.16%, being the smallest for short-maturity futures and increasing with contract maturity. Thus, the Nordic electricity market seems to conform a contango-relationship with futures prices above spot prices, which is consistent with the previous findings by Botterud et al. (2002), Mork (2006), Botterud et al. (2010), Gjolberg and Brattested (2011), Lucia and Torro (2011), and Huisman and Kilic (2012). These results imply that the hedging needs between buyers and sellers in the Nordic electricity market are not balanced, but rather suggest that purchasers of power face greater hedging needs and are willing to pay a premium to the sellers of power for fixing the prices into the future.

The results also show that coal price, which has received little attention in the previous literature, exhibits a strong positive relationship with electricity spot and futures prices in the Nordic market. Increases in coal price – i.e. in the cost of producing electricity with coal – have a positive relationship with electricity prices, which is consistent with Redl et al. (2009) and Kauppi and Liski (2008). This highlights the role of coal in determining electricity prices in the

Nordic market, a dimension often understated by the dominant role of hydropower generation in the region.

The results also show that deviations from historical water reservoir levels have an inverse effect on electricity spot and futures prices, consistent with the previous literature on electricity spot and futures prices’ behavior in the Nordic electricity market (see for example Botterud et al., 2002; Botterud et al., 2010; Gjolberg and Brattested, 2011; Lucia and Torro, 2011; Huisman and Kilic, 2012). In addition, the results also show that electricity demand has a positive relationship with electricity prices in the Nordic market, following a natural rationale that prices increase with demand. These results are consistent with the prediction of the theoretical model by Bessembinder and Lemmon (2002), also lending support to the findings by Botterud et al. (2010).

Furthermore, the results also show that the influence of water reservoir level deviations from historical median levels, coal price, and electricity demand on electricity prices seems to decline when the time to maturity of the futures contract increases, presenting the strongest influence on short-maturity contracts and the smallest impact on long-maturity contracts.

I also find that the influence of the physical factors in the market – i.e. water reservoirs, coal price and electricity demand – on futures premium are opposite to their effects on electricity prices. Deviations from historical water reservoir levels are positively correlated with futures premiums, and coal price and electricity demand exhibit a negative relationship with the futures premium. Furthermore, the relationship between these physical factors and the futures premium increases with contract maturity, inversely to what was observed with their impact on electricity prices.

Furthermore, the results show that electricity futures in the Nordic electricity market possess forecasting power over the future electricity spot price, lending strong support to the findings by Huisman and Kilic (2012), providing further evidence on the forecasting power of electricity futures in the Nordic market. Moreover, the results present no evidence of time-varying risk premiums in the Nordic market, also consistent with Huisman and Kilic (2012).

Finally, a comparison of synthetic and real futures prices shows that price discrepancies between these contracts do exist. For yearly futures the results are consistent with previous research by Kristiansen (2007), as the synthetic futures prices show good correspondence with the observed market prices, the deviations at maximum being around 25 basis points on average. This price difference is greater for quarterly futures, observed futures prices being on average 0.21% to 1.62% above the synthetic prices. For monthly futures this average price difference is as high as 2.01% for the month-ahead future and 0.69% for the 2-month contract, suggesting that opportunities for arbitrage would exist in the Nordic market, contradictory to Wimschulte (2010). The price differences are large enough to prevail even if an estimate of transaction costs is included in the analysis, the opportunities for systematical arbitrage disappearing only when transaction costs reach levels above 2% of the futures price. However, the economic significance of these risk-free profits is, on average, rather low.

1.5. Structure of the study

The remainder of this thesis is organized as follows: First, the Nordic electricity market organization and characteristics are discussed briefly. Second, the theoretical background on futures pricing and electricity futures is examined together with the previous research on electricity futures pricing in the Nordic electricity market. The fourth section presents the hypotheses for this study, followed by description of the data in Section 5 and methodology in Section 6. Section 7 presents the analysis and results, and finally Section 8 concludes.

2. NORDIC ELECTRICITY MARKETS

In this section I first briefly discuss the Nordic electricity markets, their history and organization, then proceeding to examine the market’s characteristics before moving on to the theoretical background in the next section.

2.1. History and Organization of the Nordic Electricity Market

The Nordic Power Exchange, Nord Pool, has its roots in the Norwegian power market. Prior to the European-wide deregulation of electricity markets that began with the passing of the European Commission’s Electricity Directive in 1996, Norway started the liberalization of its electricity market in 1991 when the law deregulating the market for trading power went into effect. The independent Norwegian power exchange was established in 1993, followed by the establishment of Norwegian-Swedish power exchange and the world’s first international power exchange, Nord Pool, in 1996. Finland joined the market in 1998, and the Nordic market became fully integrated as Denmark followed in the year 2000 (NASDAQ OMX Europe, 2012; Nord Pool [a], see also Botterud et al., 2002; and Lucia and Schwartz, 2002).

The electricity financial market has evolved together with the development of the physical market and the overall operating environment of the marketplace. The financial market for electricity forwards was established together with the Norwegian power exchange in 1993, and the variety of products and the market's functioning has developed throughout the market's existence. Financially settled forward power contracts – instead of physically settled contracts – were introduced to the market and the forward products were standardized in 1997. A new product structure replacing seasonal products with quarters was gradually introduced in 2003, listed for the first time in the beginning of 2004, and the time horizon of weekly futures was shortened to 8-9 weeks and gradually down to 6 weeks in 2005. All contracts with delivery period from 2006 onwards were listed in Euros instead of Norwegian Crowns, allowing easier cross-border trade and further standardization with other products and exchanges (NASDAQ OMX Europe, 2012).

According to Nord Pool (Nord Pool [b]), 73 percent of all electricity in the Nordic region was traded on Nord Pool in 2011, which resembles the wide coverage of the exchange in the region. Nord Pool data shows that there were around 370 power suppliers in Nord Pool Spot power market in November 2012, consisting of the major energy companies in the region and of a number of smaller and more local players (Nord Pool [c]). Put together, these statistics show that the Nord Pool exchange covers the majority of the traded electricity in the region and connects a significant number of players in the market, and therefore it can be argued that Nord Pool presents us with a rather comprehensive picture of the electricity markets in the Nordic region.

In Nord Pool the trading is organized in two complementary markets, Elspot for day-ahead trading and Elbas for intraday trading. The Elspot market operates as an auction, where prices are calculated at 12:00 CET for delivery of power for each of the 24 hours on the next day based on the orders by the market participants. After the market participants have submitted their orders, equilibrium between the aggregated supply and demand curves is established for all bidding areas and a *system price* is calculated based on the sale and purchase orders.

System price is the price balancing the supply and demand conditions in the entire Nordic market area, and it is used as the reference price for the financial contracts. Transmission capacity constraints are not taken into account in calculating the system price, but if congestion occurs, different area prices are introduced to relieve the bottlenecks in transmission capacity through a pricing mechanism. However, as the system price – the reference price for financial products – disregards transmission capacity constraints and because the financial contracts in Nord Pool are settled in cash and no physical transfer of power takes place in futures contract settlement, this does not present any complications for the futures market.

To smooth the electricity supply and demand, an electricity market needs to be continuously balanced (Lucia and Schwartz, 2002). The intraday Elbas market operates as a balancing mechanism between the supply and demand of power, allowing market participants to trade power close to the delivery hour to balance the supply and demand conditions, which may fluctuate between the day-ahead market cut-off time and the assigned delivery period. Due to the role of the Elbas market as a balancing mechanism, the day-ahead Elspot market is considered to represent the spot market in the Nordic power markets, as argued by Lucia and Schwartz (2002); Mork (2006); and Huisman and Kilic (2012). Therefore a more detailed examination of the balancing market functioning is out of the scope of this study.

In addition to the spot- and intraday power markets, a very important component of the Nordic electricity market functioning is the electricity financial market, which is organized at NASDAQ OMX Commodities exchange. The electricity financial market serves an important role in the whole electricity market functioning by allowing suppliers and purchasers of electricity to hedge their future deliveries and receipts of power with financial instruments – electricity futures and forwards – thus offering a means of protecting against fluctuating electricity prices. The reference price for all futures and forward contracts is the Nord Pool system price.

NASDAQ OMX Commodities exchange lists power futures are up to 6 weeks into the future and forwards are traded monthly up to 6 months, quarterly contracts 8-11[2] quarters ahead, and yearly forwards up to 10 years into the future in the for the base load (NASDAQ OMX Commodities [a]). The longer term forward contracts are cascaded (split) three days before they reach maturity so that yearly contracts are split into quarters and quarterly contracts are cascaded into months, whereas the shorter futures and forwards contracts (weekly and monthly) are not subject to

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[2] The current year's remaining quarters and two rolling years in quarters

cascading in the Nordic power market (NASDAQ OMX Commodities [a]). The year-ahead forward, for example, is first cascaded into four quarterly contracts at its maturity, and each of these quarterly contracts are finally cascaded into three monthly contracts at their maturities.

The futures and forward contracts are marked to market daily. The weekly futures are subject to both daily mark-to-market settlement and a final reference price settlement after the expiry date, which covers the difference between the final closing price of the futures contract and the system price in the delivery period (NASDAQ OMX Commodities [b]). However, for forward products there is no settlement during the trading period prior to the expiry date and the mark-to-market amount is accumulated (but not realized) as a daily loss/ profit throughout the trading period. The mark-to-market balance is realized in the delivery period, where the settlement is carried out in the same way as for the futures contracts. Hence, cash is required in the participants' cash accounts only during the delivery period, starting at the expiry date of the contract.

2.2. Nordic Electricity Market Characteristics

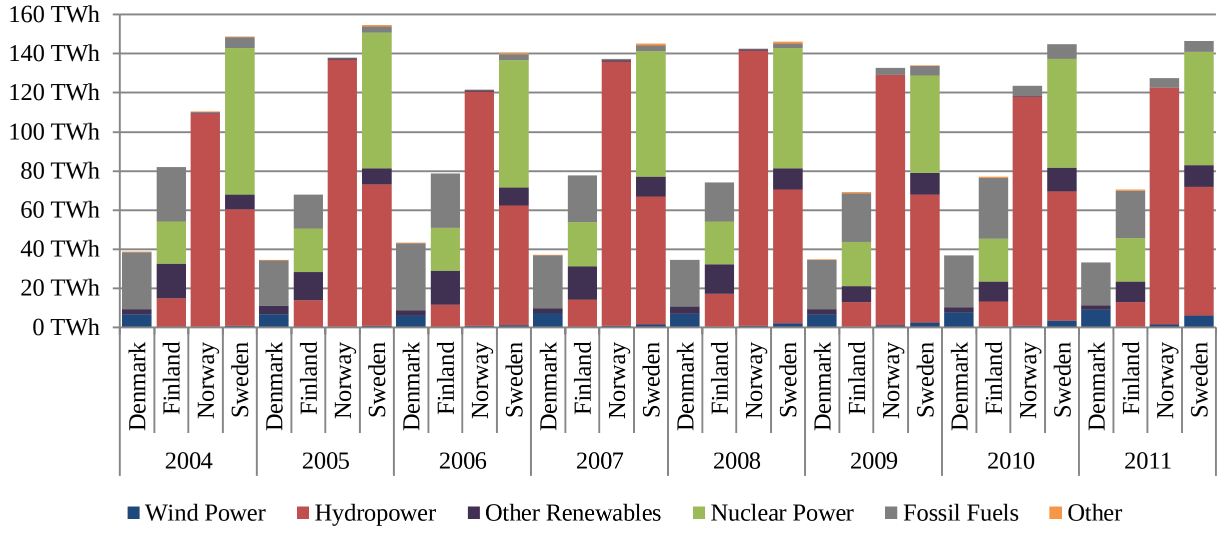
The Nordic electricity market is unique in many ways. Nord Pool presents an unmatched environment for examining electricity prices not only because the market has a relatively long history of exchange-organized trading, but more importantly because of its environmental and geographical characteristics: The market serves as a power exchange for four countries with varying power supply structures, the overall electricity generation is dominated by hydropower production with coal playing an important role in adjusting power supply to meet the demand peaks, and electricity demand varies both with economic activity and seasonally in the course of the year. This section briefly discusses these characteristics that make the Nordic electricity market unique, thus making it both interesting and important to examine the market’s dynamics.

2.2.1. Electricity generation in the Nordic region

The Nordic electricity market is unique in the way that it brings together four countries with different power production structure, thus harmonizing the power prices in the four countries – to the extent that transmission capacity does not present constraints to power transfer across national borders, whereas area prices become the relevant measure for electricity price when congestion occurs. As the focus of this thesis is on the regional system price and futures contracts settled against the system price, area prices or contracts for difference are not covered in a more detail.

All in all, the four Nordic countries are very different in terms of their power generation structure, as may be observed from the Figure 1 below: Denmark is the smallest power producer in the region, representing roughly ten percent of the region’s total supply of around 400 TWh annually. The country enjoys a slightly milder climate and uses fossil fuels and wind as the main means of power generation with zero nuclear power capacity. Finland accounts for roughly a fifth of the power generation in the region with a versatile mix of hydro (ca. 20% of the country’s production), other renewables (ca. 15%), nuclear (ca. 30%) and fossil fuels (ca. 35% power of generation). On the contrary, Norway produces basically all its electricity using hydropower, representing around 35% of the region’s electricity production. Sweden is the largest power generator in the region with slightly below 40% share of the total, hydro and nuclear power together accounting for over 80% of the country’s production.

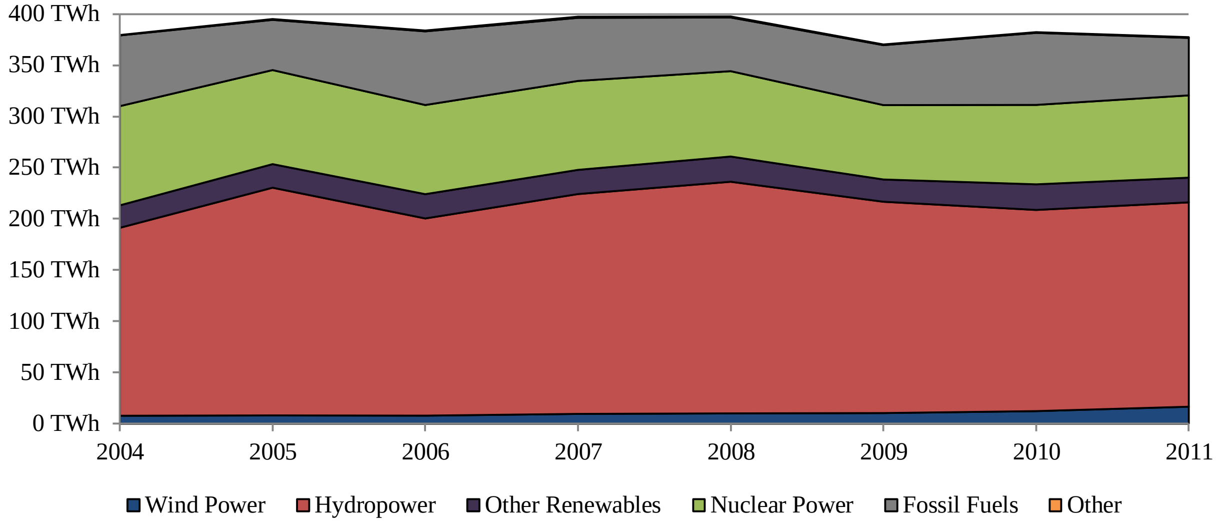
Figure 1. Electricity generation in the Nordic region by country, 2004 – 2011.
The figure shows the annual total power generation in Denmark, Finland, Norway and Sweden in terawatt hours (TWh) of power by production type between 2004 and 2011. Other Renewables consist of solar power, renewable waste- and recycling fuels, and Fossil Fuels include natural gas, coal, oil and peat.



Sources: Nord Pool, Nordel annual reports 2004 - 2008, and ENTSO-E Statistical Yearbooks 2008-2011

The total annual power generation in the Nordic power market is around 400 TWh, about half of which is produced by hydropower, as shown in Figure 2 on the next page, which highlights the importance of hydropower in the Nordic power market. Wind power and other renewable sources of electricity, such as solar power and renewable waste- and recycling fuels, represent in total ca. 10% of the power generation, and thus play a smaller role in the Nordic market. Nuclear power represents around 20% of the power generation, and the proportion of fossil fuels – i.e. natural gas, coal, oil, peat, non- renewable waste- and recycling fuels – fluctuates between 12% and 19 % of the total power generation in the region.

Figure 2. Electricity generation in the Nordic region, 2004 – 2011.
The figure shows the combined annual total power generation in Denmark, Finland, Norway and Sweden in terawatt hours (TWh) of power by production type between 2004 and 2011. Other Renewables consist of solar power, renewable waste- and recycling fuels, and Fossil Fuels include natural gas, coal, oil and peat.

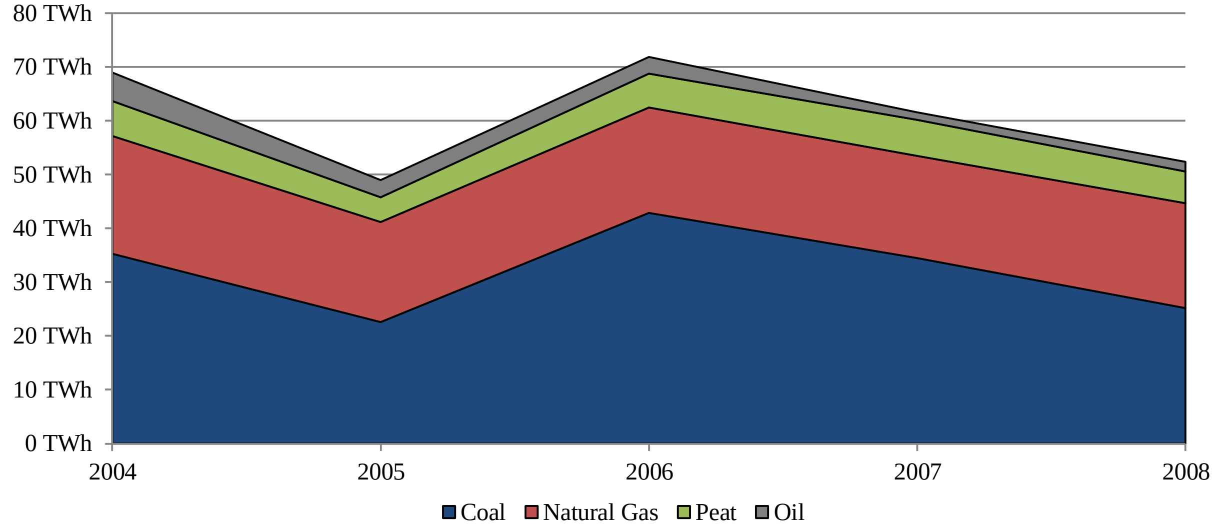


Sources: Nord Pool, Nordel annual reports 2004 - 2008, and ENTSO-E Statistical Yearbooks 2008-2011.

When examining the power generation structure in the Nordic market in a more detail, it is apparent that hydropower production is the cornerstone in the market with its 50% production of the total, complemented by a steady one-fifth generation by nuclear power. However, fossil fuels seem to be the balancing factor between the combined supply of hydro- and nuclear power and the electricity demand, their proportion of total generation increasing when the proportion of hydropower generation decreases and vice versa. This can be seen from the Figure 2 above by observing years 2004, 2006 and 2009 when the proportion of fossil fuels increases and the proportion of hydropower is lower. The inverse seems to take place in years 2005 and 2008 when the proportion of hydropower peaks and fossil fuels seem to adjust accordingly, the proportions of nuclear power and other renewables remaining seemingly flat.

When breaking down the Fossil fuels category into its components in Figure 3 on the next page, it can be seen that coal is the largest source of power in this category, representing 46-60% of the fossil fuels-based power production. Natural gas production accounts for around 20 TWh in annual power production, peat for around 10% of the fossil fuels category, and oil is the smallest of the fossil fuels in terms of power generation.

Figure 3. Fossil fuels power generation in Nord Pool area 2004 – 2008.
The figure shows the combined annual total power generation with fossil fuels in the Nord Pool area. The figures are in terawatt hours (TWh) of power between 2004 and 2008.

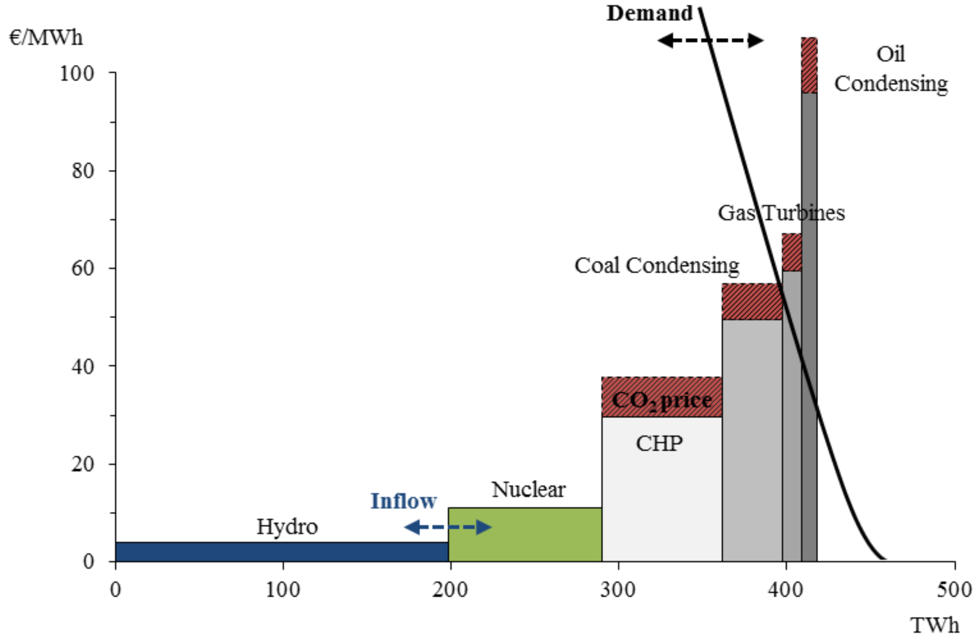


Source: Nordel annual reports 2004 - 2008.

Furthermore, the figure 3 above not only highlights the importance of coal in the fossil fuel-based power generation, but also shows the important role of coal in balancing the Nordic power supply: The amount of coal-generated power fluctuates from 22.6 TWh in 2005, when the fossil fuel-based power generation was at its lowest and hydropower generation in its peak levels, to 42.9 TWh in 2006 when fossil fuel generation peaked and the annual hydropower generation was at its lowest levels. Thus, it appears that coal-fired power generation seems to provide the balancing power supply when the availability of cheap hydropower is scarce.

An explanation for this can be found by examining the marginal power production cost curve, an illustration of which is presented in Figure 4 on the next page. Production cost is on the y-axis of the Figure 4 and the production quantity is presented in the x-axis by the different means of power generation, where the cheapest production method is on the left-hand side at the origin and the most expensive on the right-hand side of the x-axis. Hence, the blocks at the x-axis represent the supply of power, their width representing the generation capacity and the height of the block on the y-axis representing the marginal production cost, all the blocks combined thus forming the discrete production supply curve. Demand, which in the electricity markets is rather inelastic as electricity demand price elasticity is low in the short run (see Redl et al., 2009; Hellmer and Wårell, 2009 and Kauppi and Liski, 2008), is pictured with the black line in the figure, and the market price is found at the interception of the demand curve and the discrete supply curve.

Figure 4. Power production price curve in the Nordic electricity market.
The figure presents an illustrative picture of the power production price curve in the Nordic electricity market, where the production cost is on the y-axis, denominated in €/MWh of electricity production, and the annual total production is on the x-axis. The blocks in the figure represent different means of power production, and the width of these blocks signal the available generation capacity, their height representing the production cost. The red striped areas illustrate the price increases caused by the EU ETS CO_2 emissions allowances. The annual power demand in the region is illustrated with the black demand curve in the picture. This simplified illustration ignores wind- and biomass-based power generation, as they are marginal in size relative to the total production capacity.



Illustrative picture, adapted from Partanen et al. (2012), Energiamarkkinavirasto (2010), Kara et al. (2008) and Nord Pool (2004).

The figure 4 above further illustrates the dominant role of hydropower in the Nordic market, especially in setting the marginal price in the market. As hydropower represents roughly a half of the total power generation in the market and its marginal production cost is close to zero, fluctuations in the hydropower supply – i.e. in water inflows, pictured with the blue dashed arrows in the figure – shift the other means of production in the x-axis of the curve. If the amount of nuclear power generation remains stable, as discussed with Figure 1 earlier, and does not balance the hydropower generation fluctuations so that power demand could be satisfied with hydro and nuclear only, the next means of generation in the x-axis are CHP, i.e. combined heat and power, and coal condensing, both using coal as raw material. Thus, should electricity demand in the Nordic market exceed the combined production capacity of hydro and nuclear, the marginal production methods setting the marginal production cost, i.e. the market price that balances supply and demand, are coal fired methods of production and thus the marginal price in the market should be linked to coal price.

In addition, another important factor affecting the cost of coal fired power in the European Union area is the price of the emission allowances that have a significant impact on the cost of coal-based power production. For example, Kara et al. (2008) estimated that the average electricity spot price would increase by 0.74 €/MWh for every 1€ per tonne CO_2 allowance price in the Nordic area between 2008 and 2012. However, as the functioning of the European Union Emissions Trading Scheme (EU ETS) is not in the focus of this thesis, the impacts of emission allowance prices are not discussed in a more detail, but are merely pictured in Figure 4 above.

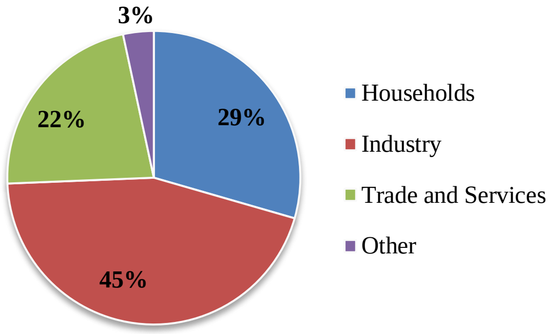
Moreover, if electricity demand in the market cannot be satisfied with hydro, nuclear and coal-related production, the next means of production in the x-axis are gas turbines and oil condensing. As natural gas prices have historically been generally highly correlated with oil price (see, for example, Krichene, 2002, and Villar and Joutz, 2006) and oil condensing by definition turns oil into power, the cost of these means of production is highly dependent on oil price.

Compared to reality, this of course is a simplified picture of the market price development, as wind power, other renewables and new emerging electricity generation methods such as molecular fuel cells utilizing liquid–liquid interfaces (see, for example, Peljo et al. 2011) – that are marginal in generation capacity in relation to the total power generation in the Nordic market – should be incorporated into the power supply curve, together with the net import of electricity from neighboring areas. The import of electricity should naturally increase in quantity as the price differences between the Nordic market and neighboring areas (such as Russia, Poland and Germany, for example) increase in favor of the neighboring areas, thus relieving the price pressure on times of high electricity demand, and turn to exports when the price differences are reversed in favor of the Nordic market, thus increasing the price in the region. However, a deeper analysis of the electricity supply curve and the dynamics of electricity imports and exports are out of the scope of this thesis, and thus I will settle for the simplified supply curve description here.

2.2.2. Electricity demand in the Nordic region

Another distinctive characteristic in the Nordic electricity market is the behavior of electricity demand in the region. Electricity consumption in the Nordics is relatively high compared with other European countries, driven by the combination of cold winters and electricity heated houses and a relatively high proportion of energy intensive industries (NordREG, 2012). Availability of electricity together with a rich supply of raw materials, such as wood and minerals, has provided a fertile ground for the development of energy-intensive industry structure (IEA, 2013). A bit less than a half of the total electricity consumption in the Nordic region is attributable to industry use, 29% for housing, and 22% for trade and services, according to Nordel statistics (Nordel, 2008).

Figure 5. Electricity consumption by sector, 2008.
The pie chart shows the distribution of the total electricity consumption in the Nord Pool region (396.1 TWh in 2008) by sector. Households include power consumption in residential heating and lighting usage, Industry consists of industrial electricity consumption, Trade and Services include electricity consumption in these activities, also including transport, and Other covers the sectors other than the aforementioned, including for example agricultural electricity consumption.

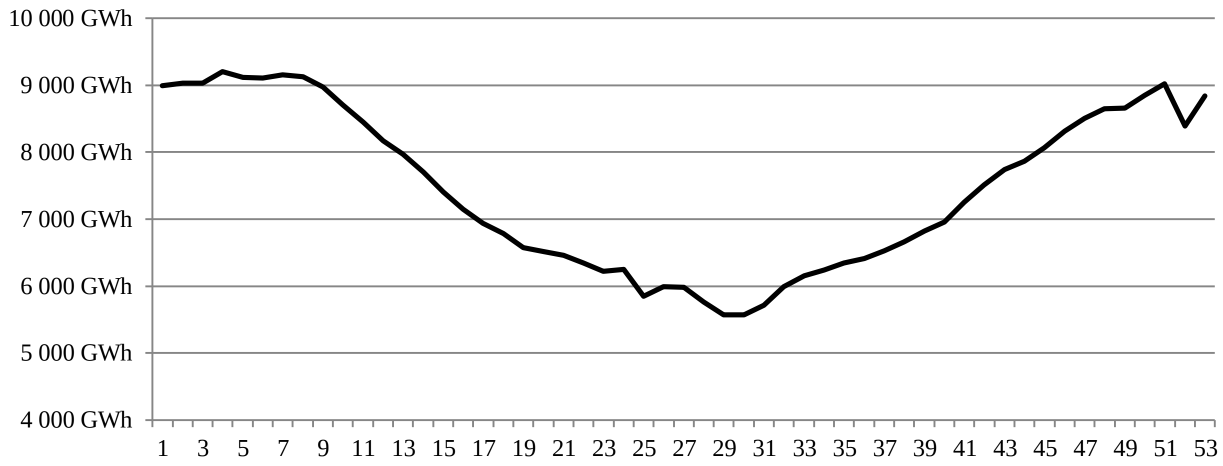


Source: Nordel Annual Statistics 2008 -report.

Hence, electricity demand in the Nordics is generally driven by temperature variation – i.e. heating and lighting demand – and economic growth – i.e. combined demand of industry and the trade and services sector (NordREG, 2012). Due to the natural seasonality in temperatures following the yearly cycle, electricity consumption for heating and lighting presents a seasonal pattern with lower electricity demand in the summer months and higher consumption during the winter (see for example NordREG, 2012).

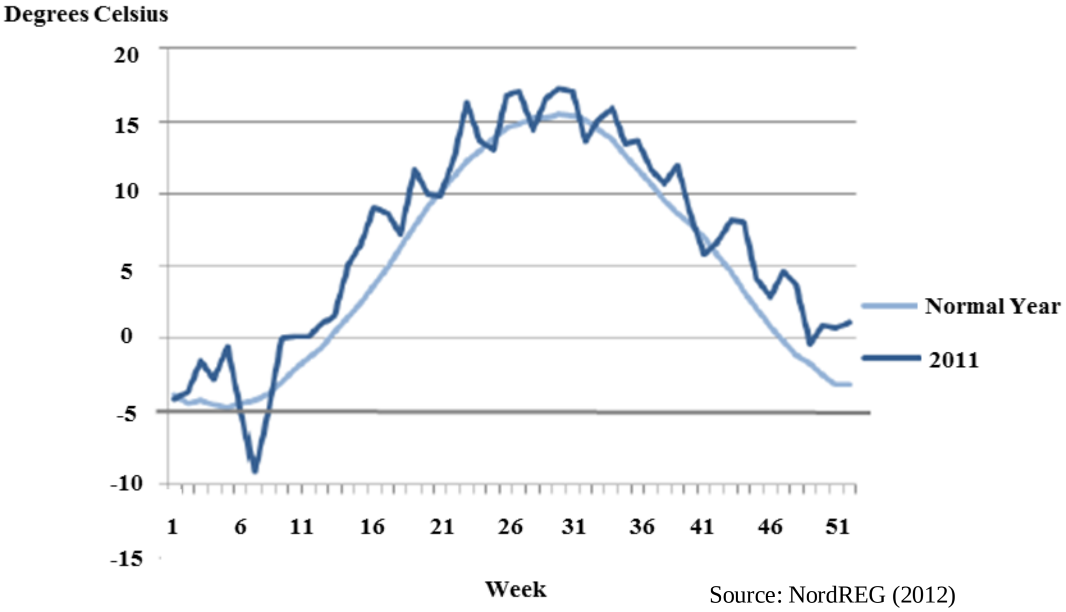
This can be observed from the Figure 6 on the next page, which portrays the mean electricity consumption in the Nord Pool area by week, showing that electricity demand in Nord Pool is the highest during the winter months and the lowest in the summer around week 30. This highlights the natural relationship between electricity demand and different seasons of the year in the region.

Figure 6. Mean electricity demand in Nord Pool region by week.
The figure shows the mean electricity demand in the Nord Pool region by week, based on weekly electricity demand data between week 1 in 2000 and week 30 in 2011. The data was gained from the Economics department Aalto University School of Business, and was originally collected from Nord Pool.



When comparing the average weekly electricity demand in Figure 6 and the temperature curve in Figure 7 below, it can easily be seen that electricity demand seems to be inversely correlated with temperature: the demand is at its peaks during the coldest weeks of the year, whereas the warmest weeks of the year are accompanied with the lowest power demand levels in the annual cycle.

Figure 7. Illustration of the mean temperature in the Nordic region.
The picture illustrates the weekly mean temperature in the Nordic region, measured in 12 Nordic cities (Oslo, Bergen, Trondheim, Tromsø, Helsinki, Ivalo, Stockholm, Gothenburg, Östersund, Luleå, Copenhagen and Billund). The picture is retrieved from the NordREG Nordic Market report 2012 (NordREG, 2012).

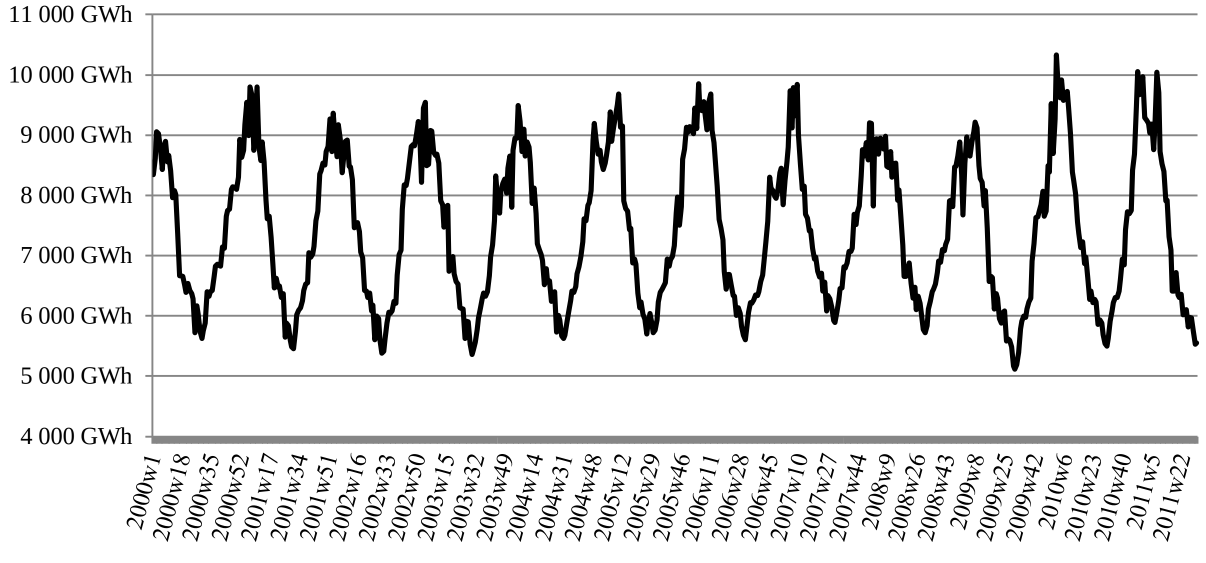


Source: NordREG (2012)

In addition to the seasonality in electricity demand, another important component of the electricity demand in the Nordic market is the industrial- and trade and services sectors' demand, as shown in Figure 5 earlier. These sectors account for roughly two thirds of electricity consumption in the Nord Pool region, and their consumption is driven by economic activity (NordREG, 2012). This – and also the cyclical nature of electricity demand in the region – can be observed from the Figure 8 below, which portrays the weekly electricity demand in the Nord Pool area between 2000 and 2011. For example, when the financial crisis stalled the economic activity in late 2008, the electricity demand in the Nordic region dropped by 3.2% from 2008 to 2009 while the GDP in the region fell by 9.8%, according to Eurostat statistics[3].

The decline in power demand in 2009 is especially visible during the summer, when the electricity consumption in the region fell well below its yearly average levels. This highlights the link between economic activity and electricity demand: as the heating and lighting demand is at its lowest during the summer months, the role of industrial demand as the cornerstone of electricity demand is underlined as it seems to set the base level for power demand in the region.

Figure 8. Electricity demand in Nord Pool area, 2000 – 2011.
The figure presents the total weekly electricity consumption in GWh in the Nord Pool region between week 1 in 2000 and week 30 in 2011. The data was gained from the Economics department Aalto University School of Business, and was originally collected from Nord Pool.



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[3] The inflation adjusted Euro denominated gross domestic product (GDP) figures were retrieved from the Eurostat database for Denmark, Finland, Norway and Sweden.

In overall, during the time period 2000 - 2011 the overall electricity consumption in the Nordic region has remained flat, increasing only 0.10% during these ten years, whereas the combined GDP of Denmark, Finland, Norway and Sweden rose by 43%, according to inflation-adjusted figures by Eurostat. Thus, it is important to note that power demand is affected by various factors such as temperature, economic activity and its distribution between the sectors in the economy, just to mention a few examples. However, modeling the electricity demand determinants in the Nord Pool area is out of the scope of this study, and therefore not examined in a more detail here. An interested reader is advised to turn to the seminal book by Robert Halvorsen (Halvorsen, 1978) for a more detailed analysis on electricity demand determinants.

3. THEORETICAL BACKGROUND

Commodity futures markets can be seen to serve two important social functions, as pointed out by Serletis (1991): First, the transfer of commodity price risk, and, second, the provision of unbiased forecasting by the futures price of the future spot price. This is also reflected in the academic research on the topic, as the previous studies on the relationship between spot and futures prices in commodities can be divided into two main lines of research: research on information content in futures prices and their forecasting ability, and research on futures pricing and futures contracts valuation. These two avenues for research, however, should not be considered mutually exclusive, but should rather be viewed as complementary because they both provide valuable contributions in developing our understanding about the relationship between spot and futures prices and their interrelatedness.

The first line of research stems from the underlying assumption that futures markets are efficient and rational. Thus, the research focus is on developing understanding about the information borne in futures prices and their forecasting ability, and on studying the existence and nature of time varying futures premiums (see, for example, Fama and French, 1987).

The second line of research, on the other hand, aims more to shed light on the markets' efficiency through studying the relationship between spot and futures prices in different commodities markets by developing and testing futures pricing models. This line of research focuses on empirically testing the market functioning, market efficiency and futures risk premiums. The aim is to identify the factors influencing the market functioning and causing the possible deviations from the efficient market -based futures pricing models, finally developing and adjusting futures pricing models to better cater for the distinctive characteristics in different commodity markets. Next, the theoretical foundations in futures pricing are first presented, before proceeding to discuss the theoretical frameworks for pricing electricity futures and the previous research in the Nordic electricity market.

3.1. Futures and Forwards Pricing

Futures and forward contracts are contracts between a buyer and a seller agreeing on the delivery of an asset at a predetermined price at a predetermined time in the future, where the seller of a futures contract agrees to deliver the asset on a future date and the buyer agrees to pay the predetermined price for the asset in the future. As the terms of the trade taking place on a future date are agreed upon today, futures and forwards allow buyers and sellers to hedge their exposure against future variations in the asset price, thus making these contracts a valuable means of hedging against price risks for market participants.

First, it is important to distinguish between futures and forward contracts. Many practitioners as well as academics tend to view forward and futures contracts as synonymous for the sake of simplicity (see, for example, Lucia and Torro, 2011). However, as Black (1976) and Cox et al. (1981) point out, forwards and futures differ not only in contractual structure, but more importantly in their payment schedules, i.e. in the timing of cash flows, as also argued by Wimschulte (2010). In the absence of arbitrage, both forward and futures prices must equal the spot price of the underlying commodity or asset at maturity and the contract prices are determined so that a forward or a futures contract has zero value when initiated.

As shown by Black (1976), the difference in pricing these contracts arises from the payment schedule, which with forwards is a one-off payment at the maturity of the contract, whereas futures contracts are marked to market during the life of the contract. In the context of a constant interest rate these two streams of payments are essentially the same so that the prices of futures and forward contracts are equal, as pointed out by Cox et al. (1981). They continue that generally this is not the case as interest rates generally are not constant but stochastic, and furthermore, that forward and futures prices may diverge in perfect frictionless markets only under stochastic interest rate conditions.

Nevertheless, as the differences between electricity forward and futures prices per se are not in the core of this thesis, I content to forego the differentiation between forward and futures premiums in the analysis. Instead, I use these terms interchangeably as both futures and forward prices are used in determining the futures premiums. This approach was also chosen by Mork (2006), whereas Lucia and Torro (2011) find it sufficient to treat forwards and futures as if they were identical.

3.1.1. Futures Pricing for Investment and Consumption Assets

The classical approaches to futures pricing link futures prices to spot prices under a no-arbitrage condition. The price of a futures contract is derived from the current spot price under the assumption that if the futures price does not equal the current spot price plus the related arbitrage costs, there will be arbitrageurs in the market who will eventually balance the market to follow the no-arbitrage conditions. Thus, this no-arbitrage approach to futures pricing relies on the assumption that markets are efficient, and if arbitrage opportunities exist, the arbitrageurs will exploit the mispricing and consequently push the prices back to satisfy the no-arbitrage conditions.

Following this approach, consider a market participant entering a futures contract to sell a commodity at a predetermined price at a predetermined time in the future to hedge her exposure against the price volatility of the underlying commodity. Alternatively, the market participant can buy the commodity in the spot market, store it until the future delivery date determined in the futures contract, and thus protect herself from adverse price changes. The no-arbitrage condition dictates that the futures price equals the spot price of the underlying commodity plus the cost of holding the commodity in the inventory and the cost of capital, either the opportunity cost of the forgone interest or the cost of borrowing to finance the purchase of the commodity. If this was not the case, the arbitrageurs could make a risk-free profit on the price differential, and again, their bids in the market would eventually push the prices back to the no-arbitrage state.

In his seminal book on futures and other derivatives, Hull (2009) provides well-founded theoretical background for futures pricing, and here I follow Hull in identifying the generally accepted basic formulae for futures pricing.

As Hull (2009, p. 99) points out, it is important to distinguish between investment assets and consumption assets when considering forward and futures contracts. He defines *investment asset* as an asset that is held for investment purposes by significant number of investors, and *consumption asset* as an asset that is held primarily for consumption. Stocks and bonds are good examples of investment assets, whereas commodities are consumption assets – even though this categorization is not exclusive, as many commodities can also be held in investment purposes. In the scope of this analysis, both investment assets and consumption assets are meaningful because electricity by definition is a consumption asset, but electricity derivatives can be considered as investment assets by extending Hull's definition to also apply to electricity financial markets, where there is a limited number of investors but still sufficient liquidity and numerous outside speculators.

Following Hull (2009), for investment assets and commodities held for investment purposes the relationship between futures and spot prices can be expressed in a general form using the equation

$$F_{t,T} = S_t e^{rT}, \tag{1}$$

where F_t is the price at time *t* for the future delivery at time *T*, S_t is the spot price for the underlying commodity at time *t*, *r* is the continuously compounding risk free interest rate, and *T* is the time to maturity. The distinction between investment assets and consumption assets is important here, as costs related to holding assets in storage are excluded from Equation 1.

Nevertheless, with commodities the storage costs can generally be assumed to incur, and on a more general level, the storage costs should be included in the equation for consumption assets, as given by

$$F_{t,T} = (S_t + U)e^{rT}, \tag{2}$$

where *U* is the net present value of all the storage costs during the life of a futures contract (Hull, 2009, p. 116).

3.1.2. Basis

An important concept in futures markets is the *basis*, which refers to the difference between the futures price and the spot price (or cash price, see Fabozzi, 2000, p. 521) of the underlying asset. Letting $F_{t,T}$ denote the futures price at time t for delivery of a commodity at T, and S_t the spot price of the underlying commodity at time t, the basis can be written as

$$\text{Basis} = F_{t,T} - S_t. \tag{3}$$

Alternatively, the basis can be nominalized by dividing it with S_t, arriving at the relative basis

$$\text{Relative basis} = \frac{F_{t,T} - S_t}{S_t}. \tag{4}$$

In general, the basis merely expresses the difference between the futures price and the spot price of the underlying commodity, and therefore it is also referred to as the *futures premium* (see, for example Mork, 2006).

However, with regards to the commodity futures market it also has additional descriptive content. As explained by Gjolberg and Brattested (2010), a high basis in commodity futures suggests high cost of carry, whereas a negative basis may imply low convenience yields. Also according to the expectations hypothesis, the basis may be interpreted to contain information about the expected variability in the spot price and expected risk premium.

From these features of the basis it can be seen that it is linked to convenience yield, cost of carry, and the expectations hypothesis, which are examined in the next two subsections.

3.1.3. Convenience yield, Cost of Carry and the Theory of Storage

Even though futures contracts can be used by market participants to hedge their exposures against market price fluctuations in commodity markets, futures contracts cannot fully provide their holder with the same benefits as holding the physical consumption commodity can. As Fama and French (1987) point out, the convenience yield arises either from the productive value held by the inventory or from holding inventories to meet unexpected demand. Indeed, holding the physical commodity provides its holder with protection against unexpected events on a broader range – for example in the case of higher than expected demand, production shortages and delivery failures etc. – than futures contracts, which only provide protection against price fluctuations. Thus, physical inventory in a commodity serves as a buffer against unexpected events, and is not dependent on financial market functioning or does not bear counterparty risk. For example, a chocolate manufacturer can use its cocoa inventory in chocolate manufacturing in the case of a delivery failure, whereas futures contracts simply cannot be used in the manufacturing process.

The benefits from holding the physical asset are sometimes referred to as the *convenience yield* provided by the commodity (Hull, 2009, p. 117), which can be defined as

$$F_0 e^{yT} = (S_0 + U)e^{rT}, \tag{5}$$

where y is the convenience yield. According to Hull (Hull, 2009, p. 117), "the convenience yield reflects the market's expectations concerning the future availability of the commodity". This is a natural conclusion, assuming that a shortage in the availability of an input commodity has a negative influence on a producer as it can lead to stockouts and production interruptions or cause temporary price spikes for the input commodity. Thus, the lower the expectations about the future availability of a commodity, the higher the value of holding the commodity in inventory, and the higher the convenience yield. When the inventory levels are high, the probability of shortages becomes smaller, thus resulting in a lower convenience yield. On the other hand, low inventories make shortages more likely and thus increase convenience yields (Hull, 2009, p.118).

The classical approach to commodity futures pricing, which was also used as an example in the beginning of this section, is referred to as the *cost of carry* (see Hull, 2009, p. 118; Pindyck 2001) or *the theory of storage* (see Kaldor, 1939; Working, 1948; Working, 1949; Telser, 1958; Brennan, 1958; and Fama and French, 1987).

The cost of carry links futures prices to spot prices under a no-arbitrage condition, dictating that futures price equals the spot price plus the costs of holding the commodity in inventory, i.e. storage costs and cost of capital. Following Hull (2009, p. 118), the futures price for a consumption asset can be defined as

$$F_0 = S_0 e^{(c-y)T}\,, \tag{6}$$

y denoting the convenience yield and c denoting the cost of carry, which Pindyck (2001) defines as the sum of two components: the cost of physical storage and the forgone interest. However, the concept of physical storage, and thus the cost of carry are ambiguous in the electricity market context, and therefore alternative approaches have been examined to circumvent the difficulty in pricing electricity futures using the cost of carry approach.

3.1.4. Expectations Hypothesis

Another classical approach to futures pricing is the expectations hypothesis, which postulates that the futures price equals the expected spot price plus a risk premium, in essence implying that the current futures price would contain power to forecast spot prices (see Fama and French, 1987; Mork, 2006; and Huisman and Kilic, 2012). The expectations hypothesis relies on the assumptions that markets are efficient and that arbitrage opportunities do not exist, assuming that all available information is incorporated in the futures prices, and therefore the current futures price contains information about the expected changes in the future spot price plus the expected risk premium (Huisman and Kilic, 2012). Hence, the relationship between the futures price and the expected future spot price implied by the expectations hypothesis may be expressed using the following equation:

$$F_{t,T} = E_t(S_T) + P_{t,T}\,, \tag{7}$$

where $F_{t,T}$ is the futures price for delivery at time T at time t, $E_t(S_T)$ is the expected future spot price S_T at time t, and $P_{t,T}$ is the risk premium. The sign of the risk premium component, as Gjolberg and Brattested (2010) point out, depends on the hedging demand in the market, being zero in a balanced market where hedging demand and supply are exactly matched. Hence, the futures price should be equal to the expected spot price unless the hedging demand is unbalanced, causing the futures price to deviate from the expected spot price by the risk premium.

According to Gjolberg and Brattested (2010), “the traditional approach in numerous studies has been to compare the futures price observed at t with the spot price that materializes at $+i$, typically defining the difference as a ‘forecast error’.” However, as Gjolberg and Brattested (2010) continue, the difficulty is in determining what part of the price difference is attributable to risk premium, and what part of the difference is caused by nonrational expectations or market inefficiency.

Furthermore, the expectations hypothesis is rather controversial in the literature, and there is a line of research that disagrees with the propositions presented by the expectations hypothesis (see Cochrane, 2005, for a survey). For example, Fama and French (1987) comment that "there is little agreement on whether futures prices contain expected premiums or have power to forecast spot prices". They study the behavior of 21 commodity futures prices and find evidence of forecasting power for only 10 of them, concluding that the theory of storage possesses better explanatory power over the difference between futures prices and spot prices than the expectations hypothesis. The approach by Fama and French (1987) is examined in a more detail in Section 7.3. of this thesis.

3.2. Electricity Futures Pricing

Electricity differs from physical commodities in two important ways: First, electricity cannot be economically stored in large quantities. Of course, electricity can be stored to some – relatively small – extent by filling up hydropower reservoirs or charging batteries when electricity prices are low, but in overall it may be concluded that storing electricity in large quantities is not economically feasible (see Bessembinder and Lemmon (2002); Botterud et al. (2002); Mork (2006); and Huisman and Kilic (2012) for further discussion on electricity storability).

Second, electricity prices are subject to extremely high price volatility. A reason for high volatility in electricity prices stems from the non-storable nature of the commodity. As electricity cannot be stored, electricity prices are volatile because there are no inventories that could be used to smooth supply or demand shocks (Bessembinder and Lemmon, 2002). This makes hedging against price variation very important especially for electricity wholesalers and consumers. The importance of hedging against price volatility, especially on the demand side, is magnified by the fact that power prices are subject to sudden upward spikes (Bessembinder and Lemmon, 2002).

These unique characteristics of electricity as a non-storable commodity present challenges for using traditional futures pricing models for valuing electricity futures and forwards contracts. With physical commodities, such as metals for example, the cost-of-carry relationship links spot and futures prices under a no-arbitrage condition. Similar strategies cannot be applied in the case of electricity because storing electricity economically and in large quantities is not possible, and thus, as Bessembinder and Lemmon (2002) argue, futures prices for electricity need not conform to the cost-of-carry relationship. Therefore the no-arbitrage approach to pricing derivative securities cannot be applied in the usual manner.

As a remedy, Bessembinder and Lemmon (2002) propose an equilibrium approach to model the economic determinants of power futures prices. They come to a conclusion that the futures price is generally a biased forecast of the future spot price, the anticipated variance of wholesale spot prices decreasing the futures premium and the anticipated skewness of wholesale spot prices increasing the futures premium. Bessembinder and Lemmon (2002) also run simulations to test their model, which confirm the model's prediction that futures prices exceed the expected spot prices when either expected demand or demand volatility are high, due to the positive skewness induced in the spot power price distribution, whereas on the other hand their model implies that the forward power price is a downward biased predictor of the future spot price if expected power demand is low and demand risk is moderate.

Their equilibrium approach model thus presents two different outcomes, depending on the power market conditions. However, this indicates that there is a nonzero premium in electricity futures prices, which, according to Bessembinder and Lemmon (2002), provides incentives for financial intermediaries to create instruments to allow outside speculators to include power positions in their portfolios, which would then be expected to decrease the magnitude of the futures premium (Bessembinder and Lemmon, 2002). Mork (2006) also argues that if premiums are present in the futures market, this would seem to be an invitation for speculators to enter the market and profit from trading with other market participants who are willing to pay to reduce risk, eventually reducing the futures premium as more players willing to assume the risks enter the market.

As the cost-of-carry approach to futures pricing cannot be followed in pricing electricity futures, some researchers have turned to the expectations hypothesis approach in electricity futures pricing (see Huisman and Kilic, 2012; and Gjolberg and Brattested, 2010). However, as explained earlier, this approach has not gained universal acceptance, as it is problematic in the sense that it is difficult to identify what causes the deviations between the expected future spot price and the actual spot price at maturity. Fama and French (1987) present an approach to examine the forecasting power of futures contracts, and in section 6.3. of this paper I follow their approach to test whether electricity futures in the Nordic market possess forecasting power over the future spot price or not.

3.3. Previous Literature on Nordic Electricity Markets

The previous literature on the relationship between futures and spot prices in the Nordic electricity market is a rather new branch in the literature, its emergence on a wider range dating back to the early 2000’s. The literature mainly focuses on the relationship between futures and spot prices through examining the existence and nature of futures premiums and their risk premium components, the forecasting ability of electricity futures, and the drivers influencing these concepts. The explanatory factors mainly studied in the literature are the hydro reservoir levels and the seasonality of electricity prices, both very characteristic features of the Nordic power market. In addition, some studies have also tried to shed light on the market’s efficiency, and also the extreme price spikes during the winter 2002-2003 have received attention in the literature. Here I provide a brief overview to the key findings in the previous literature before proceeding towards hypothesis building.

Botterud et al. (2002) first study the relationship between electricity spot and futures prices in Scandinavia, based on Nord Pool electricity spot and futures prices data from the opening of the Nord Pool futures market in September 1995 until the end of 2001. Botterud et al. (2002) argue that in general the futures prices’ ability to predict the spot prices is rather low, being better for one-week ahead than one-year ahead futures due to the much shorter time to delivery. This is a natural result, as shorter time to delivery enables more up-to-date and more accurate information to be incorporated in the futures prices, and because forecasting accuracy can generally be expected to decrease with longer forecasting horizon.

The analysis by Botterud et al. (2002) shows that futures prices on average were above spot prices during their sample period, implying a contango-relationship between electricity futures and spot prices. Therefore they conclude that there is a negative risk premium in the electricity futures market. However, their conclusions are contradicted by later studies by Mork (2006), Gjolberg and Brattested (2011), Lucia and Torro (2011), and Huisman and Kilic (2012). Nevertheless, these contradictory conclusions do not imply inconsistency in the research results per se, but they rather highlight the differences in methodological approaches and in defining the concept of risk premium, which is not unambiguous in the literature.

Mork (2006), studies the dynamics of risk premiums and the relationship between electricity spot and futures prices in the Nord Pool electricity market, seeking to test whether risk premiums are present, together with testing whether the presence of a number of outside speculators in the market between 2000 and 2002 reduced these risk premiums. Using an equilibrium approach, where futures price is split into expected spot price and risk premium components, Mork (2006) finds that risk premiums in the Nord Pool futures market were significantly positive between 1997 and 1999, but were quite low in the period from 2000 to 2002 when outside speculators were present in the market, thus suggesting that the presence of outside speculators might have caused the decline in the risk premiums. Mork's (2006) findings do not support the conclusions drawn by Botterud et al. (2002) that futures risk premiums would be negative in the Nord Pool market, although Mork finds that after the large trading companies left the market in 2002, the market does not show significant futures premiums, and Mork's (2006) trend analysis indicates that these premiums could have in fact have become negative.

In a more recent paper, Botterud et al. (2010) analyze 11 years of historical spot- and futures prices in the Nord Pool electricity market between 1996 and 2006, also finding that futures prices tend to be higher than spot prices. However, they conclude this to imply a negative convenience yield, which they find to be increasing with time to delivery. Botterud et al. (2010) also find that the convenience yields are slightly more negative in the period 2002 - 2006 than in the period 1996 – 2001 and that the standard deviations are lower in the 2002 - 2006 period, which they find to be a possible indication of a more mature market in the latter part of the analysis period. This is somewhat consistent with Mork (2006), who points out that the futures premiums in the Nordic electricity market were lower between 1997 and 1999 than after 2002.

In their study, Gjolberg and Brattested (2011) analyze the forecasting performance of the four-week and six-week futures prices in the Nord Pool power market from 1995 to 2008. They derive the risk premium from the expectations hypothesis, assuming that under a no-arbitrage condition the futures price must be equal to the expected spot price plus a risk premium component. Similarly to Botterud et al. (2002), Botterud et al. (2010) and Mork (2006), they find that on average the basis has been positive, i.e. the futures prices have been above the spot prices. Gjolberg and Brattested (2011) also find the basis to have been strongly positively skewed, which is consistent with the theoretical work by Bessembinder and Lemmon (2002). In addition, they argue that short-term futures prices have been biased forecasts for the subsequent spot prices, presenting a forecast error of 7.4% - 9.3%, which they argue to be too large to be interpreted as a risk premium only, concluding that this may be taken as evidence of market inefficiency.

Gjolberg and Brattested (2011) also find that the forecast error has increased during the most recent years in their sample, and, contradicting the findings of Lucia and Torro (2011), they find no significant variations in risk premiums across seasons.

Lucia and Torro (2011) study the relationship between electricity spot and futures prices through the futures risk premium concept using a data for a set of short maturity futures contracts traded in the Nord Pool market between January 1998 and October 2007. They find significant positive risk premiums in short-term electricity futures prices, similarly to Gjolberg and Brattested (2011).

In addition, alike the observation by Botterud et al. (2002) that both the futures and spot prices show a seasonal pattern, Lucia and Torro (2011) find seasonality also in the risk premiums. They point out that the significance and size of the premiums varies seasonally over the year, being zero in spring and summer, positive in autumn, and the largest in winter, which contradicts the findings of Gjolberg and Brattested (2011), who find no significant support for seasonal variation in risk premiums. Lucia and Torro (2011) interpret their results to support the view that the risk premium in the Nordic electricity market is large and positive for contracts with delivery during demand peak periods. This is also consistent with the prediction of Bessembinder and Lemmon’s (2002) theoretical model, which implies that the futures premium increases with expected demand or demand variance.

Because the high dependency on hydropower in electricity generation is characteristic for the Nordic power market, plenty of research has turned to hydro reservoir levels to seek explanation for electricity market behavior. Botterud et al. (2002) conduct a graphical examination of the electricity spot and futures prices in comparison to the actual and historical average hydro reservoir levels in Norway, which enables them to explain some situations within their sample period: they find that high reservoir levels result in low spot electricity prices – enabling the spot prices to go below the futures price – but when the actual reservoir level falls below the average, they notice a sharp increase in the spot price and the spot price exceeding the futures price. Thus, Botterud et al. (2002) conclude that a water inflow analysis is helpful in explaining the deviations between spot and futures prices. However, they point out that the deviations in reservoir levels can only be used as an explanatory factor for the futures contracts with long maturities, as the near-term change in reservoir levels is very limited.

Lucia and Torro (2011) also incorporate the hydro reservoir levels into their analysis, finding that unexpectedly low hydro capacity has additional explicative power in explaining futures premiums. Interestingly, they also find that abnormally high hydro reservoir levels did not have a significant influence on the risk premiums and the basis. They argue this to support the important role the tighter market conditions play in explaining the behavior of the relationship between futures and spot electricity prices, as agents react to unexpectedly low reservoir levels by modifying the risk premiums and correcting their expectations about the future risk premiums. This is a rational conclusion, since in tighter market conditions the probability of price spikes is more likely and therefore the buyers are willing to pay a higher premium for hedging against these price spikes. And vice versa, the speculators would demand higher risk premiums for assuming the price risks on times of high volatility, resulting in higher risk premiums.

Botterud et al. (2010) also incorporate variables describing the underlying physical state of the market – such as hydro inflow, reservoir levels, and electricity demand – into their analysis, finding the relationship between spot and futures prices to be clearly linked to the physical state of the system. They find that the spot price in the Nord Pool market exhibits some seasonality, similarly to Lucia and Torro (2011). They also find that the convenience yield also varies by season, depending on the storage levels in hydro reservoirs. They find the risk premium to present a less distinct seasonal pattern, but find strong relationships between futures risk premiums and average spot price, deviations from normal water inflows and electricity demand.

In addition, Botterud et al. (2010) argue that differences between the supply and demand sides in terms of risk preferences and the ability to take advantage of short-term price variations can contribute to explain the observed convenience yield and risk premium. Nevertheless, their regression analysis with a combination of physical and market variables only has limited explanatory power for the observed convenience yield and risk premia, which they interpret as a possible sign that the market is still relatively young, and that the spot and futures prices cannot be explained by market fundamentals only.

Apart from examining the relationship between spot and futures prices and the causes for the difference between these two variables, the supply shock that hit the Nordic electricity market in winter 2002-2003 has received some attention in the literature. The Nordic region experienced a combination of low water reservoir levels and very cold temperatures in the winter of 2002-2003, which resulted in extremely high and volatile electricity prices. Mork (2006) tests whether this period of high prices and volatility in winter 2002-2003 caused more buyers to hedge in the futures market, but finds no statistical support for the hypothesis that consumers would have reacted to high prices and price volatility by purchasing more fixed-price contracts, driving up the wholesalers' hedging demand and thus the futures premiums in the market. On the contrary, Mork (2006) finds that the trend seems to be the opposite, even though he points out that there is not enough data for drawing solid generalizations.

Lucia and Torro (2011) also briefly examine the supply-shock that hit the market in the winter 2002-2003 and its implications to the electricity market. They provide support to the view that Nord Pool market participants priced futures contracts mainly based on risk considerations until the unprecedented circumstances that shocked the market around the winter 2002–2003, after which, the market conditions changed in the Nord Pool market. This is supported by their finding that the general level of spot prices did noticeably increase after the turbulent period, the risk premiums were larger and also the seasonal patterns seemed to have faded away.

Some of the previous research has also tried to analyze the market efficiency in the Nordic power market. In an efficient forward market the price of forward contract should equal the time-weighted average of the underlying shorter maturity futures contracts with equal maturity (Kristiansen, 2007), since generally in an efficient and well-functioning market with no risk-free arbitrage opportunities the price of a futures contract should equal the time weighted average of the futures contract's sub-components. Hence, the time weighted average of the shorter maturity futures used to construct a position equal to a longer maturity futures contract should result in the same price, given efficient market conditions and no opportunities for risk-free arbitrage.

Kristiansen (2007) investigates whether the pricing of forward contracts in the Nord Pool market is efficient by constructing synthetic forward contracts. He finds that inefficiencies in the pricing of synthetic seasonal contracts constructed by monthly contracts exist, whereas the pricing inefficiencies are less prevalent and there is generally a good correspondence between the yearly forward prices and the synthetic yearly prices for the yearly contracts constructed by seasonal contracts. On the contrary, Wimschulte (2010) shows that although the prices of the synthetic futures portfolios are on average below the corresponding forward prices, these price differentials are not economically significant when accounting for the transaction costs. This is consistent with the theoretical model by Cox et al. (1981) and, according to Wimschulte (2010), shows that the pricing in the Nord Pool forward market can be regarded efficient.

Based on his findings, Kristiansen (2007) argues that price discrepancies between the seasonal and monthly forward contracts might be attributable to the market's immaturity. He also finds the synthetic forwards' price deviations from the futures prices to decrease over time when the market becomes more mature, but points out that the sample is not sufficient to support further generalization of these results. Kristiansen's (2007) interpretation of the market's immaturity is consistent with the suggestion by Botterud et al. (2010) that the electricity futures market might have become more mature in the period from 2002 to 2006 than it was between 1996 and 2001.

Finally, there have also been some comparisons between the hydro dominated Nordic electricity market and other electricity markets. This research has provided important information about the different dynamics between the characteristically different electricity markets.

In a recent paper, Huisman and Kilic (2012) examine the risk premiums contained in the electricity futures prices in the hydro-driven Nord Pool market and natural gas-driven Dutch power market, basing their analysis on the theory of storage. They find evidence of reliable forecasting power in futures prices from both markets, thus contradicting earlier findings by Botterud et al. (2002) and Gjolberg and Brattested (2011), but also that "the extent to which futures prices contain information about expected future spot prices and/or risk premiums depend on the storability of the type of fuel used in the market wherein the futures contract delivers". Their results present evidence that time-varying risk-premiums exist in the Dutch power market, where electricity is generated mainly using the storable fossil fuels, but not in the hydro-reliant Nord Pool market, thus implying different behavior in these two power markets. Drawing from the observed differences, Huisman and Kilic (2012) conclude that as time-varying risk premiums exist in markets with perfect storability, but not in markets with imperfect storability, one cannot apply the same model to all electricity markets. They suggest that forward models for markets with imperfect storability should depend heavily on price expectations, and should include time-varying risk premiums for markets with perfect storability. Hence, it seems impossible to import futures pricing models from other commodity markets to electricity markets as such, which makes it important to understand the factors determining the market behavior and to adjust the theoretical models accordingly.

On the contrary to Huisman and Kilic (2012), Redl et al. (2009) analyze spot and forward price behavior in Nord Pool and the European Energy Exchange (EEX) in Leipzig, Germany, finding that price formation in these markets is influenced by historic spot market prices, thus yielding a biased forecasting power of long-term contracts. They argue that although the EEX and Nord Pool markets are physically only weakly interconnected, the main characteristics with regard to price formation on the forward markets are similar. They find the current spot price to have a significant influence on futures prices in both markets, which prompts them to question the forecasting power of the forward price.

In conclusion, the previous literature about the relationship between spot and futures prices in the Nordic electricity market seems to be generally rather unanimous about the market providing support to the contango-hypothesis, i.e. that on average the futures prices are above spot prices (for example Botterud et al., 2002; Mork, 2006; Botterud et al., 2010; Gjolberg and Brattested, 2011; Lucia and Torro, 2011; Huisman and Kilic, 2012, observe this phenomenon). Also the significance of hydro reservoir levels in explaining the market behavior receives uncontested support, although there is much lesser research devoted to this topic (see, for example Botterud et al., 2002; Botterud et al., 2010; Gjolberg and Brattested, 2011; Lucia and Torro, 2011; Huisman and Kilic, 2012). The hypothesis of forecasting power of futures prices over the future spot price also seems to be controversial, as Huisman and Kilic (2012) find evidence of the forecasting ability, which on the contrary receives low or no support from Botterud et al. (2002), Redl et al. (2009), and Gjolberg and Brattested (2011). Another suggestion arising in a few papers is that the market seems to have been immature in the late 1990's (see Botterud et al., 2010; Kristiansen, 2007) which raises the question whether the market has become more mature over time.

Although in overall the previous findings are quite consistent, the main divergences arise from the presence and sign of risk premiums, the time varying nature of futures premiums, and the ability of futures prices to forecast future spot prices. Thus, the previous literature leaves ample of room for further studies, and also calls for additional testing of the market's maturity.

3.4. The relationship between coal and electricity prices in the Nordic market

As discussed in Section 2.2. earlier, the marginal power generation costs on the supply side are important for the price formation in electricity markets (for further discussion see, for example, Redl et al., 2009). This can also be seen from the power production price curve (Figure 4) presented earlier in Section 2.2.1., which shows that coal-fired plants that can be switched on when the electricity prices reach high enough levels provide additional generation capacity at times of high demand, and thus often set the marginal cost of electricity. This view is extended by Botterud et al. (2010), who argue that although the Nordic electricity market is dominated by hydropower generation, the electricity price is often determined by thermal generation – i.e. coal-fired combined heat and power plants – either directly or indirectly through the hydropower plants' water values, which basically represent the opportunity cost of thermal generation.

However, coal price and its relationship with electricity prices has received little attention in the Nordic market, possibly due to the dominant role of hydropower in the market. Kauppi and Liski (2008) incorporate coal price into their fundamental model they use to estimate the Nordic electricity market structure that best explains the main behavioral patterns in pricing, storage, and production in years 2000-2005. Their focus is on examining the market power – which they do find to exist in the Nordic market – and thus they do not focus more on the influence of coal price on electricity spot and futures prices or futures premium.

In addition, Redl et al. (2009) construct a fundamental model consisting of year-ahead coal and gas power generation costs, quadratic coal power generation costs, and the current electricity spot price to explain the year-ahead forward price of electricity from January 2005 to April 2008. They find the year-ahead generation costs of gas-fired plants and coal-fired plants, quadratic generation costs of coal-fired plants as well as power spot prices to provide a good explanation of the year-ahead electricity price. They find the costs of coal-fired plants to have a positive relationship with the year-ahead futures price, and more generally that the year-ahead electricity prices do depend on year-ahead generation costs, which is in line with economic theory on equilibrium relationships for forward pricing. Furthermore, they conclude that electricity forward prices are also influenced by current spot prices and that the recent trends in spot prices have a significant impact on the futures price.

On a more general level, the relationship between coal price and electricity prices has been tested in other markets. Mohammadi (2009) presents evidence of significant long-run relations between electricity and coal prices in the U.S. market, and He et al. (2010) find coal prices to have a significant impact on electricity prices in China.

Although the Nordic market is very different from these markets in its fundamental characteristics, I seek to test whether the coal price also has an influence on electricity prices and the futures premium in the hydro-dominated Nordic market.

4. HYPOTHESES

This section presents the main hypotheses in this study. First, I begin with the examination of the relationship between futures and spot prices, i.e. the futures premium or the basis, in the Nordic power market. Second, I proceed to analyze the factors affecting electricity spot and futures prices in the Nordic market, together with their effects on the futures premium. Third, I study whether the actual futures prices in the Nordic market differ from synthetic futures prices, presenting opportunities for arbitrage using synthetic futures. Finally, I test whether futures prices in the Nordic electricity market possess forecasting power over the future spot price.

As argued earlier in Section 3 of this paper, the basis, i.e. the difference between the futures price and the spot price, reflects the hedging balance between the buyers and sellers in the electricity market. Based on the previous literature on the Nordic electricity market (see for example Botterud et al., 2002; Mork, 2006; Botterud et al., 2010; and Gjolberg and Brattested, 2011) I expect to find that the hedging pressure for electricity producers and retailers is not balanced in the Nordic power market, therefore indicating a nonzero futures premium. This is examined using the first hypothesis:

H_{1a}: There is a nonzero futures premium in the Nordic electricity market, i.e. $F_{t,T} \neq S_t$.

Furthermore, based on the findings in the previous literature (see for example Botterud et al., 2002; Mork, 2006; Botterud et al., 2010; and Gjolberg and Brattested, 2011), I expect the Nordic electricity market to follow a contango-relationship, i.e. the futures price on average to be above the spot price. Futures prices above the spot price would also indicate that electricity purchasers face greater pressure to hedge their purchases against price volatility than the electricity producers. Hence, I present the following hypothesis:

H_{1b}: On average, the futures price exceeds the spot price in the Nordic electricity market, i.e. $F_{t,T} > S_t$.

Proceeding to the analysis of the factors affecting the spot and futures prices and the futures premium, I expect to find that the water reservoir levels, electricity demand, and the cost of marginal electricity production method explain variation in electricity spot and futures prices. Since water reservoirs represent the availability of cheap hydropower, the levels below historical averages reflect scarcity in cheap supply of electricity and thus contribute to increase electricity prices. This is tested using the second hypothesis:

H_{2a}: Deviations from historical water reservoir levels are inversely correlated with electricity spot and futures prices.

As with any commodity, also with electricity it is a natural assumption that an increase in demand creates an upward pressure on the prices, and thus I expect the electricity demand above historical levels to be reflected in electricity prices. Moreover, because the marginal production method in the price curve sets the price for electricity, the price increases with the cost of the marginal production method. As discussed in Sections 2.2. and 3.4. earlier in this thesis, because coal powered plants often act as the marginal production method setting the market price for electricity, I expect coal price to have a positive relationship with electricity prices.

All in all, I expect to find that the cost of marginal electricity production method, for which I use coal price as a proxy, and electricity demand explain variation in electricity spot and futures prices, as formulated in the following hypothesis:

H_{2b}: Electricity spot and futures prices are positively correlated with coal price and electricity demand.

Furthermore, as I hypothesize that the current conditions of the water reservoir levels, electricity demand and the cost of marginal electricity production method, i.e. coal price, have a significant impact on the pricing of close-to-maturity electricity futures. I do not expect these factors to have a significant influence on the long-term electricity futures prices, as the currently prevailing conditions in the market mostly cannot be assumed to prevail for lengthy periods of time. For example, when arguing that as water reservoir levels (to some extent at least) can be assumed to exhibit mean reversion, the effect of the current status of the system should be more significant for the close-to-maturity futures than for the longer-term electricity futures. Therefore I present the following hypothesis:

H_{2c}: The impact of water reservoir levels, coal price and electricity demand on electricity futures prices is greater for spot- and shorter term futures prices and smaller for very long-term futures.

After examining how the fundamental factors in the market environment affect the spot and futures prices, I proceed to study their effects on the futures premium. Bessembinder and Lemmon (2002) argue that the futures premiums are the largest when electricity prices are high and volatile, and thus I expect to find that deviations from historical water reservoir levels have an impact on the futures premium so that the premium increases when the water reservoir levels are low. This can be formulated into a hypothesis as

H_{3a}: Deviations from historical water reservoir levels are inversely correlated with futures premium.

Similarly, I expect the futures premium also to be influenced by coal price and electricity demand so that

H_{3b}: Futures premiums are positively correlated with coal price and electricity demand.

Furthermore, as the previous hypotheses H_{2a} and H_{2b} assume the impacts of the fundamental factors (i.e. water reservoir levels, electricity demand, and coal price) to be of similar direction for both spot and futures prices, the magnitude of this influence on spot and futures prices determines the sign of the impact on futures premium. The hypothesis H_{2c} postulates that the impact of the fundamental factors on prices is larger for spot and short-term futures price, and hence their effect on the futures premium should be greater for the short-term than for the long-term futures. This is presented in a hypothesis format as:

H_{3c}: The impact of water reservoir levels, coal price and electricity demand on futures premium is greater for the short-maturity than for the long-maturity futures.

Finally, I proceed to study the efficiency of the futures pricing in the Nordic electricity markets. Assuming there is no possibility for arbitrage in the market, as explained by Kristiansen (2007), Fleten and Lemming (2003) and Wimschulte (2010), the price of a long-term futures contract should equal the time weighted average of shorter futures contracts covering the same time period, which are here referred to as *synthetic futures*. Thus, I hypothesize the following relationship to hold in the Nordic electricity market:

H_4: Futures prices are equal to synthetic futures prices

Furthermore, following Fama and French (1987) and Huisman and Kilic (2012), the analysis is extended to examination of the forecasting ability of electricity futures. In essence, I test whether the expectations hypothesis approach to electricity futures pricing yields sufficient results to support the argument that the current futures price contains information about the expected future spot price, or should the claims about the forecasting ability of electricity futures be rejected in the Nordic electricity market.

As shown by Huisman and Kilic (2012) in their recent paper, in markets where electricity is mainly produced by imperfectly storable fuels such as hydro, wind and solar, electricity futures prices contain information about expected changes in the spot price. On the contrary, in their examination of 21 commodities, Fama and French (1987) find evidence of forecasting power only for 10 commodity futures. However, their study did not include any energy commodities, which calls for further examination in this area. In addition, the commodities for which they found evidence of futures’ forecasting power were either highly perishable products with high storage costs (broilers, eggs, hogs, cattle, pork bellies, and orange juice) or commodities with high storage costs in relation to their value (oats, soy beans, soy meal, and plywood).

Thus, despite the lack of general acceptance for the expectations hypothesis, the previous literature seems to support the view that futures prices possess forecasting power in commodities with imperfect storability or high storage costs relative to their value. This leads us to the fourth hypothesis:

H_5: Electricity futures prices possess forecasting power over the future electricity spot prices.

Finally, before proceeding to explain the data and methodology in this study, Table 2 summarizes the hypotheses:

Table 1. Table of Hypotheses

H_{1a}	There is a nonzero futures premium in the Nordic electricity market, i.e. $F_{t,T} \neq S_t$.
H_{1b}	On average, the futures price exceeds the spot price in the Nordic electricity market, i.e. $F_{t,T} > S_t$
H_{2a}	Deviations from historical water reservoir levels are inversely correlated with electricity spot and futures prices
H_{2b}	Electricity spot and futures prices are positively correlated with coal price and electricity demand
H_{2c}	The impact of water reservoir levels, coal price and electricity demand on electricity futures prices is greater for spot- and shorter term futures prices and smaller for very long-term futures
H_{3a}	Deviations from historical water reservoir levels are inversely correlated with futures premium
H_{3b}	Futures premiums are positively correlated with coal price and electricity demand
H_{3c}	The impact of water reservoir levels, coal price and electricity demand on futures premium is greater for the short-maturity than for the long-maturity futures
H_4	Futures prices are equal to synthetic futures prices
H_5	Electricity futures prices possess forecasting power over the future electricity spot prices

5. DATA SOURCES AND SAMPLE DESCRIPTION

In order to study the hypotheses presented above, I tried to collect a data sample as exhaustive and detailed as possible. Therefore the data for this study is a combination of different data sets obtained from various sources.

5.1. Electricity spot and futures price data

As the focus of this thesis is in the Nordic electricity market and its behavior, the electricity spot price data in the analysis is from the Nord Pool power exchange. Unfortunately, the spot price data was too costly to be accessed directly through Nord Pool, the approach taken by most of the previous researchers in this area. Therefore I turned to the Economics department at the Aalto University School of Business, where I received invaluable help from doctoral student Anna Sahari, who kindly shared the data she had collected for her research purposes with her colleagues. This set of Nord Pool market data includes the day-ahead spot market data for the Nord Pool system price, consisting of daily closing price observations for the Nord Pool system price from 3.1.2000 to 25.7.2011, totaling 4,224 daily observations.

I also received the futures price data for the research from the Economics department at the Aalto University School of Business, and the data set included daily closing prices for weekly futures between 3.1.2000 and 30.12.2008, for monthly futures between 7.4.2003 and 30.6.2011, for quarterly futures from 2.1.2004 to 19.10.2010, and between 3.1.2000 and 25.7.2011 for the yearly futures.

As electricity is traded seven days a week in the day-ahead spot market in Nord Pool Power Exchange but futures contracts are traded only on weekdays in the NASDAQ OMX Commodities Europe Exchange, I needed to match the spot price data with the futures price data. Therefore I have excluded those days from the final sample when no trading in the NASDAQ OMX Commodities Europe Exchange took place, i.e. the weekends and bank holidays were removed from the final sample.

In addition, to ensure that the final sample data is reliable and consistent, all those observations for futures contracts where the closing price was recorded to be zero were excluded. In the original data this is most likely due to the fact that no trading with this specific instrument took place on the trading day – not because the futures price would be zero, as it is hard to argue that electricity delivery at a point in future would not bear any value at all – and therefore these zero price observations were excluded from the final sample.

The data for weekly futures contracts - as with all the futures contracts in the sample - includes only the weekday price observations for the futures, excluding weekends and bank holidays. In the beginning of the sample period, during years 2000-2003, the data consists of weekly futures contracts with maturity ranging from 1 to 51 weeks in the future, whereas in the latter part of the data the number of quoted weekly futures decreases to 8. Therefore I focus the analysis on the eight closest-to-maturity weekly futures contracts with delivery from 1 to 8 weeks in the future.

The daily price data for the monthly futures between 7.4.2003 – 30.6.2011 ranges from price quotes for 3 monthly futures on 7.4.2003 to quotes for 6 monthly futures from 1.9.2003 onwards. In total, the sample includes 12,099 daily futures prices for the six closest-to-maturity monthly futures contracts with delivery from 1 to 6 months in the future, when price quotes are available.

For quarterly futures contracts the data set from 2.1.2004 to 19.10.2010 consists of daily price observations for quarterly futures with time to maturity ranging from 1 up to 12 quarters, i.e. three years, into the future. However, the sample includes lengthy periods when price quotes for futures with delivery from 9 to 12 months in the future are not available, and therefore the focus of the analysis is on quarterly futures between 1 and 8 quarters ahead.

The data for yearly futures contracts is rather comprehensive, including daily price quotes for almost 11 years of trading days from 3.1.2000 to 25.7.2011. The price quotes for yearly futures range from 1 to 5 years into the future in the sample, and all of these were included into the analysis when the price information is available.

In conclusion, the final sample consists of 2,889 daily spot price quotes for Nord Pool system price between 3.1.2000 and 31.12.2011; 13,488 daily prices for 6 closest-to-maturity weekly futures on 2,248 trading days between 3.1.2000 - 30.12.2008; 12,099 daily prices for 8 different monthly futures on 2,062 trading days between 7.4.2003 - 30.6.2011; 11,193 daily observations for 8 quarterly contracts on 1707 trading days between 2.1.2004 and 19.10.2010; and 11,204 daily prices for 5 yearly futures between 2,889 days of trading from 3.1.2000 to 25.7.2011.

All in all, the analysis covers the 11-year period from 3.1.2000 to 25.7.2011, in which there are overlapping price quotes for electricity spot and weekly, monthly, quarterly and yearly futures for 1,255 trading days during four years between 2.1.2004 and 30.12.2008. The full data sample and descriptive statistics for the final sample are presented in the Table 3 on the following page.

Table 2. Sample descriptive statistics for electricity spot and futures prices.
The table presents the descriptive statistics for the electricity spot and futures prices in the sample. Spot price refers to the Nord Pool daily system price, and the futures contracts in the sample are presented in the Item-column. All prices are presented in €/MWh. The Full sample -column represents all the available observations in the data set and the Final sample –column shows the observations included in the final sample, N denoting the number of daily price observations. The right-hand side statistics are reported for the Final sample only. The data was received from the Economics department at the Aalto University School of Business, and was originally collected from Nord Pool.

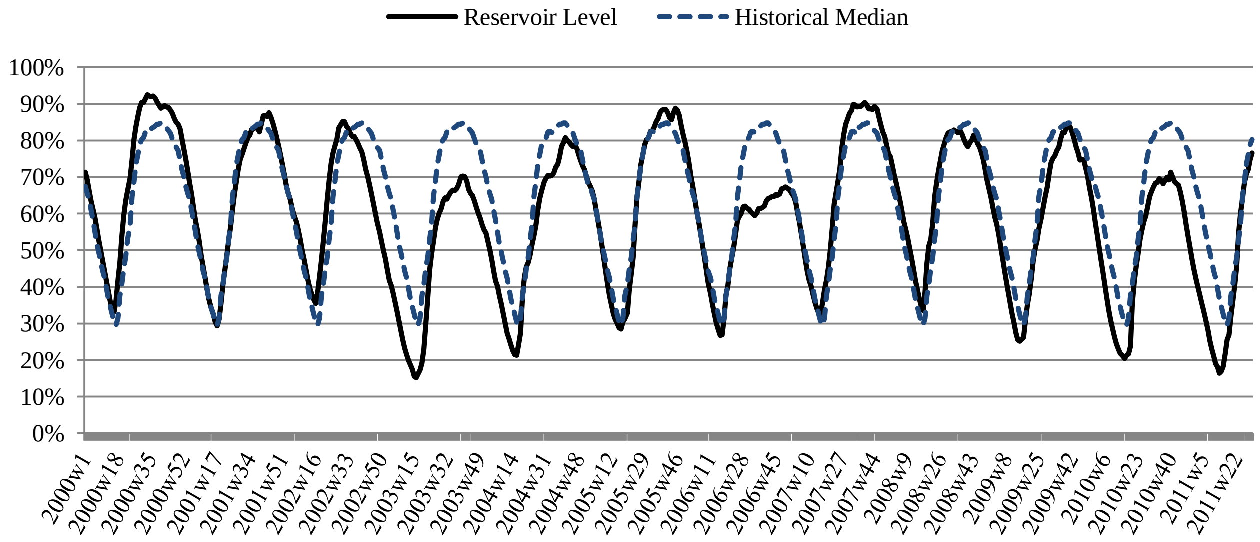
	Item	Time period	Full sample N	Final sample N	Mean	Median	Standard Deviation	Minimum	Maximum
	Spot price	3.1.2000 - 25.7.2011	4224	2889	35.51	32.53	15.83	4.78	134.80
Weekly futures	W+1	3.1.2000 - 30.12.2008	2248	2248	31.85	28.98	14.92	5.65	120.63
	W+2	3.1.2000 - 30.12.2008	2248	2248	32.47	29.62	15.19	6.84	121.60
	W+3	3.1.2000 - 30.12.2008	2248	2248	32.84	29.88	15.30	7.81	120.23
	W+4	3.1.2000 - 30.12.2008	2248	2248	33.05	29.88	15.32	8.63	119.54
	W+5	3.1.2000 - 30.12.2008	2243	2243	33.19	29.99	15.37	8.69	118.16
	W+6	3.1.2000 - 30.12.2008	2238	2238	33.24	30.20	15.24	8.86	113.29
	W+7	3.1.2000 - 29.3.2005	1286	1286	26.49	24.73	12.60	9.05	110.61
	W+8	3.1.2000 - 21.3.2005	1278	1278	26.41	24.56	12.34	9.05	103.05
Monthly futures	M+1	1.9.2003 - 30.6.2011	1966	1942	38.63	34.73	12.54	19.55	82.00
	M+2	1.8.2003 - 30.6.2011	1986	1964	40.12	36.93	12.98	19.45	81.75
	M+3	1.7.2003 - 30.6.2011	2009	1987	41.10	38.50	13.51	18.75	85.00
	M+4	2.6.2003 - 30.6.2011	2028	2005	41.59	39.37	13.96	17.94	84.95
	M+5	2.5.2003 - 30.6.2011	2048	2024	41.71	39.14	13.85	16.83	86.50
	M+6	7.4.2003 - 30.6.2011	2062	2039	41.44	38.13	13.26	16.32	88.50
Quarterly futures	Q+1	3.10.2005 - 19.10.2010	1269	1269	46.14	43.90	13.85	22.89	83.00
	Q+2	1.7.2005 - 19.10.2010	1335	1335	47.23	46.00	12.49	25.80	84.73
	Q+3	1.4.2005 - 19.10.2010	1396	1396	45.62	45.50	8.99	32.36	75.83
	Q+4	3.1.2005 - 19.10.2010	1456	1456	44.25	43.70	8.77	27.10	64.50
	Q+5	1.10.2004 - 19.10.2010	1520	1520	43.71	43.27	10.18	23.45	70.60
	Q+6	1.7.2004 - 19.10.2010	1586	1586	42.72	41.00	10.83	23.20	73.23
	Q+7	1.4.2004 - 19.10.2010	1644	1644	41.24	42.00	10.08	25.05	72.50
	Q+8	2.1.2004 - 19.10.2010	1707	1707	40.53	41.35	9.88	24.80	63.50
	Q+9	2.1.2004 - 30.9.2010	1340	0	-	-	-	-	-
	Q+10	2.1.2004 - 30.6.2010	877	0	-	-	-	-	-
	Q+11	2.1.2004 - 31.3.2010	450	0	-	-	-	-	-
	Q+12	22.9.2009 - 23.12.2009	12	0	-	-	-	-	-
Yearly futures	Y+1	3.1.2000 - 27.7.2011	2871	2869	33.26	30.60	12.96	15.41	69.75
	Y+2	3.1.2000 - 27.7.2011	2891	2889	32.20	28.29	12.24	16.40	67.58
	Y+3	17.1.2000 - 27.7.2011	2882	2880	32.38	28.33	12.01	17.25	67.40
	Y+4	15.6.2006 - 27.7.2011	1285	1283	48.83	46.63	6.47	39.93	68.00
	Y+5	15.6.2006 - 27.7.2011	1285	1283	49.98	46.72	7.56	41.48	70.25

5.2. Water reservoir level data

Similarly to the electricity price data, the data for water reservoir levels was received from the Economics department at the Aalto University School of Business, and it was originally collected from Nordic public statistics and Nord Pool Spot website. The water reservoir levels are reported in the data set from the first week of year 2000 until the last week of 2011 both as the absolute weekly average water reservoir filling levels in the Nordic countries and as a percentage of the maximum water reservoir capacity, a figure published by Nord Pool. Nord Pool publishes the water reservoir levels as a percentage of the current maximum filling levels, and as an example of the magnitude, it may be mentioned that the total water reservoir capacity in the Nordic region was 121,429 GWh on 2.1.2012 (Nord Pool [d], 2013).

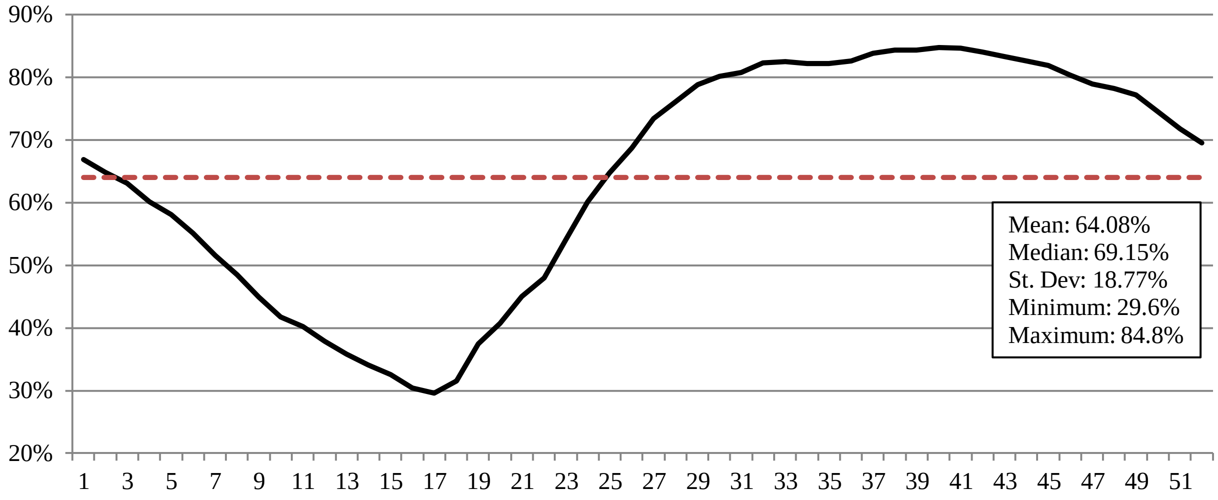
All in all, the sample consists of 626 weekly water reservoir level observations in the Nordic market. In addition, the data sample also includes the weekly historical median water reservoir levels as a percentage of the maximum capacity in the Nord Pool region, originally provided by Nord Pool based on historical data dating back to the year 1990. The figure 9 presents the weekly average water reservoir filling levels from 2000 to 2011 together with the historical weekly median water reservoir levels, both as a percentage of the maximum capacity.

Figure 9. Weekly average water reservoir levels by week 2000 – 2011.
The figure presents the weekly average and historical median water reservoir filling levels as a percentage of the total water reservoir capacity from 2000 to 2011. Historical median filling levels are based on historical data from 1990 to the beginning of each year. The data was received from the Economics department at the Aalto University School of Business, and it was originally collected from Nordic public statistics and Nord Pool Spot website.



As can be seen from the Figure 9 on the previous page, the water reservoir levels are highly cyclical, following a natural seasonal pattern and reaching their lowest levels in the spring with melting snow and precipitation and the highest levels in the autumn. During the sample period from the year 2000 to 2011, the water reservoir levels seem to follow their historical average levels quite accurately in general, with the largest deviations occurring during the historical times of peak- and bottom- reservoir levels within the year, i.e. in the spring and autumn, as highlighted by an examination of the historical weekly median water reservoir levels pictured in Figure 10 below.

Figure 10. Historical weekly median water reservoir levels as a percentage of maximum reservoir capacity.
The figure shows the historical weekly median water reservoirs levels in Nord Pool area, based on Nord Pool data on historical weekly median water reservoir levels as a percentage of maximum reservoir capacity between years 1990 and 2012 (Nord Pool [d], 2013). The dashed red line represents the mean of the weekly historical median filling levels, and the box on the right-hand side of the chart presents the summary statistics for the historical weekly median water reservoir levels.



As shown in the Figure 10, the water reservoirs reach their lowest levels – ca. 30% of the maximum capacity – in the spring around weeks 16 and 17, after which the precipitation and melting snow begin to fill the reservoirs again and the reservoir levels increase steadily until reaching their maximum filling levels of ca. 85% around weeks 40 and 41 in the autumn.

This data together with the electricity price data enables the examination of the influence of the deviations from historical water reservoir levels on electricity spot and futures prices and the futures premium, and these relationships are covered in a more detail in the analysis section.

5.3. Coal price data

The coal price data for the analysis was retrieved from Thomson Reuters Datastream database, where daily closing prices for API 2 coal quoted in the Intercontinental Exchange (ICE) were available for a time period from 17.7.2006 to 25.7.2011, the end of our sample period, amounting to 1311 daily closing price observations. The prices are quoted in U.S. dollars per ton of coal, and therefore the dollar denominated price quotes were converted into Euros by using the daily European Central Bank (ECB) Euro foreign exchange reference rates, downloaded from the ECB Statistical Data Warehouse website (ECB [a]). The daily API 2 coal price in euros per ton is presented in Figure 11 below, where the price spike of 2008, when the coal price increased dramatically in less than six months driven by increased demand and higher transportation charges due to oil price increases, is highly visible. As a more detailed analysis on coal price developments is out of the scope of this study, it is not examined further here, but for example He et al. (2010), and Freme (2008) provide more perspective on coal price developments.

Figure 11. The daily API 2 coal prices (€/ton), 17.7.2006 – 25.7.2011.
The figure presents the daily closing prices for API 2 coal for delivery into the Amsterdam, Rotterdam, and Antwerp region in the Netherlands, converted from U.S. dollars per ton into euros per ton. Price data was retrieved from Thomson Reuters Datastream database, and daily USD to Euro exchange rates were retrieved from ECB Statistical Data Warehouse.

Because no exchange traded coal products with delivery in the Nordic region are available, I chose to use the API 2 coal price as a proxy for the coal price in the Nordics. API 2 is the price of coal delivered into the Amsterdam, Rotterdam, and Antwerp region in the Netherlands and

Belgium (see ICE [a]), the geographically closest point of delivery for exchange-traded coal from the Nordic perspective. In order to use the API 2 coal price as a proxy for the cost of coal in the Nordic region, an assumption has to be made that the cost of transporting the coal from the API 2 -region to the Nordics is constant. Using a constant proxy for transportation costs does not influence the shape of the coal price curve, but rather shifts the slope by the amount of the assumed constant transportation costs, thus not influencing the nature of the results. For simplicity, a constant zero transportation cost is assumed in the analysis. Moreover, coal price – although the key cost driver as the raw material for coal fired electricity generation – does not perfectly reflect the cost of coal generated electricity as it does not capture the conversion rate of coal into power nor the efficiency of the conversion in different types of coal-fired plants. However, the detailed technical analysis is out of the scope of this study, and thus the API 2 coal price is considered to provide a sufficient view on the influence of coal price changes on the Nordic electricity market.

5.4. Electricity demand data

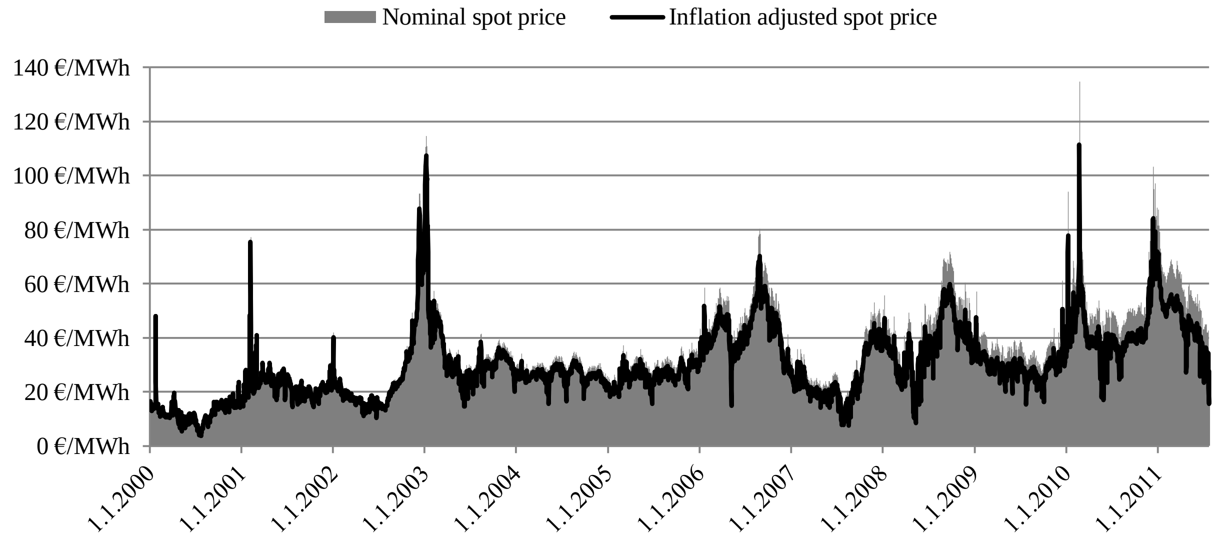
The electricity demand data used in this study was also received from Anna Sahari at the Economics department at Aalto University School of Economics. The demand data consists of weekly electricity consumption observations in the Nord Pool region between the first week of the year 2000 and week 30 in 2011, originally reported by Nord Pool. In total, the sample thus includes 604 weekly electricity demand observations, plotted in the Figure 8 in section 2.2.2. In the interest of space, the demand data is not covered in a more detail in this section, as its main characteristics are presented in section 2.2.2. earlier in this paper.

5.5. Characteristics of electricity spot and futures prices in Nord Pool

In overall, the electricity spot and futures prices in the Nord Pool electricity market are very volatile, which is characteristic for electricity markets. As shown in Table 3 earlier, the electricity spot price in the Nordic power exchange was on average 35.51 €/MWh during the period 3.1.2000 – 25.7.2011, accompanied by high standard deviation, ca. 45% relative to the mean spot price. The mean figures are similar for all the futures contracts in the sample, although the statistics are not directly comparable as they represent different time periods for the futures contracts. The standard deviation relative to the mean values is the highest with weekly futures, close to 50%, around 30% with monthly futures, between 20% and 30% with quarterly futures, and somewhat below 40% for the first three yearly futures and above 10% for 4- and 5-year contracts[4]. All in all, the descriptive statistics for the spot and futures prices do imply that the prices are very volatile, as the standard deviations and the spreads between the minimum and maximum prices are relatively large.

This is further demonstrated by the Figure 12 below, which presents the Nord Pool system spot price for the period 1.1.2000 – 25.7.2011 in euros per megawatt hour of electricity.

Figure 12. Nord Pool electricity spot price 2000 – 2011.
The figure shows the daily closing quotes for electricity spot price in the Nord Pool exchange, i.e. the Nord Pool system price, from 1.1.2000 to 25.7.2011. The grey area represents the daily nominal spot price, and the black line plots the inflation-adjusted spot price, adjusted with the Euro area Harmonized Index of Consumer Prices (HICP) Overall index. All price quotes are in euros per megawatt hour. The HICP index is published monthly as an annual rate of change by the European Commission (Eurostat) and European Central Bank, and the calculations are based on Eurostat data. The annual rates of inflation were converted to monthly inflation rates and used for daily price observations in a given month. The Nord pool system price data was received from the Economics department at the Aalto University School of Business, and was originally published by Nord Pool.



As illustrated in Figure 12, the electricity spot price in the Nordic power market is highly volatile, ranging from less than 10€/MWh to over 130€/MWh, and extreme price spices occur rather often – especially in the first months of the year when the winter is at its coldest. This pattern is also observable when the spot prices are averaged by the week of the year, as shown in Figure 13 on the next page. Figure 13 shows that the electricity spot price during the sample period is the highest during the mid-winter months and the lowest during the summer, recording its highest

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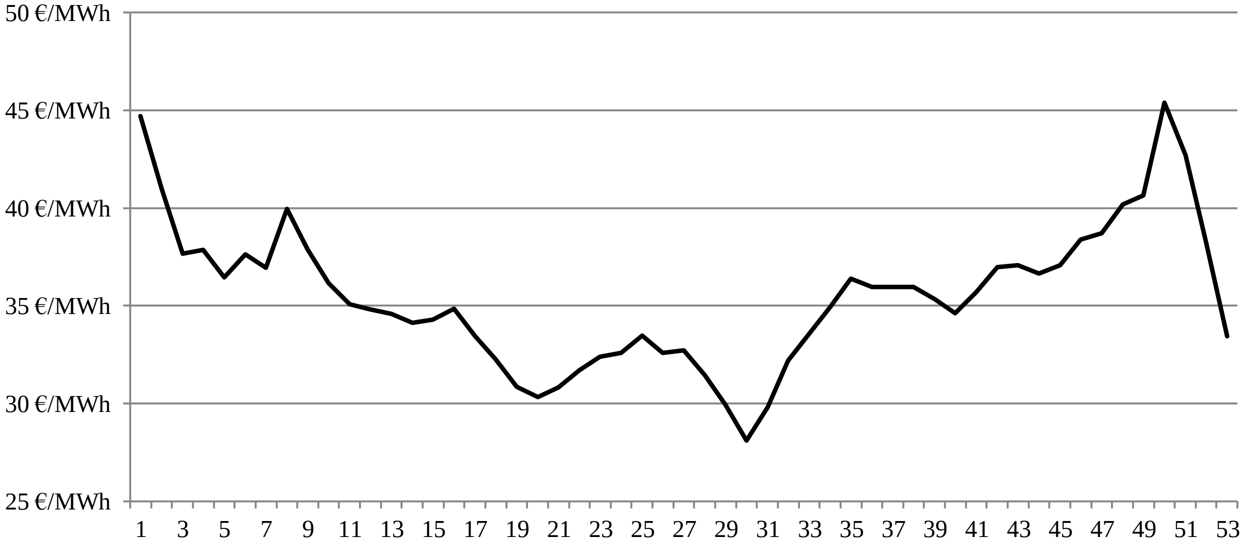
[4] This difference is explained by the fact that for the 4- and 5-year futures contracts no price data is available during 3.1.2000 – 14.6.2006, a period including the extremely volatile time periods in winters 2001 and 2003.

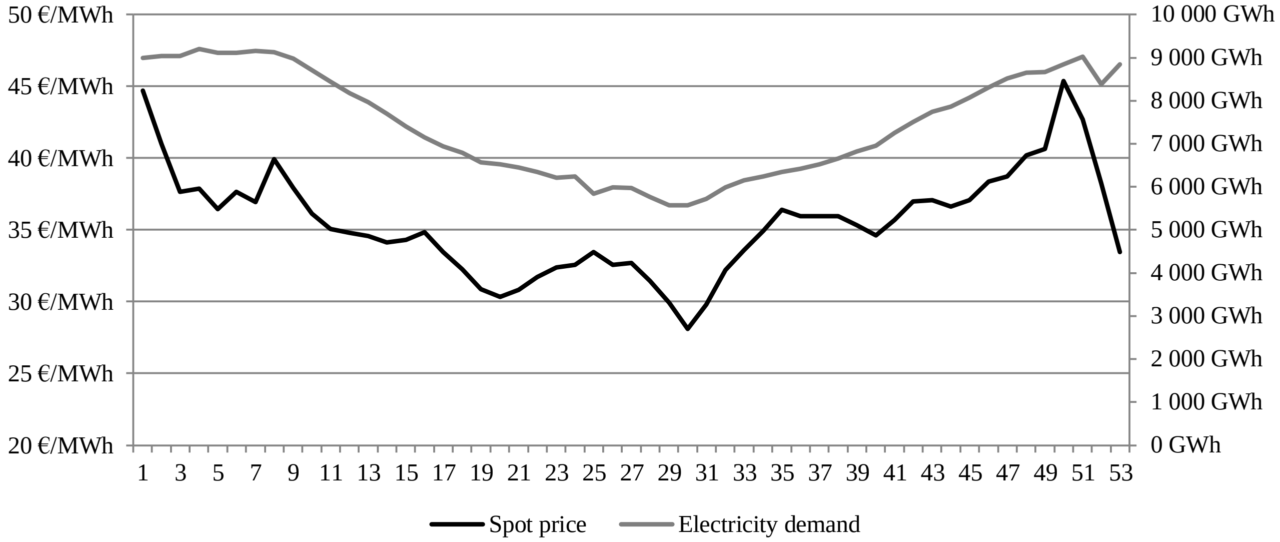
values in weeks 1 and 50 and the lowest values in weeks 29 and 30 in late July. Interestingly, the weekly average spot price for week 53 drops significantly in comparison to the other weeks around it, but this is explained by the fact that the sample period includes only 7 daily price observations for the leap year week 53 that took place in years 2004 and 2008 during the sample period, and the overall price level especially in late 2004 was well below the average price level.

Figure 13. Nord Pool electricity spot price by week 2000 – 2011.
The figure illustrates the weekly average Nord Pool system price, based on daily price quotes from 1.1.2000 to 25.7.2011. The price quotes are in euros per megawatt hour. The data was received from the Economics department at the Aalto University School of Business, and was originally published by Nord Pool.



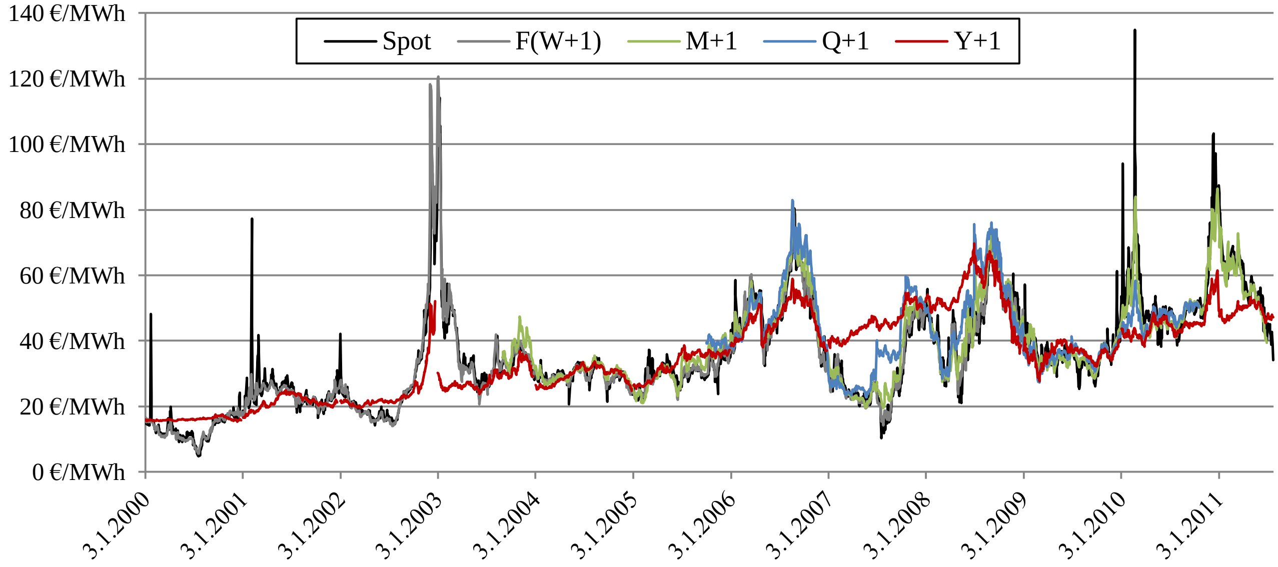
A comparison of the average weekly spot price to the average weekly electricity demand in the Nord Pool area highlights the relationship between these two variables, as shown in the Figure 14 on the next page. The weekly electricity spot price and electricity demand averages have a strong correlation, 0.78, and they seem to follow similar patterns throughout the year. Both electricity spot price and demand reach their lowest weekly average levels in the summer in week 30, being the highest during the mid-winter. This illustrates the seasonality both in electricity demand and spot prices, underlining the seasonal nature of the Nordic electricity market.

Figure 14. Average electricity spot price and electricity demand in the Nord Pool area by week.
The figure illustrates the weekly average Nord Pool system price, based on daily price quotes from 1.1.2000 to 25.7.2011, together with the mean electricity demand in the Nord Pool region by week, based on weekly electricity demand data between week 1 in 2000 and week 30 in 2011. The price quotes are in euros per megawatt hour, presented in the left-hand side y-axis, and the demand data is in GWh, represented by the right-hand side y-axis. The data was received from the Economics department Aalto University School of Business, and was originally collected from Nord Pool.



Finally, the figure 15 on the next page presents an overview on the behavior of the electricity spot and futures prices in the Nordic market. Electricity spot price seems to be closely followed by the week- and month-ahead futures prices. The front-quarter future deviates more from the spot price, being somewhat less volatile, whereas the year-ahead futures price does not present similar price spikes or declines as the spot price does. This is a natural pattern, considering that the fundamental factors currently causing volatility in the spot price should by definition have a strong influence on the short-maturity contracts whereas this influence should be smaller in magnitude for the longer futures contracts, unless the factors causing the price volatility can be assumed to persist for longer time-periods in the market or to be permanent in nature.

Figure 15. Electricity spot and futures prices in the Nordic market, 2000 - 2011.
The figure shows the daily closing quotes for electricity spot price in the Nord Pool exchange, i.e. the Nord Pool system price, from 1.1.2000 to 25.7.2011, the daily closing prices for the week-ahead contract in the NASDAQ OMX Commodities exchange from 3.1.2000 to 31.8.2008, between 3.1.2003 and 30.6.2011 for the month-ahead contract, 3.10.2005 – 19.10.2010 for the quarter-ahead contract, and 3.1.2000 – 25.7.2011 for the year-ahead contract. The price quotes are in euros per megawatt hour. The data was received from the Economics department at the Aalto University School of Business, and was originally published by Nord Pool.



6. METHODOLOGY

This section briefly explains the methodological approaches used in the analysis section and derives the formulae specific to this thesis, whereas the general formulae for futures pricing were presented in Section 3 of this thesis, and are thus only briefly referred to in this section.

6.1. Futures premium and the factors explaining its behavior

In the examination of the futures premium, I refer to the Equations 3 and 4 presented in Section 3.1. to determine the sign and magnitude of the basis and the relative basis for weekly, monthly, quarterly and yearly futures during the sample period between 3.1.2000 and 25.7.2011. This examination allows us to determine whether a nonzero futures premium exists, together with its characteristics such as its sign, intra-year seasonality, and development over the sample period.

Hence, the basis is calculated for each of the futures contracts as given by the Equation 3, where Basis = $F_{t,T} - S_t$. The basis thus presents a means of studying the existence and nature of the futures premium in the Nordic electricity markets, but to examine the relative magnitude and economic significance of the basis, also the nature of the basis in relation to the electricity spot price needs to be analyzed. Therefore the relative basis for the futures contracts in the sample can also be calculated using the formula described in Equation 4, where Relative basis = $\frac{F_{t,T} - S_t}{S_t}$.

After studying the existence and nature of the futures premium, I proceed to the analysis of the factors explaining the behavior of the futures premium. To gain understanding of the factors affecting the futures premium, I use the ordinary least squares (OLS) regression analysis. In the regression analysis the futures premium measures obtained from Equations 3 and 4 are regressed against a set of explanatory factors, namely the water reservoir levels, coal price, and electricity demand, using the following regression estimation:

$$Futures\ premium = \beta_0 + \beta_1 Water\ Reservoirs + \beta_2 Coal\ Price + \beta_3 Electricity\ Demand + \varepsilon. \quad (8)$$

The dependent variable in the above regression is the futures premium, i.e. the basis or the relative basis. I conduct the regressions using both absolute and relative basis for robustness, and for both regressions the independent variables are the same: the independent variable *Water Reservoirs* is the deviation of water reservoir level at time *t* from the historical average reservoir level[5] in percentages. *Coal Price*, measured as the natural logarithm of the API2 coal price in €/t, is a proxy for the cost of producing electricity using coal, which in the Nordic market generally can be described as the most significant marginal production method after hydro-, wind- and nuclear production. *Electricity Demand* is the natural logarithm of the total electricity demand in the Nordic region at time *t*. Newey-West -tests for heteroskedasticity and autocorrelation are also conducted for robustness.

6.2. The factors affecting electricity prices

In addition to examining the behavior of the futures premium in the Nordic power market, it is also in the scope of this paper to examine the factors affecting the electricity spot and futures prices in the region. This analysis presents us with an opportunity to further test the past research on the Nordic power market context, which has widely supported the view that the hydro reservoirs contribute to explain the market's behavior (see for example Botterud et al., 2002; Botterud et al., 2010; Gjolberg and Brattested, 2011; Lucia and Torro, 2011; Huisman and Kilic, 2012). To extend the previous literature on this topic, I also present two additional variables that I

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[5] $Water\ Reservoirs = Water\ Reservoir\ level_t - Historical\ median\ water\ reservoir\ level$

hypothesize to influence the prices in the market, which are essentially the same as used in the analysis of the futures premium: coal price and the total electricity demand in the region. To identify if these factors contribute to explain the behavior of the spot and futures prices in the Nordic power market, the dependent variable OLS regression in the Equation 8 used in the previous section is replaced with electricity spot and futures prices, arriving at regressions

$$Electricity\ Spot\ Price = \beta_0 + \beta_1 Water\ Reservoir\ Level\ Difference + \beta_2 Coal\ Price + \beta_3 Electricity\ Demand + \varepsilon. \tag{9}$$

and

$$Electricity\ Futures\ Price = \beta_0 + \beta_1 Water\ Reservoir\ Level\ Difference + \beta_2 Coal\ Price + \beta_3 Electricity\ Demand + \varepsilon. \tag{10}$$

These regressions allow me to examine, whether the fundamental explanatory variables contribute to explain the behavior of the electricity spot and futures prices in the Nordic market.

6.3. The forecasting ability of electricity futures

In order to analyze the forecasting ability of electricity futures in the Nord Pool market, I begin from the expectations hypothesis standpoint to futures pricing. The expectations hypothesis approach postulates that the current futures price equals the expected future spot price at time T

$$F_{t,T} = E_t(S_T) + P_{t,T}\,, \tag{11}$$

where $F_{t,T}$ is the futures price for delivery at time $t + T$, $E_t(S_T)$ is the expected future spot price S_T at time t, and $P_{t,T}$ is the risk premium. I follow Fama and French (1987) and Huisman and Kilic (2012), and subtract the current spot price S_t from both sides of the Equation 11, arriving at

$$F_{t,T} - S_t = E_t(S_T) - S_t + P_{t,T}, \tag{12}$$

where the futures basis $F_{t,T} - S_t$ consist of two components, the expected change in the spot price between t and T, $E_t(S_T) - S_t$, and the expected risk premium $P_{t,T}$.

This formulation of the basis can be organized as follows:

$$P_{t,T} = F_{t,T} - E_t(S_T), \tag{13}$$

which arrives at the expectations hypothesis definition of the risk premium component.

Futhermore, following Fama and French (1987) and Huisman and Kilic (2012), assuming that market expectations are rational, i.e. forecast errors are random and have a mean of zero, the change in spot price and the futures basis may be estimated using the following regression equations:

$$S_T - S_t = \alpha_1 + \beta_1\left(F_{t,T} - S_t\right) + u_{t,T} \tag{14}$$

and

$$F_{t,T} - S_T = \alpha_2 + \beta_2\left(F_{t,T} - S_t\right) + z_{t,T}. \tag{15}$$

According to Fama and French (1987), when β_1 is positive, the identified basis at *t* has the ability to predict the spot price change from t to T (represented by $S_T - S_t$ in the Equation 14 and consequently the futures price $F_{t,T}$ has forecasting power over the future spot price. Furthermore, a positive β_2 indicates that the basis at *t* possesses information about the expected futures premium at *T*. Thus, the left-hand-side of Equation 16, $F_{t,T} - S_T$, is the realized risk premium, containing information about the expected futures premium $P_{t,T}$, which equals $F_{t,T} - E_t(S_T)$, as presented in Equation 15 above. According to the expectations hypothesis, this relationship should hold if it is assumed that market expectations are rational and if futures prices contain information about the expected futures prices and risk premiums.

As pointed out by Fama and French (1987), the above Equations 14 and 15 are subject to an adding-up constraint as the realized premium $F_{t,T} - S_T$ and the change in spot price from *t* to *T* sum up to the basis $\left(F_{t,T} - S_t\right)$ and therefore the intercepts and the slope coefficients in Equations 14 and 15 must sum up to one. Thus, the regressions allocate all the variation in the basis either to the expected premium, the expected change in the spot price, or to their combination (Fama and French, 1987). Therefore these equations allow me to examine, whether the variation in the basis contributes to forecasting power or to time varying risk premiums, or to both of these two.

6.4. Futures pricing efficiency – Observed and synthetic futures prices

For the analysis of the efficiency of the futures pricing in the Nordic electricity market, I examine whether the futures prices follow the no-arbitrage conditions. Since electricity is a flow commodity (Fleten and Lemming, 2003), it is delivered not at a single point of time but rather over a period of time. However, the futures contracts in the scope of this analysis are settled in cash during the delivery period, and thus the physical flow of electricity need not be considered in pricing these futures contracts. Here, I ignore the time value of money in this approach because the futures contracts are marked to market during the delivery period and no cash is tied for margins before the beginning of the settlement period. Furthermore, Kristiansen (2007) finds that the results for synthetic futures do not significantly differ with the inclusion of the time value of money, and in some estimations even yield better results when ignoring the time value of money.

Assuming that markets are efficient and no opportunities for arbitrage exist, following Kristiansen (2007), the above defined relationship can be proven by using three futures contracts, all trading equal amounts of electricity. The first contract $F_{0,M}$ has a delivery period from time 0 to time M, the second contract $F_{0,m}$ delivers from time 0 to m, and the third contract $F_{m,M}$ from time m to time M. The prices for these contracts at time *t* are $f_{0;0,M}$, $f_{0;0,m}$ and $f_{0;m,M}$, respectively.

Keeping in mind that, ignoring margin deposit requirements, a market participant can enter a futures contract with no initial cash outlay and that futures contracts are marked to market daily during the delivery period, the cash flows from these three contracts may be presented in a tabular form in Table 3 below.

Table 3. Cash flows from futures contracts $F_{0;M}$, $F_{0;m}$ and $F_{m;M}$.
$F_{0,M}$ denotes a futures contract with delivery period from time 0 to time M, $F_{0,m}$ represents a contract with delivery from time 0 to time m, $F_{m,M}$ has the delivery period from m to M, and their respective cash flows are represented in columns $F_{0,M;}$ $F_{0,m;}$ and $F_{m,M}$. The column $F_{0,m;}$ + $F_{m,M}$ represents the combined cash flows from futures contracts $F_{0,m;}$ and $F_{m,M}$.

Time	$F_{0,M}$	$F_{0,m}$	$F_{m,M}$	$F_{0,m} + F_{m,M}$
0	0	0	0	0
1	$\Delta t(S_1 - f_{0;0,M})$	$\Delta t(S_1 - f_{0;0,m})$	0	$\Delta t\big(S_1 - f_{0;0,m}\big) + 0$
…	…	…	…	…
m-1	$\Delta t(S_{m-1} - f_{0;0,M})$	$\Delta t(S_{m-1} - f_{0;0,m})$	0	$\Delta t\big(S_{m-1} - f_{0;0,m}\big) + 0$
M	$\Delta t(S_m - f_{0;0,M})$	$\Delta t(S_m - f_{0;0,m})$	0	$\Delta t\big(S_m - f_{0;0,m}\big) + 0$
m+1	$\Delta t(S_{m+1} - f_{0;0,M})$	0	$\Delta t(S_{m+1} - f_{0;m,M})$	$0 + \Delta t(S_{m+1} - f_{0;m,M})$
…	…	…	…	…
M-1	$\Delta t(S_{M-1} - f_{0;0,M})$	0	$\Delta t(S_{M-1} - f_{0;m,M})$	$0 + \Delta t(S_{M-1} - f_{0;m,M})$
M	$\Delta t(S_M - f_{0;0,M})$	0	$\Delta t(S_M - f_{0;m,M})$	$0 + \Delta t(S_M - f_{0;m,M})$

As can be observed from the Table 3, the cash flows from the futures contract $F_{0,M}$ covering the whole period from time 0 to time M are very similar to the combined cash flows from futures $F_{0,m}$ and $F_{m,M}$ that cover the shorter time periods from 0 to m and from m to M. Both these alternatives have identical exposures to spot price development, and the difference lies in the time profile of the futures contract the spot price is settled against, as also pointed out by Kristiansen (2007). In the absence of arbitrage, the prices of the longer contract $F_{0,M}$ and the shorter contracts $F_{0,m}$ and $F_{m,M}$ are set so that the values of the cash flows from these alternatives are equal (Kristiansen, 2007). In a mathematical form, this relationship may be expressed as

$$\sum_{i=1}^{M} f_{0;0,M} = \sum_{i=1}^{M} f_{0;0,m} + \sum_{i=1}^{M} f_{0;m,M}. \tag{16}$$

Thus, it may be concluded that the combined cash flows from the sub-period futures have identical exposures to spot price developments and thus their prices ought to be equal in the absence of arbitrage (see Kristiansen, 2007; Wimschulte, 2010). As it has been shown that these cash flow profiles ought to be identical, let us approach the pricing of multiperiod futures using a simple example, where the time value of money is ignored. In the absence of arbitrage, the time *t* price of a futures contract for delivery of electricity at time *t+2* must equal the time-weighted average of the prices of a futures contract from *t* to *t+1* and a futures contract from *t+1* to *t+2*. This condition may be expressed by using the following formula:

$$F_{t,t+2} = \frac{([t+1]-t)\times F_{t,t+1} + ([t+2]-[t+1])\times F_{t+1,t+2}}{(t+2)-t}, \tag{17}$$

where $F_{t,t+2}$ is the time *t* price of a 2-period futures contract with delivery at time *t+2*, $F_{t,t+1}$ is the time *t* price of a 1-period futures contract with delivery at time *t+1*, and $F_{t+1,t+2}$ is the time *t+1* price of a 1-period futures contract with delivery at *t+1*. In the above equation $(t+1)-t$ denotes the number of days between *t* and *t+1*, $(t+2)-(t+1)$ the number of days between *t+2* and *t+1*, and $(t+2)-t$ is the number of days between *t+2* and *t*, and for simplicity I will denote these as $d_{t,t+1}$; $d_{t+1,t+2}$; and $d_{t,t+2}$, respectively.

On a more general level, the multiperiod futures pricing relationship may be written as

$$F_{t,T} = \frac{d_{t,t+1}\times F_{t,t+1} + d_{t+1,t+2}\times F_{t+1,t+2} + \cdots + d_{T-2,T-1}\times F_{T-2,T-1} + d_{T-1,T}\times F_{T-1,T}}{d_{t,T}} \tag{18}$$

or as

$$F_{t,T} = \sum_{i=t}^{T-1} \frac{(d_{i,i+1} \times F_{i,i+1})}{d_{i,i+1}} \tag{19}$$

As may be observed from the above Equation 19, the futures price $F_{t,T}$ is expressed as the weighted average of a series of futures prices over the delivery period (Fleten and Lemming, 2003). Furthermore, as Kristiansen (2007) phrases it in a more general form, the price of a futures contract with long delivery period is the weighted average of the prices of shorter futures contracts within the delivery period.

Thus, as shown in Equation 19, the price of the futures contract with a longer delivery period equals the time-weighted average of the underlying sub-period futures prices. This allows us to examine the efficiency of futures pricing in the Nordic electricity market through comparing the prices of longer futures contracts (e.g. quarterly and yearly futures) by constructing combinations of shorter futures contracts (e.g. weekly and monthly contracts) that cover the same time period. This comparison allows us to examine, whether these prices differ from each other and whether pricing inefficiencies exist in the Nordic electricity market, thus seeking to answer the third research question in this thesis:

3) *Does the Nordic electricity futures market present opportunities for arbitrage*

The baseline assumption is that the Nordic electricity market follows efficient market conditions, i.e. there is no possibility for arbitrage. Therefore, as explained by Kristiansen (2007), Fleten and Lemming (2003) and Wimschulte (2010), the price of a long-term futures contract should equal the weighted average of shorter futures contracts (synthetic futures) covering the same time period. Thus, testing the fourth hypothesis,

H_4: Futures prices are equal to synthetic futures prices

allows us to examine the existence of possible pricing discrepancies between actual futures prices and synthetic futures prices, which would signal that opportunities for arbitrage might exist.

7. ANALYSIS AND RESULTS

In this section I seek to answer the research questions through testing the hypotheses presented in Section 4 by using the methodologies explained in the previous section. In the analyses, the weekly data for water reservoir levels and electricity demand are combined with the daily electricity spot and futures prices and coal prices by giving all the trading days in the week the same value, which is the average weekly water reservoir level or electricity demand on that week. This aggregation may have an influence on the results, but weekly averages for electricity demand and especially for the water reservoir levels can be considered representative for the daily values, and thus not to cause major distortions on the results.

7.1. Futures premium in the Nordic electricity market

As explained in Section 3 of in this thesis, the difference between the futures price and the spot price, referred to as the basis or the futures premium, reflects the hedging balance between the buyers and sellers in the electricity market. As argued in the hypothesis section, I expect to find that this hedging balance is not perfectly matched in the Nordic electricity market at all times, which dictates that a nonzero futures premium would exist in the Nordic power market.

In order to find support for this argument, let us proceed to test the first hypothesis:

H_{1a}: *There is a nonzero futures premium in the Nordic electricity market, i.e.* $F_{t,T} \neq S_t$.

In addition to merely testing the existence of a nonzero futures premium in the Nordic market, I also seek to gauge the size of the basis and also its economic significance. In order to measure the absolute size of the futures premium, the current spot price is subtracted from the current futures price as shown in the Equation 3, where *Basis* = $F_{t,T} - S_t$. Furthermore, to analyze economic significance of the basis in relation to the overall electricity price level, the size of the basis relative to the spot price is used as described in Equation 4, where *Relative basis* = $\frac{F_{t,T} - S_t}{S_t}$.

In addition to examining the existence of a nonzero basis and its economic significance in the Nordic electricity market, I also seek to test the sign of the futures premium. Based on previous literature by Botterud et al. (2002), Mork (2006), Botterud et al. (2010), and Gjolberg and Brattested (2011), I expect the basis to be positive on average, i.e. the electricity prices in the Nordic electricity market to follow a contango-relationship. This relationship would also indicate that electricity purchasers face greater pressure to hedge their purchases against price volatility than the electricity producers. In order to examine this, I turn to test the hypothesis H_{1b}:

H_{1b}: *On average, the futures price exceeds the spot price in the Nordic electricity market, i.e.* $F_{t,T} > S_t$.

An analysis of means for weekly, monthly, quarterly and yearly futures in the sample allows the testing of the above presented two hypotheses, and Tables 4 and 5 below present the descriptive statistics for the absolute and relative basis.

Table 4. Descriptive statistics for the absolute basis in €/MWh.
The table shows the descriptive statistics for the absolute basis during the sample period 3.1.2000 – 25.7.2011 in €/MWh, calculated as $F_{t,T} - S_t$. The t-statistic represents the one-sample t-statistic for the mean, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively. The price data was received from the Economics department at the Aalto University School of Business, and was originally published by Nord Pool.

	Daily price observations	Mean	t-statistic	Median	Standard deviation	Minimum	Maximum	Positive values (%)
F(W+1) – S_t	2248	-0.07	-0.94	-0.09	3.59	-52.97	58.36	48.35 %
F(W+2) – S_t	2248	0.55	6.68***	0.37	3.91	-53.52	61.12	56.41 %
F(W+3) – S_t	2248	0.92	10.45***	0.69	4.18	-54.43	58.36	59.30 %
F(W+4) – S_t	2248	1.13	12.27***	0.74	4.37	-55.35	47.01	59.70 %
F(W+5) – S_t	2243	1.27	13.02***	0.85	4.64	-56.08	53.51	59.74 %
F(W+6) – S_t	2238	1.33	12.98***	0.94	4.83	-56.78	41.85	59.87 %
F(W+7) – S_t	1286	0.25	1.91	0.32	4.73	-57.72	41.85	52.64 %
F(W+8) – S_t	1278	0.23	1.72	0.39	4.71	-57.72	25.33	52.97 %
F(M+1) – S_t	1962	0.35	3.01**	0.55	5.18	-52.55	17.22	55.86 %
F(M+2) – S_t	1984	1.15	7.77***	1.33	6.60	-62.97	22.59	59.78 %
F(M+3) – S_t	2007	1.72	9.25***	1.97	8.33	-82.32	27.32	63.08 %
F(M+4) – S_t	2026	2.01	9.27***	2.19	9.77	-85.50	31.42	63.18 %
F(M+5) – S_t	2046	2.10	8.79***	2.05	10.80	-87.27	36.57	61.24 %
F(M+6) – S_t	2060	1.99	8.02***	1.30	11.27	-85.80	37.76	57.23 %
F(Q+1) – S_t	1269	2.47	10.63***	1.94	8.28	-77.10	28.17	65.33 %
F(Q+2) – S_t	1335	3.98	13.11***	2.92	11.07	-86.37	36.77	65.62 %
F(Q+3) – S_t	1396	3.34	10.58***	2.56	11.80	-84.90	40.07	61.60 %
F(Q+4) – S_t	1456	2.71	9.10***	2.03	11.37	-84.30	32.76	61.26 %
F(Q+5) – S_t	1520	2.65	8.71***	2.41	11.87	-92.30	38.81	58.82 %
F(Q+6) – S_t	1586	2.55	7.93***	1.12	12.80	-93.80	41.89	55.99 %
F(Q+7) – S_t	1644	1.88	6.10***	0.80	12.52	-91.75	38.87	53.77 %
F(Q+8) – S_t	1707	1.73	6.23***	1.22	11.46	-90.65	31.89	58.23 %
F(Y+1) – S_t	2869	-0.20	-0.98	-0.26	11.12	-91.10	35.37	47.79 %
F(Y+2) – S_t	2889	-1.20	-5.15***	-0.69	12.48	-93.50	36.14	46.94 %
F(Y+3) – S_t	2880	-0.87	-3.64***	-0.31	12.77	-92.50	36.41	48.33 %
F(Y+4) – S_t	1283	2.36	5.74***	3.16	14.74	-89.80	36.11	57.83 %
F(Y+5) – S_t	1283	3.69	9.03***	4.96	14.63	-89.05	35.44	62.28 %

Table 5. Descriptive statistics for the relative futures premium.

The table shows the descriptive statistics for the daily relative basis in the sample period 3.1.2000 – 25.7.2011, calculated as $\frac{F_{t,T} - S_t}{S_t}$. The t-statistic presents the one-sample t-statistic for the mean, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively. The price data was received from the Economics department at the Aalto University School of Business, and was originally published by Nord Pool.

	Daily price observations	Mean	t-statistic	Median	Standard deviation	Minimum	Maximum	Positive values (%)
$(F_{w+1} - S_t)/S_t$	2248	-0.16 %	-0.82	-0.29 %	9.02 %	-68.58 %	97.27 %	48.35 %
$(F_{w+2} - S_t)/S_t$	2248	1.96 %	8.34***	1.33 %	11.15 %	-69.29 %	101.86 %	56.41 %
$(F_{w+3} - S_t)/S_t$	2248	3.36 %	11.84***	2.47 %	13.44 %	-70.48 %	120.20 %	59.30 %
$(F_{w+4} - S_t)/S_t$	2248	4.26 %	13.08***	2.55 %	15.45 %	-71.66 %	143.57 %	59.70 %
$(F_{w+5} - S_t)/S_t$	2243	4.90 %	13.51***	2.94 %	17.19 %	-72.61 %	164.49 %	59.74 %
$(F_{w+6} - S_t)/S_t$	2238	5.31 %	13.55***	3.23 %	18.53 %	-73.51 %	165.72 %	59.87 %
$(F_{w+7} - S_t)/S_t$	1286	2.79 %	4.98***	1.18 %	20.09 %	-74.74 %	177.40 %	52.64 %
$(F_{w+8} - S_t)/S_t$	1278	2.98 %	5.08***	1.51 %	20.94 %	-74.74 %	177.40 %	52.97 %
$(F_{M+1} - S_t)/S_t$	1961	2.15 %	6.69***	1.48 %	14.25 %	-78.00 %	113.86 %	55.89 %
$(F_{M+2} - S_t)/S_t$	1984	4.97 %	11.92***	3.84 %	18.57 %	-76.46 %	158.78 %	59.78 %
$(F_{M+3} - S_t)/S_t$	2007	7.34 %	13.5***	5.46 %	24.38 %	-68.81 %	212.96 %	63.08 %
$(F_{M+4} - S_t)/S_t$	2026	9.04 %	13.27***	5.58 %	30.66 %	-72.74 %	269.42 %	63.18 %
$(F_{M+5} - S_t)/S_t$	2046	10.23 %	13.18***	5.25 %	35.11 %	-73.54 %	316.29 %	61.24 %
$(F_{M+6} - S_t)/S_t$	2060	10.68 %	12.8***	3.33 %	37.87 %	-72.48 %	368.73 %	57.23 %
$(F_{Q+1} - S_t)/S_t$	1269	9.92 %	12.88***	4.93 %	27.46 %	-57.20 %	255.94 %	65.33 %
$(F_{Q+2} - S_t)/S_t$	1335	16.99 %	15.23***	7.29 %	40.76 %	-64.07 %	356.04 %	65.62 %
$(F_{Q+3} - S_t)/S_t$	1396	17.11 %	15.62***	6.48 %	40.94 %	-62.98 %	309.46 %	61.60 %
$(F_{Q+4} - S_t)/S_t$	1456	15.49 %	15.03***	5.29 %	39.33 %	-62.54 %	319.90 %	61.26 %
$(F_{Q+5} - S_t)/S_t$	1519	15.41 %	14.05***	6.83 %	42.74 %	-68.47 %	378.98 %	58.79 %
$(F_{Q+6} - S_t)/S_t$	1586	15.78 %	13.31***	3.23 %	47.22 %	-69.58 %	409.06 %	55.99 %
$(F_{Q+7} - S_t)/S_t$	1643	13.60 %	13.05***	2.42 %	42.24 %	-68.06 %	315.80 %	53.74 %
$(F_{Q+8} - S_t)/S_t$	1707	12.27 %	13.25***	3.45 %	38.26 %	-67.25 %	311.41 %	58.23 %
$(F_{Y+1} - S_t)/S_t$	2869	7.77 %	11.20***	-0.93 %	37.18 %	-75.88 %	339.92 %	47.79 %
$(F_{Y+2} - S_t)/S_t$	2889	6.46 %	8.64***	-2.21 %	40.21 %	-77.67 %	352.91 %	46.94 %
$(F_{Y+3} - S_t)/S_t$	2880	8.05 %	10.43***	-1.11 %	41.40 %	-78.66 %	355.55 %	48.33 %
$(F_{Y+4} - S_t)/S_t$	1283	18.26 %	14.06***	8.11 %	46.53 %	-66.62 %	352.62 %	57.83 %
$(F_{Y+5} - S_t)/S_t$	1283	21.16 %	16.43***	11.51 %	46.11 %	-66.06 %	346.08 %	62.28 %

These results are rather mixed when examining the absolute and relative basis for the different futures contracts. In overall, the standard deviations and the spreads between minimum and maximum basis values are very high, which is characteristic for the highly volatile electricity market. The proportion of positive basis observations ranges from 46.94% for the 2-year future to 65.62% for the 2-quarter future, which as such does not signal strong clustering of observations on either side. However, the fact that the smallest imbalance in the distribution of positive and negative basis observations – which unsurprisingly is in the week-ahead futures with the shortest time to maturity – is as large as 3.29% does signal that most of the basis observations are nonzero, which would provide support to the hypothesis that nonzero futures premiums do exist in the Nordic electricity market. Furthermore, to verify this conclusion, the proportion of positive basis observations was calculated from all the sample observations, arriving to 56.79% of all sample observations for the basis being positive and 43.21% negative. This implies that the daily observations of the basis in the Nordic electricity market seem to be more weighted towards being positive, i.e. that in almost 57 percent of the sample observations the futures price is above the current spot price.

However, the skewed distribution of the daily basis observations between positive and negative values only shows that the basis is positive on 57% of the days observed, but does not as such signal anything about the size of the basis on average. Therefore, further examination is needed to examine, whether the basis averages towards zero or does it provide support to the hypothesis of a nonzero basis.

In this analysis the attention should be directed towards the relative basis, which as a relative measure is not as prone to changes in the overall price level of electricity as the absolute basis is, and thus the relative basis observations are comparable over time, which is not the case with the absolute basis observations: When the overall electricity price level is high, a small basis in relative terms can be documented as a high absolute price difference between the future and spot price, and vice versa, a proportionally large basis in times of low electricity prices can be documented as a small absolute price difference, which might distort the interpretation of the results. All in all, I have still presented the results for the absolute basis in Table 4 to present the reader with the idea about the magnitude of the futures premium in absolute euros per megawatt hour, but the focus is on the relative basis measure in the analysis of the results.

With weekly contracts the average basis is rather close to zero, ranging from -0.16% for the one-week future to 5.31% for the 6-week future, and the proportion of positive basis observations ranges from 48.35% to 59.87% for the same instruments. The standard deviation is also the smallest with one-week futures (9.02%), increasing with time to maturity and reaching 20.94% for the 8-week future. The same pattern is repeated when examining the spread between the minimum and maximum basis values, as the spread ranges from 166% for the one-week contract to over 250% for the 7- and 8-week futures. These statistics underline the extremely high volatility in the electricity markets. With weekly futures the positive and negative basis observations seem to be rather evenly distributed for 1-, 7- and 8-week futures, but disproportionally weighted towards positive for futures with two to six weeks to maturity.

These statistics imply that at least for the one-week futures the relative basis cannot be argued to be nonzero, contradictory to my hypothesis, but the futures basis seems to increase with time to maturity up to 5.31% for the 6-week future, after which the average relative basis declines to below 3% for the 7-and 8-week futures contracts.

However, the sample restrictions contribute to explain why the 7-and 8-week futures break the otherwise consistent pattern, as the data for the 7-and 8-week futures extend only until the end of March 2005, and thus does not include the tight market conditions experienced during the winter 2001-2002 and especially in winter 2002-2003 when spot prices were extremely high for lengthy periods of time (see also Mork, 2006; and Lucia and Torro, 2011). If the sample for weekly futures is broken down to pre-and post-April 2005 –periods, the average relative basis values for all weekly futures seem to be lower during the pre-April 2005-period than in the post-April 2005 period, and both the subsamples present the same pattern of futures premium being the smallest for weekly futures and increasing with contract maturity, thus explaining the inconsistency in Table 6. In the interest of space, the subsample statistics are not reported here.

The statistics for the monthly futures contracts show similarities with the weekly futures, further supporting the hypotheses of a nonzero futures premium and a contango-relationship in the Nordic electricity market. Even though the absolute basis for the front-month futures contract is small, only 0.35€/MWh, in relative terms the average basis is 2.15%, increasing with time to maturity and reaching an average level of 10.68% for the 6-month futures contracts. Also the balance between positive and negative values is in overweight in favor of positive basis observations as 56 - 63 percent of the daily basis values are positive. Hence, the monthly futures seem to provide support to both hypotheses. Furthermore, the basis variation also seems to increase with time to maturity, as for monthly futures both the standard deviation and especially the minimum-maximum spread is mostly larger than for weekly futures, reaching levels above 300%. The astonishingly high maximum values of 316% and 369% for the 5-and 6-month futures relative to spot price were recorded during the summer 2007, when the spot prices were on extremely low levels, but the 5-and 6-month futures with delivery on the coming winter were trading close to long-term average levels.

For both quarterly and yearly futures the mean relative basis values are all significantly positive, suggesting support for the hypotheses about a nonzero and positive futures premium. For quarterly futures the average relative basis is the smallest (9.92%) with the front-quarter contract, similarly to weekly and monthly futures, but surprisingly the largest with 2-and 3-quarter futures (16.99 and 17.11%, respectively). For all quarterly contracts also the median relative basis is positive, and a clear majority of the daily observations are positive, ranging from 65.33% for the front-quarter future to 53.77% for the 7-quarter future. Thus, it may be concluded that the findings for the quarterly contracts present support for the hypotheses that the futures premium is nonzero and that the futures price on average is above the spot price.

The mean relative basis for 1-, 2- and 3-year futures is less than 10 percent for all, but around 20% for the 4- and 5-year futures, thus suggesting the basis to increase with maturity. Interestingly though, the median values for the three first yearly futures are negative, being -0.93% for the front-year future, -2.21% for the 2-year future and -1.11% for the 3-year future. There are also more negative daily observations for the first three yearly futures than positives and the max-min spreads reach levels above 400 percent, mainly driven by the extremely high maximum values. These together with the mean and median statistics would imply that despite a slight majority of the daily basis observations being negative for these three contracts, there are very high positive values in the sample that pull the average above zero even though the median values remain negative. However, when examining the average futures premiums for the yearly contracts, the results suggest that a nonzero futures premium exists and that it is positive on average for all maturities.

To summarize the results, it may be concluded that on average the futures premium in the Nordic electricity market seems to be nonzero for a clear majority of the futures contracts – if not for all of them, as the one-week futures contract seems to be the only significant exception. Furthermore, the futures price on average seems to be above the spot price for all maturities, implying a contango-relationship in the Nordic power market. Thus, the results are consistent with the previous findings by Botterud et al., 2002; Mork, 2006; Botterud et al., 2010; Gjolberg and Brattested, 2011; Lucia and Torro, 2011; Huisman and Kilic, 2012, and provide sufficient support for both hypotheses that first of all, a nonzero futures premium exists, and second, that the futures price on average exceeds the spot price in the Nordic electricity market. This reflects that the hedging balance between the buyers and sellers in the Nordic market is not perfectly matched and that the hedging pressure is higher for electricity purchasers than for the producers, thus resulting in a positive futures premium.

As it has now been shown that a nonzero futures premium exists in the Nordic electricity market, its median values ranging from -2.33% to 11.51% and average values from 1.96% to 21.16%, we may proceed to further examine its behavior and the factors affecting it.

7.2. The factors influencing electricity spot and futures prices and the futures premium in the Nordic market

In this section the factors affecting the spot and futures prices in the Nordic electricity market are briefly examined first, after which I analyze the behavior of the futures premium.

7.2.1. The factors affecting the spot and futures prices in the Nordic electricity market

As discussed in the hypothesis section, I expect to find a strong negative relationship between electricity prices and the difference in current water reservoir levels and their historical averages, and a positive relationship between electricity prices and coal price and electricity demand. The analysis is conducted using OLS-regression estimation of the following equation:

$$Electricity\ price = \beta_0 + \beta_1 Water\ Reservoirs + \beta_2 Coal\ Price + \beta_3 Electricity\ Demand + \varepsilon.$$

The regression results are presented in Table 6 on the following pages, which shows that the results support my hypotheses. The difference between the current water reservoir level and their historical median levels is inversely correlated with electricity spot price, and the relationship is statistically significant at 99% confidence level. Consistent with previous literature (see Botterud et al., 2002; Botterud et al., 2010; Gjolberg and Brattested, 2011; Lucia and Torro, 2011; Huisman and Kilic, 2012) the results suggest that water reservoirs above their historical levels have a negative influence on the spot price, and vice versa, although the coefficient for water reservoir level difference is rather small.

The second independent variable, coal price, has a positive relationship with electricity spot price as hypothesized, and the results are also statistically significant at 99% confidence level. The results signal that increases in coal prices – i.e. in the cost of producing electricity with coal – have a positive relationship with electricity prices, which is consistent with Redl et al. (2009) and Kauppi and Liski (2008). Also the electricity demand has a positive and statistically significant relationship with the spot price, following a natural rationale that prices increase with demand.

All in all, the electricity spot price in the Nordic region seems to increase with coal price and electricity demand, and to decrease when water reservoir levels are above their historical levels and the supply of cheap hydropower is secure. Hence, the results provide support to the hypotheses H_{2a} and H_{2b}. However, the coefficient for deviations from historical water reservoir levels is rather small, whereas coal price seems to have the largest impact on the electricity spot price, as a one percent change in coal price leads to a 1.06% change in electricity spot price.

The Table 6 on the next page presents the regression results for time period 17.7.2006 – 30.12.2008, when data for all variables was available, and thus enables a better comparison of the influence of the physical factors on electricity spot and futures prices with different maturities.

When extending the time period under examination to 17.7.2006 – 25.7.2011 the regression estimates are not significantly different, but do not support comparisons of futures with different maturities as price data for all futures was not available for the whole time period. These regressions were also performed, but in the interest of space and because the results are similar to the ones shown in Table 6, these results are not reported here. In addition, I also performed an OLS regression analysis, where the sample was restricted to include only those days when the electricity demand was above its historical median level for the same week. Again, the results are not significantly different from the ones reported in Table 6, and are thus not presented here.

Table 6. The factors explaining the behavior of electricity spot and futures prices in the Nordic market.
The table reports the results for the OLS regression estimation of the equation $Electricity\ price = \beta_0 + \beta_1 Water\ Reservoirs + \beta_2 Coal\ Price + \beta_3 Electricity\ Demand\ + \varepsilon$, where Electricity price is the dependent variable, and separate regressions are run for spot price and all futures contracts. β_0 is the intercept, Water reservoirs represents the difference between current and historical water reservoir levels, Coal price is the €/t price for API2 coal, and Electricity demand is the electricity demand in the Nord Pool area in GWh. All price data is converted into natural logarithms, as also is the electricity demand data. The data consists of daily observations between 17.7.2006 - 30.12.2008. The t-statistics are reported in parentheses below the coefficient estimate, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively. Coal price data was retrieved from Thomson Reuters Datastream database, and data for other dependent variables was received from the Economics department at the Aalto University School of Business.

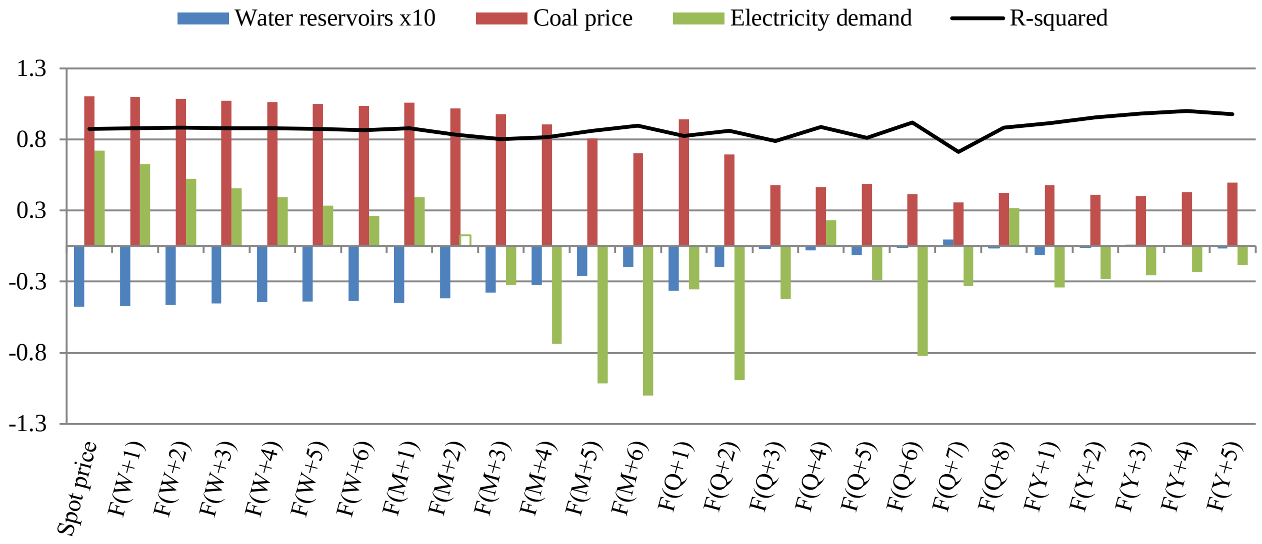
Dependent variable	Daily price observations	β₀	Water reservoirs	Coal price	Electricity demand	R²
Spot price	620	-6.9213 (-15.06***)	-0.0426 (-50.54***)	1.0566 (42.33***)	0.6736 (14.20***)	0.8271
F(W+1)	620	-6.0731 (-13.45***)	-0.0422 (-50.94***)	1.0533 (42.93***)	0.5792 (12.42***)	0.8300
F(W+2)	620	-5.0696 (-11.72***)	-0.0413 (-52.06***)	1.0401 (44.24***)	0.4762 (10.66***)	0.8373
F(W+3)	620	-4.3745 (-10.13***)	-0.0404 (-51.00***)	1.0243 (43.64***)	0.4082 (9.15***)	0.8329
F(W+4)	620	-3.7647 (-8.80***)	-0.0396 (-50.49***)	1.0158 (43.73***)	0.3453 (7.82***)	0.8320
F(W+5)	620	-3.1730 (-7.31***)	-0.0391 (-49.13***)	1.0037 (42.56***)	0.2860 (6.38***)	0.8251
F(W+6)	620	-2.4689 (-5.62***)	-0.0385 (-47.73***)	0.9889 (41.45***)	0.2154 (4.75***)	0.8182
F(M+1)	620	-3.7428 (-8.77***)	-0.0397 (-50.62***)	1.0094 (43.53***)	0.3461 (7.85***)	0.8320
F(M+2)	620	-1.1128 (-2.35)	-0.0367 (-42.26***)	0.9720 (37.82***)	0.0748 (1.53)	0.7871
F(M+3)	620	2.1939 (4.36***)	-0.0327 (-35.4***)	0.9287 (33.97***)	-0.2706 (-5.21***)	0.7521
F(M+4)	620	6.2555 (13.32***)	-0.0271 (-31.50***)	0.8558 (33.54***)	-0.6873 (-14.17***)	0.7675
F(M+5)	620	9.1806 (23.59***)	-0.0210 (-29.33***)	0.7567 (35.78***)	-0.9651 (-24.01***)	0.8136
F(M+6)	620	10.3817 (33.38***)	-0.0147 (-25.77***)	0.6567 (38.86***)	-1.0502 (-32.69***)	0.8508
F(Q+1)	620	2.6280 (5.74***)	-0.0315 (-37.52***)	0.8953 (36.01***)	-0.3035 (-6.42***)	0.7760
F(Q+2)	620	9.4694 (28.17***)	-0.0148 (-23.97***)	0.6441 (35.27***)	-0.9420 (-27.14***)	0.8145
F(Q+3)	620	5.3090 (21.95***)	-0.0015 (-3.27***)	0.4322 (32.89***)	-0.3707 (-14.84***)	0.7419
F(Q+4)	620	0.4720 (3.31***)	-0.0030 (-11.57***)	0.4165 (53.82***)	0.1823 (12.39***)	0.8389
F(Q+5)	620	4.1388 (20.04***)	-0.0062 (-16.22***)	0.4397 (39.18***)	-0.2384 (-11.18***)	0.7619
F(Q+6)	620	9.2050 (50.27***)	0.0000 (-0.01)	0.3676 (36.95***)	-0.7745 (-40.95***)	0.8719
F(Q+7)	620	5.0469 (19.62***)	0.0045 (9.63***)	0.3072 (21.99***)	-0.2810 (-10.58***)	0.6655
F(Q+8)	620	-0.0957 (-0.68)	-0.0007 (-2.89**)	0.3739 (48.77***)	0.2662 (18.27***)	0.8338

Table 6. Continued from the previous page

Dependent variable	Daily price observations	β_0	Water reservoirs	Coal price	Electricity demand	R^2
F(Y+1)	614	4.6192 (31.30***)	-0.0060 (-22.00***)	0.4314 (53.78***)	-0.2889 (-18.94***)	0.8657
F(Y+2)	620	4.3748 (40.90***)	-0.0005 (-2.52)	0.3625 (62.37***)	-0.2300 (-20.82***)	0.9074
F(Y+3)	620	4.2043 (48.12***)	0.0002 (1.16)	0.3538 (74.54***)	-0.2066 (-22.89***)	0.9347
F(Y+4)	620	3.8754 (50.78***)	-0.0007 (-4.84***)	0.3814 (91.98***)	-0.1822 (-23.12***)	0.9524
F(Y+5)	620	3.1851 (30.46***)	-0.0015 (-7.71***)	0.4458 (78.48***)	-0.1333 (-12.35***)	0.9302

For better illustration, the regression estimates are visualized in the Figure 16 below.

Figure 16. Regression estimates for factors affecting electricity prices.
The figure visualizes the regression coefficients presented in the Table 6 above. For better illustration, the coefficients for Water reservoirs are multiplied by 10. Coefficients that are not statistically significant at 99% confidence level are presented as unfilled columns, and R^2 is represented by the black line.



The results for the futures contracts are also in line with my hypotheses and with the behavior of the spot price. The coefficients for water reservoir level difference statistically significant at 99% confidence level for all futures contracts except for the 6-quarter, 2-year and 3-year contracts, being the largest for the week-ahead contract and decreasing steadily when time to maturity increases. The negative influence of water reservoir deviations becomes virtually zero for futures with maturities over 2 quarters, and actually seems to be slightly positive for the 7-quarter contract. This is highlighted in Figure 16, which illustrates the decreasing relationship between deviations from historical median water reservoir levels and the electricity spot and futures prices. All in all, we may conclude that deviations from historical median water reservoir levels are inversely correlated with electricity prices in short maturities, whereas this relationship becomes virtually zero for maturities over 2 quarters.

Consistent with my hypothesis and with the previous findings by Redl et al. (2009), the results indicate a strong positive relationship between electricity futures prices and coal price, the coefficients being also statistically significant for all maturities. The positive impact of coal price on electricity futures prices is the largest with the week-ahead contract, and also declines with contract maturity, showing a sharp drop for maturities over 2-quarters. This also implies that the current coal price has a strong impact on short-maturity electricity futures, but this influence declines while time to maturity increases, as illustrated in Figure 16.

The overall electricity demand in the Nord Pool area also seems to have a positive and statistically significant relationship at 99% confidence level, except for the 2-month contract, being the largest for the week-ahead future and decreasing with increasing contract maturity, turning negative from the 2-month future onwards. However, this relationship seems to be positive for 4-quarter and 8-quarter futures, which is somewhat puzzling, as there is no natural explanation for the positive relationship between current electricity demand and futures prices for electricity delivery in 12 or 24 months. This might be an indication of market participants' hedging schedule and the current electricity demand as its trigger, but this is not supported by the behavior of the 1- and 2-year futures' prices. Hence, the hedging behavior is at best a poor explanation for these deviations from the pattern.

All in all, the main findings from the OLS regressions analyses indicate support for the hypothesis H_{2a} that deviations from historical water reservoir levels have an inverse effect on electricity spot and futures prices, which is consistent with the findings in the previous studies (see, for example, Botterud et al., 2002; Botterud et al., 2010; Gjolberg and Brattested, 2011; Lucia and Torro, 2011; Huisman and Kilic, 2012). Furthermore, the results lend support to hypothesis H_{2b} that coal price and electricity demand are positively correlated with electricity spot and futures prices, which is also consistent with the previous research (see Redl et al., 2009; and Kauppi and Liski, 2008, for previous research on coal price influence on electricity prices, and Botterud et al., 2010, for the relationship between electricity demand and electricity prices). The results also lend support to the hypothesis H_{2c}, showing that the influence of water reservoir level deviations from historical median levels, coal price, and electricity demand on electricity prices seems to decline when the time to maturity of the futures contract increases, presenting the strongest influence on short-maturity contracts and the smallest impact on long-maturity contracts. This is a natural result, as short-term developments in water reservoir levels, coal price and electricity demand can be assumed not to prevail for longer periods of time, which also seems to be reflected in futures pricing in the market. Interestingly, the regression coefficients are the largest for coal price, highlighting its impact on electricity prices in the Nordic market.

7.2.2. The behavior of the futures premium in the Nordic electricity market

Finally, we may proceed to the analysis of the factors affecting the futures premium and its behavior in the Nordic electricity market. As shown in the previous section, the behavior of electricity spot and futures prices in the hydro-dominated Nordic market is affected by the difference between current and historical water reservoir levels, coal price, and the overall electricity demand. Furthermore, the influence of these effects seems to diminish as time to maturity increases. Next, the effects of these factors on the futures premium and its behavior are tested against the hypotheses:

H_{3a}: *Deviations from historical water reservoir levels are inversely correlated with futures premium,* and

H_{3b}: *Futures premiums are positively correlated with coal price and electricity demand.*

In order to test these hypotheses, I turn to Equation 8 presented in the methodology section:

$$Futures\ Premium = \beta_0 + \beta_1 Water\ Reservoirs + \beta_2 Coal\ Price + \beta_3 Electricity\ Demand + \varepsilon.$$

The regression analysis was conducted using both absolute and relative measure for the futures premium, both the approaches yielding similar results. Here only the results for the relative basis regressions are presented in the interest of space. Furthermore, the Table 8 on the following page presents the regression results for time the period 17.7.2006 – 30.12.2008, when data for all variables was available, allowing better comparison between futures with different maturities. When extending the time period under examination to 17.7.2006 – 25.7.2011, the regression estimates in overall are not dramatically different, but do not support comparisons of futures with different maturities as price data for all futures was not available for the whole time period. In the interest of space, these results are not reported here.

Table 7. The factors explaining the behavior of the futures premium 2006 - 2008.
The table reports the results for the OLS regression estimation for the equation
$Futures\ Premium = \beta_0 + \beta_1 Water\ Reservoirs + \beta_2 Coal\ Price + \beta_3 Electricity\ Demand\ + \varepsilon,$
where relative basis is the dependent variable, given as $\frac{F_{t,T} - S_t}{S_t}$ and measured in percentages. The independent variables are defined as follows: β_0 is the intercept, Water reservoirs represents the difference between current and historical water reservoir levels, Coal price is the €/t price for API2 coal, and Electricity demand is the electricity demand in the Nord Pool area in GWh. All price data is converted into natural logarithms, as also is the electricity demand data. The data consists of daily observations between 17.7.2006 - 30.12.2008. The t-statistics are reported in parentheses below the coefficient estimate, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively. Coal price data was retrieved from Thomson Reuters Datastream database, and data for other dependent variables was received from the Economics department at the Aalto University School of Business.

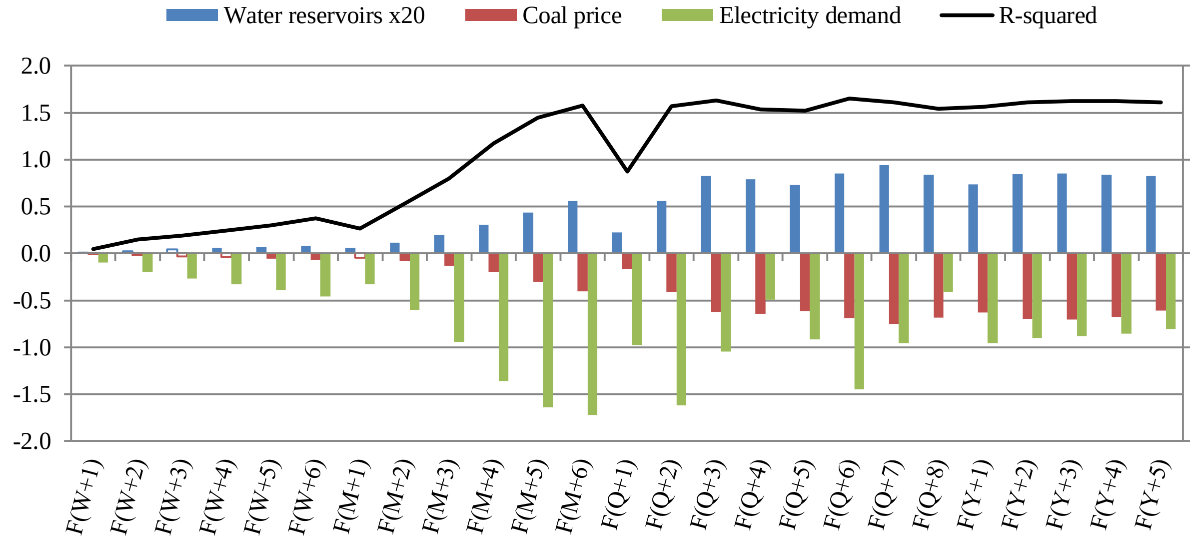
Relative basis	**Daily observations**	**β_0**	**Water reservoirs**	**Coal price**	**Electricity demand**	**R^2**
$(F_{w+1} - S_t)/S_t$	620	0.8482	0.0004	-0.0032	-0.0944	0.0242
		(3.55***)	(0.91)	(-0.25)	(-3.83***)	
$(F_{w+2} - S_t)/S_t$	620	1.8517	0.0013	-0.0165	-0.1974	0.0736
		(6.62***)	(2.48)	(-1.08)	(-6.83***)	
$(F_{w+3} - S_t)/S_t$	620	2.5468	0.0022	-0.0323	-0.2655	0.0956
		(7.69***)	(3.59***)	(-1.80)	(-7.76***)	
$(F_{w+4} - S_t)/S_t$	620	3.1566	0.0030	-0.0408	-0.3284	0.1231
		(8.74***)	(4.51***)	(-2.08)	(-8.80***)	
$(F_{w+5} - S_t)/S_t$	620	3.7483	0.0035	-0.0529	-0.3876	0.1495
		(9.90***)	(5.00***)	(-2.57***)	(-9.91***)	
$(F_{w+6} - S_t)/S_t$	620	4.4524	0.0041	-0.0677	-0.4582	0.1873
		(11.40***)	(5.79***)	(-3.19***)	(-11.36***)	
$(F_{M+1} - S_t)/S_t$	620	3.1786	0.0030	-0.0472	-0.3276	0.1317
		(9.23***)	(4.68***)	(-2.52)	(-9.21***)	
$(F_{M+2} - S_t)/S_t$	620	5.8085	0.0059	-0.0845	-0.5988	0.2665
		(14.03***)	(7.80***)	(-3.76***)	(-14.00***)	
$(F_{M+3} - S_t)/S_t$	620	9.1152	0.0099	-0.1279	-0.9442	0.3989
		(18.58***)	(11.02***)	(-4.80***)	(-18.63***)	
$(F_{M+4} - S_t)/S_t$	620	13.1768	0.0155	-0.2008	-1.3609	0.5872
		(26.83***)	(17.16***)	(-7.52***)	(-26.83***)	
$(F_{M+5} - S_t)/S_t$	620	16.1019	0.0217	-0.2999	-1.6387	0.7241
		(35.59***)	(26.09***)	(-12.2***)	(-35.07***)	
$F_{M+6} - S_t)/S_t$	620	17.3031	0.0279	-0.3999	-1.7238	0.7874
		(40.11***)	(35.25***)	(-17.06***)	(-38.70***)	
$(F_{Q+1} - S_t)/S_t$	620	9.5493	0.0111	-0.1612	-0.9771	0.4377
		(20.13***)	(12.75***)	(-6.26***)	(-19.95***)	
$(F_{Q+2} - S_t)/S_t$	620	16.3907	0.0278	-0.4124	-1.6157	0.7845
		(39.15***)	(36.21***)	(-18.13***)	(-37.36***)	
$(F_{Q+3} - S_t)/S_t$	620	12.2303	0.0412	-0.6243	-1.0443	0.8155
		(27.67***)	(50.74***)	(-26.00***)	(-22.88***)	
$(F_{Q+4} - S_t)/S_t$	620	7.3933	0.0396	-0.6401	-0.4913	0.7662
		(15.38***)	(44.86***)	(-24.51***)	(-9.89***)	
$(F_{Q+5} - S_t)/S_t$	620	11.0601	0.0365	-0.6169	-0.9120	0.7625
		(24.08***)	(43.26***)	(-24.72***)	(-19.23***)	
$(F_{Q+6} - S_t)/S_t$	620	16.1263	0.0426	-0.6889	-1.4481	0.8251
		(34.82***)	(50.13***)	(-27.38***)	(-30.27***)	
$(F_{Q+7} - S_t)/S_t$	620	11.9682	0.0472	-0.7494	-0.9546	0.8050
		(23.24***)	(49.9***)	(-26.78***)	(-17.95***)	
$(F_{Q+8} - S_t)/S_t$	620	6.8256	0.0419	-0.6827	-0.4074	0.7723
		(13.63***)	(45.56***)	(-25.10***)	(-7.88***)	

Table 7. Continued from the previous page

Relative basis	Daily observation	β₀	Water reservoirs	Coal price	Electricity demand	R^2
$(F_{Y+1} - S_t)/S_t$	614	11.5112	0.0367	-0.6254	-0.9590	0.7802
		(25.92***)	(45.06***)	(-25.92***)	(-20.90***)	
$(F_{Y+2} - S_t)/S_t$	620	11.2962	0.0421	-0.6941	-0.9037	0.8066
		(24.59***)	(49.95***)	(-27.81***)	(-19.04***)	
$(F_{Y+3} - S_t)/S_t$	620	11.1256	0.0428	-0.7028	-0.8802	0.8137
		(24.44***)	(51.24***)	(-28.42***)	(-18.72***)	
$(F_{Y+4} - S_t)/S_t$	620	10.7967	0.0419	-0.6752	-0.8559	0.8134
		(24.21***)	(51.23***)	(-27.86***)	(-18.58***)	
$(F_{Y+5} - S_t)/S_t$	620	10.1064	0.0411	-0.6108	-0.8069	0.8064
		(22.64***)	(50.20***)	(-25.18***)	(-17.50***)	

For better illustration, the regression estimates are visualized in the Figure 17 below.

Figure 17. Regression estimates for the factors affecting the futures premium.
The figure visualizes the regression coefficients presented in the Table 7 above. For better illustration, the coefficients for Water reservoirs are multiplied by 20. Coefficients that are not statistically significant at 99% confidence level are presented as unfilled columns and R^2 is represented by the black line, scaled on the secondary y-axis on the right hand side in the figure.



As presented in Table 7 and Figure 17 above, the explanatory power of the OLS-regressions, measured with the R-squared, in the regressions is rather small for the shorter futures, but generally increases with the maturity of the contracts. Interestingly, the results do not seem to present support for the hypothesis H_{3a}, but rather indicate that the difference between current and historical water reservoir levels has a positive effect on the relative basis, i.e. the relative futures premium, at all maturities, although not statistically significant for the first three weekly contracts. Furthermore, the influence on the futures premium seems to increase with maturity.

The unexpected positive relationship is likely to be explained by the behavior of the spot and futures prices examined in the previous section: As discussed, water reservoirs above historical median levels have a negative relationship with both the spot and futures prices. Since this effect diminishes with the maturity of the futures contract, the combined effect of water reservoir levels on spot and futures prices actually contributes to increase the futures premium with water reservoir levels. This is because the water reservoir levels above historical averages decrease the spot price (S_t) more than the futures prices ($F_{t,T}$), resulting in an increase in the relative futures premium, $\frac{F_{t,T} - S_t}{S_t}$. Thus, it is a natural observation that the influence of water reservoir levels on the influence on the futures premium seems to increase with maturity, given that the influence of water reservoir level deviations on electricity futures prices also declines when contract maturity increases, as shown in Figure 16 in the previous subsection.

The results indicate that coal price has a negative relationship with the futures premium for all futures, the results being statistically significant for all contracts but the first four weekly futures and the front-month contract. The results also show that the coal price's impact on the futures premium increases with contract maturity, similarly to what was observed with water reservoirs. For electricity demand, the regression results are statistically significant at 99% confidence level for all futures, implying a strongly negative relationship with the futures premium. Again, the magnitude of the influence seems to increase with contract maturity, being the smallest for weekly contracts and the largest for quarterly contracts, as previously illustrated in Figure 17.

To summarize the findings presented above, it can be concluded that the influence of these three factors on the relative futures premium are inverse compared with their influence on actual prices. Because the effect of water reservoir level deviations, coal price and electricity demand is larger for the spot price than for the futures prices, water reservoir levels above historical levels actually contribute to decrease the futures premium. In overall the impact on the futures premium seems to increase with contract maturity and the explanatory power and statistical significance of the regressions seem to be larger for the longer maturity futures.

All in all, these results suggest that the changes in the physical state of the market have a larger impact on close-to-maturity futures prices, i.e. that the market does not seem to price the changes in the physical environment for long-maturity contracts as aggressively as it does for the shorter ones. This is a natural conclusion, if one assumes that the changes in the physical state of the market can be considered to only have an impact in the short term and that the factors influencing the prices or that the prices themselves would exhibit mean reversion. Routledge, Seppi, and Spatt (1999) find implications of the latter with their equilibrium model, and Gjolberg et al. (2011) also discuss the possibility of this phenomenon in their paper.

7.3. The forecasting ability of electricity futures

For the analysis of the hypothesized ability of electricity futures to forecast the future spot price, let us turn to Equation 14, in which the left-hand-side of the equation presents the realized difference between the future spot price and the current spot price.

$$S_T - S_t = \alpha_1 + \beta_1\left(F_{t,T} - S_t\right) + u_{t,T}, \tag{14}$$

where S_T denotes the electricity spot price at time T and S_t denotes the current spot price, and thus presents the change in the spot price from t to T. The right-hand-side term $\beta_1\left(F_{t,T} - S_t\right)$ gives the coefficient β_1 for the current basis, which under the expectations hypothesis is argued to contain information about the expected change in spot price from t to T, so that consequently the futures price $F_{t,T}$ would have forecasting power over the future spot price. Assuming that market expectations are rational, i.e. the forecast errors are random and have a zero mean, the coefficient β_1 for the basis, together with the constant α_1 and the error term, are equal to the difference between future spot price and current spot price. Hence, a positive β_1 that is significantly different from zero signals that the basis at t has the ability to predict the spot price change from t to T, and consequently that the futures price $F_{t,T}$ has forecasting power over the future spot price.This allows us to test the fifth hypothesis, which postulates that

H_5: Electricity futures prices possess forecasting power over future electricity spot prices.

The full sample of data is used for the analysis, consisting of daily closing price observations for electricity spot between 3.1.2000 and 25.7.2011, from 3.1.2000 to 30.12.2008 for weekly futures, 2.1.2003 – 30.6.2011 for monthly futures, 2.1.2004 – 19.10.2010 for quarterly futures, and from 3.1.2000 to 25.7.2011 for yearly futures. However, as the analysis requires information about the realized spot price at time T, which for the long time-to-maturity futures is far in the future, the sample size is reduced by unavailability of maturity date spot prices. This is especially the case for quarterly and yearly futures, as for example the final data includes only 140 daily observations for the 5-year futures contract and 390 for the 4-year futures. With weekly futures the lack of price information for the 7- and 8-week futures, which stopped trading in the beginning of April 2005, decrease the sample size for these instruments significantly in relation to other weekly futures. The final data includes 1286 daily price observations for the 7-week futures and 1278 for the 8-week futures, which still presents us with a large enough sample for the purposes of this analysis.

The observations for each of the futures contracts under examination are presented in Table 8 on the following page, which also presents the results of the OLS regression analysis. The natural logarithm of the spot and futures price data is used for the analysis, as the logarithmic transformation of time series data follows the normal distribution more closely than the arithmetic price observations (see Osborne, 1959, and Lauterbach and Ungar, 1995). I also conducted Newey-West –tests (Newey and West, 1987) for heteroskedasticity and autocorrelation, and the statistics are reported in the Table 8 on the next page, the t-statistic columns referring to heteroskedasticity and autocorrelation consistent estimates.

Table 8. The forecasting ability of electricity futures in the Nordic electricity market.
The table presents the regression results for the regression estimation$S_T - S_t = \alpha_1 + \beta_1(F_{t,T} - S_t) + u_{t,T}$, where $S_T - S_t$ denotes the change in the spot price from t to T, $(F_{t,T} - S_t)$ is the basis, and β_1 is the coefficient for the basis indicating its forecasting power over the future spot price, while α_1 is the intercept and $u_{t,T}$ denotes the error term. The t-statistics are reported in their own columns and the asterisks ***, **, and * denote confidence at 1%, 5%, and 10% confidence levels, respectively. Newey-West tests were performed to account for heteroskedasticity and autocorrelation in the error terms. The futures price data used in the regression analysis was received from the Economics department at the Aalto University School of Business, and was originally published by NASDAQ OMX Commodities.

		Observations	**β_1**	**t-statistic β_1**	**α_1**	**t-stat. α_1**	**R^2**
Weekly	W+1	2248	0.8319	18.81***	0.0155	6.60***	0.3281
	W+2	2248	0.9487	24.89***	0.0010	0.33	0.3198
	W+3	2248	0.8019	18.79***	-0.0029	-0.69	0.2384
	W+4	2248	0.8104	25.22***	-0.0073	-1.67	0.2482
	W+5	2243	0.8376	30.87***	-0.0086	-1.85	0.259
	W+6	2238	0.8274	28.97***	-0.0077	-1.53	0.2515
	W+7	1286	0.7415	17.98***	0.0248	3.37***	0.205
	W+8	1278	0.7863	20.17***	0.0256	3.33***	0.2181
Monthly	M+1	1942	0.6937	19.42***	-0.0090	-2.83**	0.2442
	M+2	1944	0.6776	20.52***	-0.0200	-4.22***	0.1959
	M+3	1946	0.6858	22.69***	-0.0233	-3.99***	0.2148
	M+4	1946	0.7581	27.43***	-0.0250	-3.64***	0.2566
	M+5	1942	0.7694	32.66***	-0.0217	-2.96**	0.2741
	M+6	1937	0.7998	39.98***	-0.0196	-2.50	0.2943
Quarterly	Q+1	1269	0.6755	31.05***	0.0077	1.36	0.3415
	Q+2	1335	0.8912	39.15***	0.0008	0.08	0.3554
	Q+3	1396	0.9551	35.54***	0.0150	1.41	0.401
	Q+4	1443	0.9999	32.98***	0.0379	3.29***	0.3757
	Q+5	1441	0.9838	32.62***	0.0607	5.07***	0.3611
	Q+6	1448	0.8802	36.77***	0.0909	8.67***	0.3668
	Q+7	1443	0.8682	37.35***	0.1111	10.78***	0.3522
	Q+8	1443	0.6560	34.60***	0.1512	15.87***	0.2595
Yearly	Y+1	2729	0.7713	33.42***	0.2831	29.78***	0.1787
	Y+2	2499	0.9233	31.85***	0.4107	39.35***	0.269
	Y+3	2239	1.3186	41.08***	0.4145	45.54***	0.5102
	Y+4	390	1.4162	81.64***	0.3767	49.01***	0.9491
	Y+5	140	1.0576	204.87***	0.6947	433.52***	0.9929

As shown in Table 8, for weekly futures contracts the coefficient β_1 is significantly different from zero, ranging from 0.74 for the 7-week futures contract to 0.95 for the 2-week contract. All the coefficients for β_1 are also strongly statistically significant. The results from the regression analysis imply that the weekly futures contracts seem to contain information about the electricity spot price at the beginning of the delivery period, which is consistent with the findings by Huisman and Kilic (2012). Nevertheless, this is a natural finding for the weekly futures, especially for the 1- and 2-week contracts, as the conditions affecting the electricity price such as temperature, water reservoir levels and planned production outages can be forecasted rather accurately for the near-future weeks, and therefore the shorter electricity futures' prices can naturally be argued to possess forecasting power over the near-term spot prices.

Huisman and Kilic (2012) find that the monthly electricity futures from 1 to 6 months into the future possess significant forecasting power over the future spot price in the Nord Pool electricity market using a sample with 69 monthly futures price observations between 4.4.2005 and 1.12.2010. Their β_1 coefficients for the basis range between 0.83 for the 3-month future and 0.94 for the 2-month future and are significantly different from zero and not significantly different from one. In my more recent and more comprehensive sample consisting of 1937 to 1946 daily price observations for the monthly futures, the β_1 coefficients are also significantly different from zero and not significantly different from one, ranging from 0.68 to 0.80. The 2-month futures contract has the smallest coefficient for the basis, whereas the largest value is found for the 6-month futures contract. The β_1 coefficients for the monthly futures are in overall slightly smaller than with Huisman and Kilic (2012), but still significantly different from zero. Thus, consistent with Huisman and Kilic (2012), it may be concluded that monthly futures contracts in the Nordic electricity market contain significant forecasting power over the future spot price.

Interestingly, the results are similar also for futures contracts with longer time to maturity. Intuitively one could assume that the forecasting power decreases with the time horizon, but the results for the Nord Pool electricity futures imply that also the quarterly and yearly futures contracts do possess significant forecasting power. The β_1 coefficients for the current basis range from 0.66 to 1.00 for quarterly contracts and from 0.77 to 1.42 for the yearly futures contracts, all β_1 coefficients for the current basis being statistically significant and different from zero.

All in all, the results suggest that Nord Pool electricity futures possess forecasting power over the future spot price in all maturities. These results are consistent with Huisman and Kilic (2012), who also find that electricity futures contracts on the Nord Pool market contain significant forecasting power. These results are also consistent with the results by Fama and French (1987), who found evidence of futures' forecasting power with highly perishable products with high storage costs (broilers, eggs, hogs, cattle, pork bellies, and orange juice) or commodities with high storage costs in relation to their value (oats, soy beans, soy meal, and plywood). As electricity as a commodity is virtually nonstorable, combining these results with the findings of Huisman and Kilic (2012) and Fama and French (1987) signals that the futures basis contains power to forecast the future spot price in commodities with high perishability. However, information from a wider array of commodities would be needed to support such generalization, but in the scope of this analysis it may be concluded that in the Nordic electricity market the futures prices contain significant forecasting power over the future spot price in all maturities, which is consistent with the previous research on the futures' forecasting ability in nonstorable and highly perishable commodities.

7.4. Time-varying risk premiums in the Nordic electricity market

As discussed in the methodology section, the two equations

$$S_T - S_t = \alpha_1 + \beta_1\left(F_{t,T} - S_t\right) + u_{t,T}, \qquad (14)$$

and

$$F_{t,T} - S_T = \alpha_2 + \beta_2\left(F_{t,T} - S_t\right) + z_{t,T}. \qquad (15)$$

allow us to examine, whether the variation in the basis $\left(F_{t,T} - S_t\right)$ is attributable to forecasting power or to time-varying risk premiums, or to a combination of these two. In the previous section the basis was shown to contain significant forecasting power in all maturities of electricity futures in the Nordic market, and now I proceed to examine the existence of time-varying risk premiums.

Again, I follow the approach taken by Fama and French (1987) and Huisman and Kilic (2012), turning to Equation 15, where the left-hand side term $F_{t,T} - S_T$ is the risk premium realized at time T and the right-hand side term $\left(F_{t,T} - S_t\right)$ is the basis and β_2 its slope coefficient. Due to the adding up constraint discussed in the methodology section, the slope coefficients β_1 and β_2 sum up to one. Thus, as the β_1 coefficients were all shown to be positive and significantly different from zero in all maturities, the results for the β_2 coefficients are all closer to zero than one, as shown in Table 9 on the next page. Similarly to the previous section, the t-statistics reported in the Table 9 are based on heteroskedastic and autocorrelation consistent estimates of the variances (Newey and West, 1987).

Table 9. Time-varying risk premiums in the Nordic electricity market.

The table presents the results for the regression estimation $F_{t,T} - S_T = \alpha_2 + \beta_2(F_{t,T} - S_t) + z_{t,T}$, where $F_{t,T} - S_T$ denotes the risk premium realized at time T, $(F_{t,T} - S_t)$ is the basis, and β_2 is the slope coefficient for the basis indicating time-varying risk premiums, while α_2 is the intercept and $z_{t,T}$ denotes the error term. The t-statistics are reported in their own columns and the asterisks ***, **, and * denote confidence at 99%, 95%, and 90% confidence levels, respectively. The t-statistics are based on heteroskedastic and autocorrelation consistent estimates of the variances. The futures price data used in the regression analysis was received from the Economics department at the Aalto University School of Business, and was originally published by NASDAQ OMX Commodities.

		Observations	**β_2**	**t-stat. β_2**	**α_2**	**t-stat. α_2**	**R^2**
Weekly	W+1	2248	0.1678	3.81***	-0.0154	-6.54***	0.0194
	W+2	2248	0.0520	1.36	-0.0011	-0.35	0.0014
	W+3	2248	0.1976	4.63***	0.0028	0.68	0.0186
	W+4	2248	0.1897	5.90***	0.0074	1.67	0.0178
	W+5	2243	0.1627	6.01***	0.0088	1.88	0.0130
	W+6	2238	0.1722	6.03***	0.0079	1.55	0.0143
	W+7	1286	0.2587	6.27***	-0.0250	-3.40***	0.0304
	W+8	1278	0.2150	5.51***	-0.0255	-3.32***	0.0204
Monthly	M+1	1942	0.3076	8.62***	0.0090	2.83**	0.0599
	M+2	1944	0.3232	9.79***	0.0200	4.23***	0.0525
	M+3	1946	0.3139	10.38***	0.0233	3.98***	0.0542
	M+4	1946	0.2425	8.77***	0.0247	3.61***	0.0341
	M+5	1942	0.2304	9.79***	0.0217	2.96**	0.0328
	M+6	1937	0.1996	9.99***	0.0196	2.51	0.0253
Quarterly	Q+1	1269	0.3246	14.94***	-0.0076	-1.34	0.1070
	Q+2	1335	0.1083	4.76***	-0.0009	-0.09	0.0081
	Q+3	1396	0.0448	1.67	-0.0150	-1.41	0.0015
	Q+4	1443	0.0002	0.01	-0.0380	-3.31***	0.0000
	Q+5	1441	0.0157	0.52	-0.0608	-5.07***	0.0001
	Q+6	1448	0.1197	5.00***	-0.0909	-8.67***	0.0106
	Q+7	1443	0.1321	5.68***	-0.1111	-10.77***	0.0124
	Q+8	1443	0.3451	18.16***	-0.1513	-15.87***	0.0883
Yearly	Y+1	2729	0.2288	9.92***	-0.2831	-29.78***	0.0188
	Y+2	2499	0.0765	2.64*	-0.4107	-39.37***	0.0025
	Y+3	2239	-0.3180	-9.93***	-0.4143	-45.54***	0.0574
	Y+4	390	-0.4162	23.95***	-0.3767	-49.14***	0.6171
	Y+5	140	-0.0564	-10.51***	-0.6938	-443.54	0.2822

The β_2 coefficients are, apart from a few exceptions, statistically significant and they are not significantly different from zero at all maturities, ranging from -0.42 for the 4-year future to 0.35 for the 8-quarter futures contract. However, all these values are significantly different from one, and therefore it may be concluded that these results do not present evidence of time-varying risk premiums in the Nordic electricity market.

The findings are consistent with Huisman and Kilic (2012), do not find time-varying risk premiums in the Nord Pool electricity market in their analysis. However, Huisman and Kilic (2012) do find evidence of time-varying risk-premiums in the in the Dutch power market, where electricity is generated mainly using storable fossil fuels. Huisman and Kilic (2012) argue that the different results for the Dutch and Nordic power markets are attributable to the different characteristics of these two markets as no evidence of time-varying risk premiums is found in the hydro dominated Nordic electricity market. Nevertheless, the results cannot be extended to contribute to this discussion, but merely document that time-varying risk premiums do not exist in the Nordic power market.

7.5. Comparison of real futures prices to synthetic futures prices

In order to analyze whether the futures pricing in the Nordic electricity market follows efficient market conditions, i.e. that no arbitrage opportunities exist, I first construct synthetic futures that match the real futures traded in the market. More specifically, shorter period futures contracts are used to construct matching longer period futures contracts as shown in the Table 10 below.

Table 10. Synthetic futures contracts.
An illustration of the relationship between actual and synthetic futures contracts, where the left-hand side column presents the actual futures contract, the column in the middle shows the portfolio of shorter futures contracts that cover the same time period as the long-maturity contract, and the right-hand side column presents the synthetic contract built using the portfolio of short-maturity contracts that has an identical cash flow profile as the actual long-maturity futures contract.

Long-maturity futures contract	Short-maturity futures contracts	Synthetic futures contract
$F_{t,(M+1)}$	$F_{t,(W+1)}, F_{t,(W+2)}, F_{t,(W+3)}, F_{t,(W+4)}$	$sF_{t,(M+1)}$
$F_{t,(Q+1)}$	$F_{t,(M+1)}, F_{t,(M+2)}, F_{t,(M+3)}$	$sF_{t,(Q+1)}$
$F_{t,(Y+1)}$	$F_{t,(Q+1)}, F_{t,(Q+2)}, F_{t,(Q+3)}, F_{t,(Q+4)}$	$sF_{t,(Y+1)}$

As shown in the Table 10 above, a futures contract for delivery beginning in a month from time *t*, denoted $F_{t,(M+1)}$, is matched with a synthetic one-month futures contract $sF_{t,(M+1)}$, which consists of four weekly futures contracts with delivery periods starting one, two, three and four weeks after time *t*, respectively. Similarly a quarterly futures contract is matched by a synthetic quarterly futures contract consisting of three monthly futures contracts, and a year-ahead futures contract is matched by a synthetic one-year futures contract constructed by four quarterly futures.

As discussed in Section 6.4. earlier, the theoretical background dictates that, in the absence of arbitrage opportunities, the price of a multiperiod futures contract should equal the time-weighted average of the underlying shorter period futures prices for the market to be termed efficient (see Kristiansen, 2007; Lemming, 2003; and Wimschulte, 2010). To test whether this relationship holds in the Nordic electricity market, a daily time series of matching synthetic futures is constructed to support the comparison of these synthetic futures prices to the observed market prices for yearly, quarterly and monthly futures. This allows me to test the fourth hypothesis:

H_4: Futures prices are equal to synthetic futures prices

I test this hypothesis by examining the difference in the prices of observed futures contracts and the matching synthetic futures in two ways. First, the synthetic futures price is deducted from the corresponding observed market price, arriving at the absolute difference between these two prices. Second, in order to examine the relative magnitude of the price discrepancies, I divide this difference by the observed market price, arriving at the relative price difference.

After excluding the dates when no closing price quotes were available for the futures contracts, the data available for the analysis consists of 1520 daily observations for the yearly futures two years into the future and 1259 observations for the one-year futures between 1.10.2004 and 19.10.2010. The sample size is constrained by the availability of closing prices for the respective yearly and quarterly futures prices that were needed to construct the synthetic futures price. Similarly, for quarterly futures the sample consists of 1335 observations for the futures with delivery in two quarters and 1259 observations for the one-quarter futures from 1.7.2005 to 19.10.2010. For monthly futures the final sample includes 1319 daily observations for the front-month futures price and 370 observations for the two-month futures contract between 1.8.2003 and 30.12.2008. The number of observations for the futures price two months in the future is strongly decreased by the lack of price information for the 7- and 8-week futures that ceased trading in the beginning of April 2005, after which there are no price quotes available for these instruments. Therefore the construction of two-month synthetic futures using a combination of futures contracts 5-, 6-, 7- and 8-weeks into the future becomes impossible after April 2005, which significantly decreases the sample size for the 2-month synthetic contract.

7.5.1. Observed market prices and synthetic prices for yearly futures

Tables 11, 12 and 13 in this section present the summary statistics for both the absolute and relative price differences between the prices observed in the market and the synthetic futures prices for yearly, quarterly and monthly electricity futures contracts.

Table 11. Summary statistics for yearly observed and synthetic futures contract prices.
The table presents the summary statistics for the price differences between real and synthetic one- and two-year futures contracts. The absolute price differences are presented in €/MWh, and the relative price differences on the right-hand side columns are presented as percentage points. The t-statistic presents the one-sample t-statistic for the mean, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.

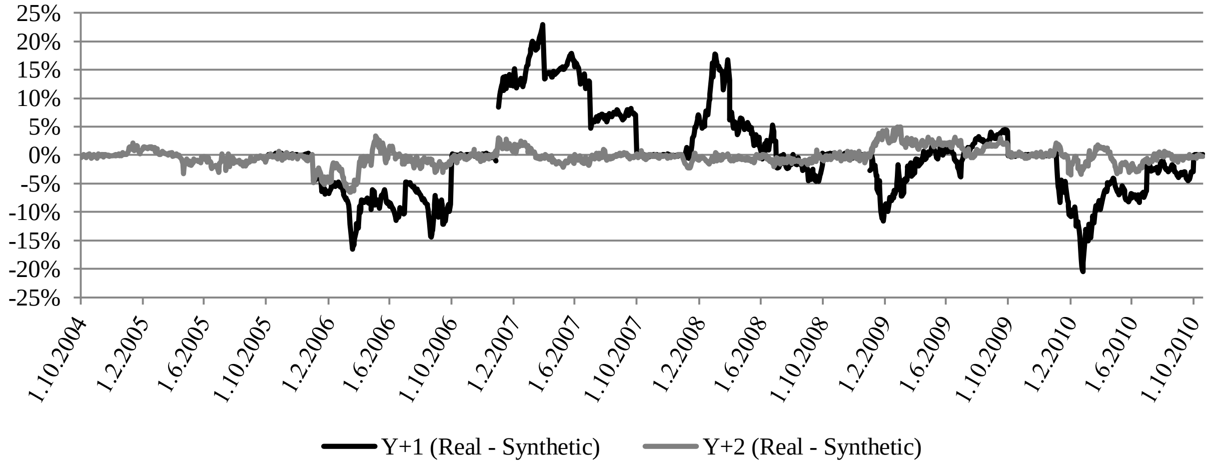
Yearly futures contracts	Price difference: Observed price - synthetic price		Relative price difference: Observed price - synthetic price	
Difference	$F_{t,(Y+1)} - sF_{t,(Y+1)}$	$F_{t,(Y+2)} - sF_{t,(Y+2)}$	$\frac{F_{t,(Y+1)} - sF_{t,(Y+1)}}{F_{t,(Y+1)}}$	$\frac{F_{t,(Y+2)} - sF_{t,(Y+2)}}{F_{t,(Y+2)}}$
Daily price observations	1259	1520	1259	1520
Mean	-0.0246	-0.1320	-0.04 %	-0.25 %
t-statistic	-0.27	-8.54***	-0.18	-6.45***
Median	-0.0434	-0.1150	-0.10 %	-0.27 %
Standard deviation	3.2865	0.6023	7.33 %	1.50 %
Minimum	-8.7963	-2.8666	-20.49 %	-6.54 %
Maximum	9.9014	1.5813	22.92 %	4.95 %
Positive values (%)	43.37 %	34.41 %	43.37 %	34.41 %
Negative values (%)	56.63 %	65.59 %	56.63 %	65.59 %

As may be observed from the Table 11 above, the results are fascinating. When concentrating on the mean and median values, it would seem that the synthetic prices match quite accurately with the observed market prices for both the one- and two-year futures contracts, the relative mean differences being -0.04% for the one-year futures and -0.25% for the two-year futures contracts and the median differences -0.10% and -0.27%, respectively. Thus, at first glance it would appear that the differences between the real market prices and the synthetic prices are rather small, the synthetic prices slightly overestimating the market prices.

However, when further analyzing the summary statistics, it becomes apparent that the story suggested by the analysis of means is not that straightforward as it would appear at the first glance. Unfortunately, the one-sample t-statistic shows that the results are statistically significant only for the 2-year futures contracts, and thus the results for the yearly futures can merely be examined as indicative. Furthermore, the price differences range from -8.80 €/MWh to 9.90 €/MWh in absolute terms for the year-ahead futures, representing variation from -20.49% to 22.92%, and the standard deviation amounts to 7.33% in relative terms. In addition, in over 56 percent of the observations the difference between the observed price and the synthetic price is negative, which further emphasizes the finding that synthetic prices seem to be above the prices observed in the market. With the 2-year futures the variation does not seem to be so dramatic as the standard deviation is 1.50%, and the results are statistically significant at 1% confidence level, the price difference ranging from -2.87€/MWh to 1.58€/MWh in absolute values, representing a relative range from a minimum of -6.54% to a maximum difference of 4.95%. However, the proportion of negative values is even higher than with the one-year futures as the price differential is negative in 65.59 percent of the cases.

The summary statistics thus suggest that the prices of synthetic yearly futures contracts follow the observed prices quite accurately on average, slightly overstating the real prices. Although not statistically significant, the year-ahead synthetic futures prices do not virtually differ from the observed market prices and with the 2-year futures the difference is a quarter of a percent. This would suggest that, on average, the pricing in the market is virtually free from arbitrage opportunities and could thus be termed efficient. However, in the case of the one-year futures the wide scale between the minimum and maximum differences and the high standard deviation casts doubt on the robustness of the results. This is more apparent when examining the standard deviation of the price differences between real and synthetic prices, as it appears that the variation is significantly lower with the 2-year futures than with the year-ahead futures. These findings are clarified by the Figure 18 below, which portrays the relative price difference between the observed real market price and the synthetic price for yearly futures.

Figure 18. Relative price difference between real market and synthetic prices for yearly futures, 2004 - 2010.
The figure illustrates the relative price difference between the observed market price and the synthetic futures price for the one- and two-year futures contracts between 1.10.2004 and 19.10.2010 in percentage points. Y+1 in the graphical illustration denotes $\frac{F_{t,(Y+1)}-sF_{t,(Y+1)}}{F_{t,(Y+1)}}$, and Y+2 denotes $\frac{F_{t,(Y+2)}-sF_{t,(Y+2)}}{F_{t,(Y+2)}}$,. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.



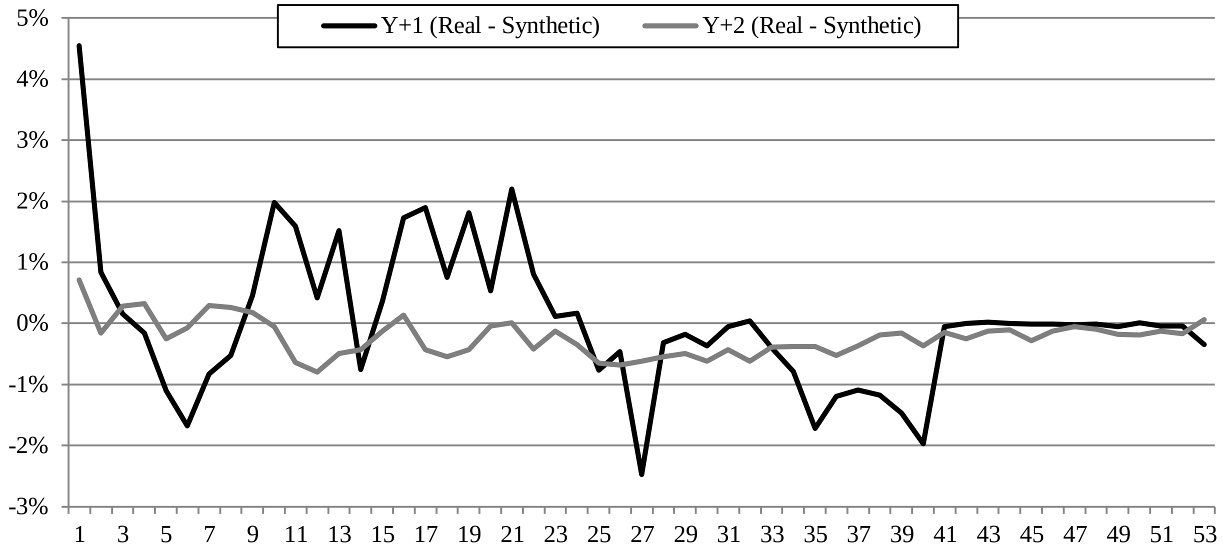
As seen in the figure 18, the difference between the observed market price and the synthetic price for the two-year contract remains relatively stable during the period under examination, but the year-ahead future expresses very high variation, which is not captured in the analysis of means. Furthermore, the graphical examination of the price differences reveals that the price difference for the year-ahead futures seems to express strong seasonality: The price spikes – either positive or negative – occur especially during the spring, which is the time of the year when water reservoir levels are filled by precipitation and melting snow.

This is better visualized in Figure 19 on the next page, which lays out the average price differences between real and synthetic prices throughout the sample period 1.10.2004 – 19.10.2010 by weeks. It can clearly be observed from the figure that whereas the price differences with the 2-year futures contract, organized as weekly averages, stay close to zero, the respective differences for the year-ahead future are more dispersed, peaking on the first week of the year and otherwise mainly clustering on the water inflow season in the spring.

The peak in price discrepancies on the first week of the year might be explained by the market participants rolling over their futures contracts and thus causing the market prices for the year-ahead futures to be above the synthetic prices constructed using quarterly futures, where the hedging adjustment is not that much clustered around the beginning of the year. But the more interesting aspect in the figure is the clustering of price difference peaks on the water inflow season in the spring, which resembles the importance of water inflow for the Nordic electricity market. The weather conditions during water inflow season in the spring strongly affect the water reservoir levels and may have long-standing influence on water reservoir levels and electricity prices, but this also seems to influence the price difference between the year-ahead futures contract and its synthetic counterpart.

Figure 19. Average relative price difference between real and synthetic yearly futures prices from 1.10.2004 to 19.10.2010, categorized by week.

The figure illustrates the relative price difference between real and synthetic yearly futures prices between 1.10.2004 and 19.10.2010 in percentage points, averaged for each week of the year. Y+1 in the graphical illustration denotes $\frac{F_{t,(Y+1)}-sF_{t,(Y+1)}}{F_{t,(Y+1)}}$, and Y+2 denotes $\frac{F_{t,(Y+2)}-sF_{t,(Y+2)}}{F_{t,(Y+2)}}$,. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.



The findings are generally consistent with the analysis of Kristiansen (2007), who uses seasonal contracts[6] to construct synthetic yearly futures contracts. Using a data set between 4.1.1999 and 27.12.2000 for year 2001 contracts, 17.1.2000 – 21.12.2001 for year 2002 futures, and 2.1.2001 – 23.12.2002 for year 2003 contracts, and correspondingly for the seasonal contracts, Kristiansen (2007) concludes that generally the correspondence between the synthetic and observed yearly forward prices is good. Kristiansen (2007) also constructs the synthetic futures incorporating the time value of money and using both monthly and continuous settlements, but arrives to the conclusion that the correspondence with observed and synthetic prices is strongest when the time value of money is ignored.

All in all, the results for the yearly futures contracts seem to imply that on average there is a good correspondence between the observed and synthetic prices, as also concluded by Kristiansen (2007), especially with the 2-year contract. Thus, the analysis suggests that the observed yearly futures prices are, on average, roughly equal to the synthetic futures prices, thus lending – at least

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[6] As explained earlier in this paper, seasonal contracts were traded in Nord Pool since April 2003, but were gradually replaced by quarterly futures first listed in January 2004 (see NASDAQ OMX Commodities Europe, 2012; and Kristiansen, 2007).

to some extent – support to the hypothesis that arbitrage opportunities do not exist – at least systematically. However, some reservations have to be made when interpreting the results, as the high variation in price differences and the high minimum and maximum price differences especially with regards to the year-ahead contracts cast doubt on the generalization of the aforementioned conclusions, and could provide arbitrage opportunities momentarily.

7.5.2. Observed market prices and synthetic prices for quarterly futures

Next, I proceed to analyze the summary statistics for quarterly futures, as Table 12 below presents the summary statistics for the differences between the observed market prices for quarterly futures contracts and the prices for synthetic quarterly contracts, constructed using the daily market closing quotes for monthly futures. In overall, the results for the quarterly contracts are somewhat similar to the yearly futures, although some differences seem to exist.

Table 12. Summary statistics of quarterly observed and synthetic futures contract prices.
The table presents the summary statistics for the price differences between real and synthetic one- and two-quarter futures contracts. The absolute price differences are presented in €/MWh, and the relative price differences on the right-hand side columns are presented as percentage points. The t-statistic presents the one-sample t-statistic for the mean, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.

Quarterly futures	Price difference: Observed price - synthetic price		Relative price difference: Observed price - synthetic price	
Difference	$F_{t,(Q+1)} - sF_{t,(Q+1)}$	$F_{t,(Q+2)} - sF_{t,(Q+2)}$	$\frac{F_{t,(Q+1)} - sF_{t,(Q+1)}}{F_{t,(Q+1)}}$	$\frac{F_{t,(Q+2)} - sF_{t,(Q+2)}}{F_{t,(Q+2)}}$
Daily price observations	1269	1335	1269	1335
Mean	0.7151	0.0109	1.62 %	0.21 %
t-statistic	9.59***	0.13	9.07***	1.15
Median	0.0654	0.0451	0.17 %	0.10 %
Standard deviation	2.6560	2.9462	6.36 %	6.63 %
Minimum	-11.7440	-18.5197	-20.33 %	-37.60 %
Maximum	11.9235	8.9297	32.37 %	22.90 %
Positive values (%)	59.81 %	54.01 %	59.81 %	54.01 %
Negative values (%)	40.19 %	45.99 %	40.19 %	45.99 %

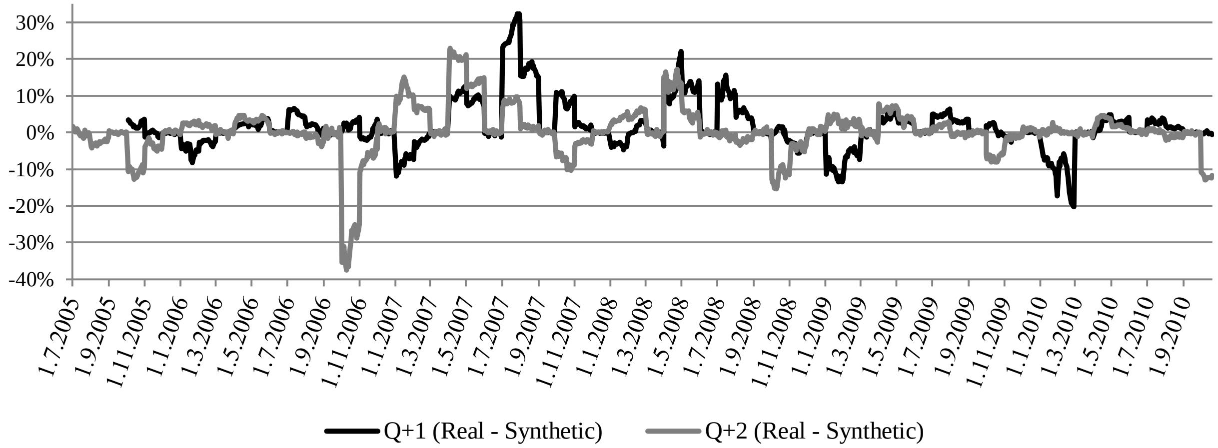
The median differences for the one- and two-quarter futures are 0.17% and 0.10%, respectively, implying no major pricing discrepancies and that the synthetic futures would now slightly understate the real market prices. Interestingly though, the average price difference for quarter-ahead futures is as high as 1.62% (0.72 €/MWh), whereas it is only 0.21% (0.01 €/MWh) for the

2-quarter futures, for which the results are not statistically significant and should thus be interpreted with caution. The minimum-maximum range goes from -20.33% to 32.37% for Q+1 –contracts and from -37.60% to 22.90% for Q+2 –futures, and the standard deviations are 6.36% and 6.63%, respectively. This explains the higher mean difference for quarter-ahead futures, especially when combined with the proportion of positive values: For quarter-ahead futures 59.81% of the observations are positive, i.e. in almost 60% of the cases the observed price is above the synthetic price, whereas for Q+2 futures only 54% of the observations are positive. Thus, it appears that for the Q+2 futures the distribution of price differences is more balanced, also contributing to the close to zero average difference.

The results for quarterly contracts differ from the results for yearly contracts in the sense that the sign of the mean and median differences is positive, suggesting that synthetic prices understate the market prices, contrary to the results from the yearly futures. Also the balance between the amount of observed positive and negative differences has shifted from negative to positive.

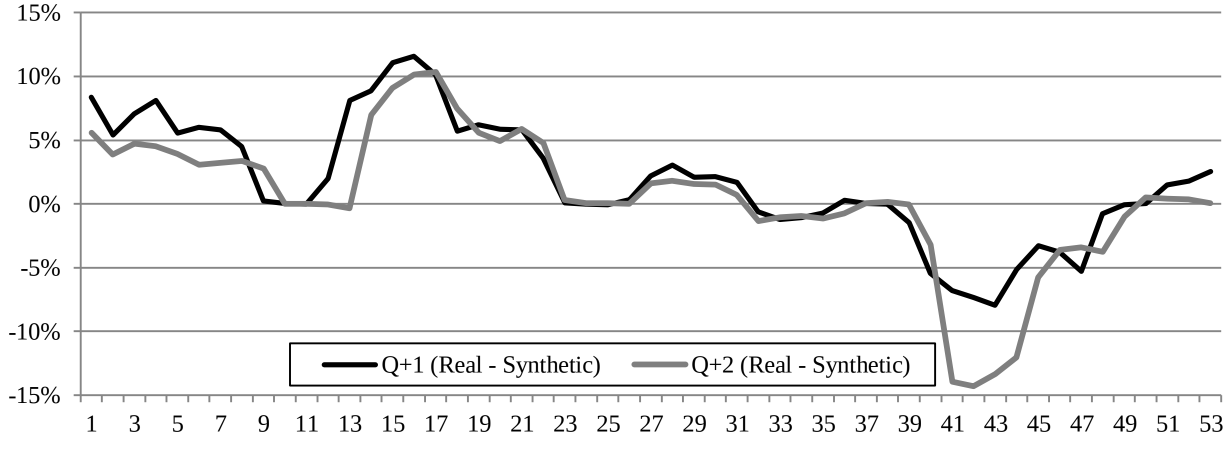
The results from analyzing the summary statistics for the quarterly futures are somewhat ambiguous, and thus do not support the hypothesis that no arbitrage opportunities would exist, even though the median differences documented in the sample do not show that there would be large and consistent over- or underpricing. This is also visible in the Figure 20 on the next page, which shows the development of the relative price difference for one- and two-quarters futures and their synthetic counterparts. Visual examination of the figure shows us that price differences do exist between real and synthetic quarterly futures, but no consistent patterns seem to prevail.

Figure 20. Relative price difference between real market and synthetic prices for quarterly futures
The figure illustrates the relative price difference between the observed market price and the synthetic futures price for the one- and two-quarter futures contracts between 1.7.2005 and 19.10.2010 in percentage points. Q+1 in the graphical illustration denotes $\frac{F_{t,(Q+1)}-sF_{t,(Q+1)}}{F_{t,(Q+1)}}$, and Q+2 denotes $\frac{F_{t,(Q+2)}-sF_{t,(Q+2)}}{F_{t,(Q+2)}}$. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.



The price differences show some signs of a seasonal pattern, which is also visible in the examination of the price differences by their weekly averages, presented in Figure 21 below. As may be observed from the graph, the price differences are of similar sign and magnitude for most of the weeks for Q+1 and Q+2 futures, being positive for the most part of the year and negative in late autumn, increasing back towards and over zero in the end of the year. During the water inflow period in the spring the price differences seem to be positive, i.e. the real prices are on average above the synthetic prices.

Figure 21. Average price difference between real and synthetic quarterly futures prices from 1.7.2005 to 19.10.2010, categorized by week.
The figure illustrates the relative price difference between real and synthetic yearly futures prices between 1.7.2005 and 19.10.2010 in percentage points, averaged for each week of the year. Q+1 in the graphical illustration denotes $\frac{F_{t,(Q+1)}-sF_{t,(Q+1)}}{F_{t,(Q+1)}}$, and Q+2 denotes $\frac{F_{t,(Q+2)}-sF_{t,(Q+2)}}{F_{t,(Q+2)}}$. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.



When comparing these findings to the ones documented by Kristiansen (2007) for the price differences between observed market prices for seasonal futures and synthetic seasonal futures contracts, the results express some similarity. Kristiansen (2007) finds that the synthetic futures' price deviations from the observed market closing prices are on average -0.18%, 0.08% and 0.44% for different seasonal contracts. My results suggest that the median price difference is 0.17% for the Q+1 futures and 0.10% for the Q+2 futures, thus representing similar magnitude as Kristiansen's (2007). However, the results suggest that the average price difference for Q+1 futures is much higher (1.62%), whereas for the Q+2 futures it is 0.21%, only slightly higher than Kristiansen's (2007) findings.

All in all, the comparison of these results for the quarterly futures and Kristiansen's (2007) findings for the seasonal futures should be considered merely indicative, as by definition this is not an apples-to-apples comparison, as the delivery periods for these instruments are different[7]. However, even the indicative comparison of results is important, as Kristiansen (2007) concludes – based on the examination of just the three abovementioned seasonal futures – that the spread between synthetic and real prices appears to decrease over time as the market becomes more mature. The results imply that the spread for the quarterly contracts has not significantly decreased when compared with Kristiansen's (2007) findings, but rather remained in the similar magnitude, as is the case with median differences, or even increased, as the average Q+1 spread suggests. As the sample in this study consists of the quarterly futures prices from 1.7.2005 to 19.10.2010, covering a time period roughly from 1 to 6 years later than Kristiansen's (2007) sample, it can be considered much more comprehensive and to portrait a more mature market. However, the results do not indicate that the pricing discrepancies between the observed and synthetic quarterly futures prices would not be present or that no arbitrage opportunities would exist, thus rejecting – at least for now – Kristiansen's (2007) prediction that pricing inefficiencies would cease to exist over time as the market becomes more mature. This seems not to have been the case, as a market participant consistently selling one-quarter contracts in the market and hedging her exposure by buying a portfolio of monthly contracts and thus constructing a similar

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[7] Quarterly contracts cover a delivery period of 3 months, whereas for seasonal contracts this was different as the three seasonal delivery periods were weeks 1–16 for Winter 1 contracts, weeks 17–40 for Summer contracts, and weeks 41–52/53 for Winter 2 contracts.

but opposite exposure to price changes in the market could have earned a risk-free profit of 1.62%, on average, between 1.7.2005 and 19.10.2010, when ignoring transaction costs.

7.5.3. Observed market prices and synthetic prices for monthly futures

Finally, the summary statistics for the price differences between the observed monthly futures prices and synthetic futures prices, constructed using market closing prices for weekly futures contracts, are presented below in Table 13. It appears that these price differences are more similar to the ones documented for quarterly futures than those for yearly futures, except for the fact that the mean price differences are statistically significant at 99% confidence level for both monthly futures under examination.

Table 13. Summary statistics of monthly observed and synthetic futures contract prices.
The table presents the summary statistics for the price differences between real and synthetic one- and two-month futures contracts. The absolute price differences are presented in €/MWh, and the relative price differences on the right-hand side columns are presented as percentage points. The t-statistic presents the one-sample t-statistic for the mean, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.

Monthly futures	Price difference: Observed price - synthetic price		Relative price difference: Observed price - synthetic price	
Difference	$F_{t,(M+1)} - sF_{t,(M+1)}$	$F_{t,(M+2)} - sF_{t,(M+2)}$	$\frac{F_{t,(M+1)} - sF_{t,(M+1)}}{F_{t,(M+1)}}$	$\frac{F_{t,(M+2)} - sF_{t,(M+2)}}{F_{t,(M+2)}}$
Daily price observations	1319	370	1319	370
Mean	0.8046	0.3501	2.01 %	0.69 %
t-statistic	18.78***	6.03***	18.14***	4.06***
Median	0.3397	0.1143	0.91 %	0.37 %
Standard deviation	1.5560	1.1168	4.03 %	3.27 %
Minimum	-3.2325	-2.1149	-10.62 %	-6.93 %
Maximum	11.4275	4.6669	23.29 %	9.78 %
Positive values (%)	68.08 %	57.57 %	68.08 %	57.57 %
Negative values (%)	31.92 %	42.43 %	31.92 %	42.43 %

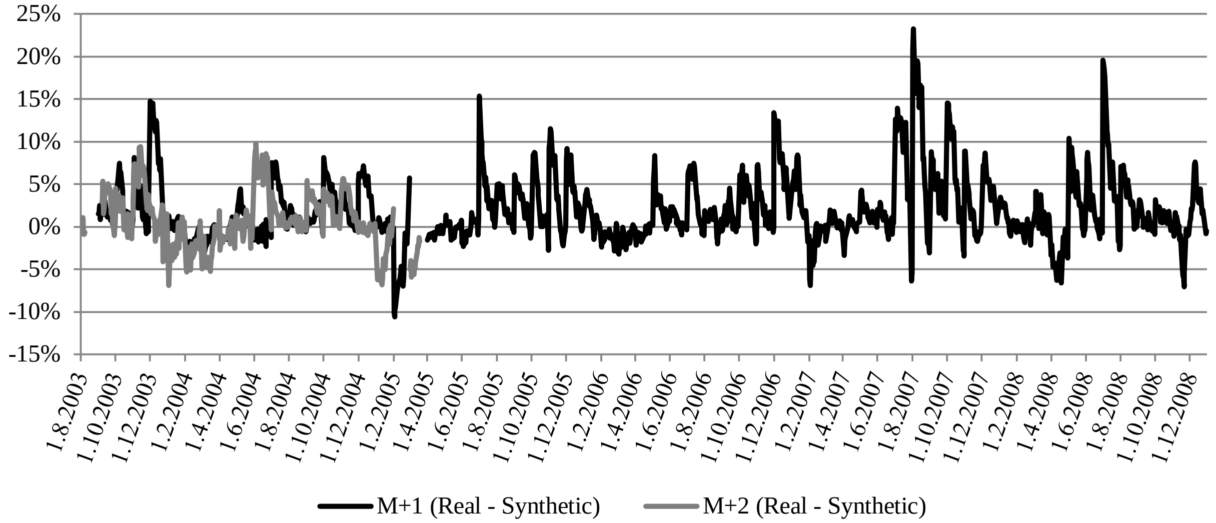
The mean price difference for month-ahead futures is relatively high, 2.01% (0.81€/MWh), and also the median price difference signals the existence of price discrepancies as it is 0.91% (0.34€/MWh). The standard deviation is 4.03% and the price differences range from -10.62% to 23.29%, also expressing high variation in price differentials. Similarly to quarterly futures, a clear majority (68.08%) of the price differences are positive, i.e. the market prices for month-ahead futures seem to be above the time-weighted average of the first four underlying weekly futures prices.

The summary statistics are similar but less extreme for the 2-months-ahead futures, for which the mean price difference is 0.69% (0.35€/MWh) and the median is 0.37% (0.11€/MWh). The standard deviation is smaller than for the month-ahead futures, 3.27%, and also the range between the minimum price difference -6.93% and the maximum difference 9.78% is narrower. Still, almost 58% of the observed price differences are positive, signaling that synthetic futures prices tend to understate the market prices for 2-month futures.

The results for the distribution of positive and negative price differentials are consistent with Wimschulte (2010), who compares 9 actual one-month futures to their respective synthetic futures between 2003 and 2008, and finds that in 58% of all observations the actual futures price is above its synthetic counterpart. However, he finds that, on average, the synthetic prices are 0.16% below the actual futures prices, and thus concludes that the hypothesis of a zero mean price differential cannot be rejected. My results are consistent Wimschulte’s (2010) results about the sign of the price differential, but are contradictory with regards to the magnitude of the price differential, which I find to be on average 2.01% for the 1-month future and 0.69% for the 2-month future. This discrepancy is likely due to the sample size, as Wimschulte’s study only consists of 50 daily price observations, compared to 1319 and 370 daily price observations in my analysis.

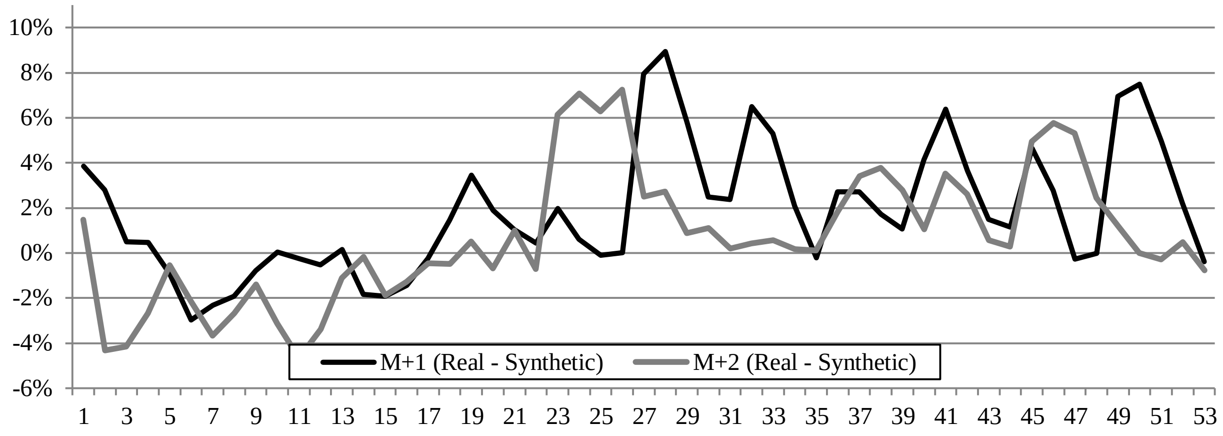
As seen in the Figure 22 on the next page, with monthly futures the price differences express very high variation. When the price differences are averaged by week, as shown in the Figure 23 on the next page, it may be observed that the monthly futures seem to present more positive price differences in the later part of the year. In other words, the real market prices seem to be above the synthetic prices not just most of the year, but especially in the latter part of the year, contradictory to what was observed with the yearly and quarterly futures. Nevertheless, it may be concluded that price differences seem to exist and vary throughout the year, but do not seem to present a distinctive pattern.

Figure 22. Relative price difference between real market and synthetic prices for monthly futures, 2003 – 2008.
The figure illustrates the relative price difference between the observed market price and the synthetic futures price for the one- and two-month futures contracts between 1.8.2003 and 30.12.2008 in percentage points. M+1 in the graphical illustration denotes $\frac{F_{t,(M+1)}-sF_{t,(M+1)}}{F_{t,(M+1)}}$, and M+2 denotes $\frac{F_{t,(M+2)}-sF_{t,(M+2)}}{F_{t,(M+2)}}$. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.



In overall, the statistics show that on average the synthetic monthly futures prices are below the market prices for the examined monthly futures and this also seems to be the case for most of the days. Thus, it is very difficult to argue that price differences would not exist, and therefore opportunities for arbitrage seem to be present in the Nordic electricity market.

Figure 23. Average price difference between real and synthetic monthly futures prices 1.8.2003 - 1.12.2008, categorized by week.
The figure illustrates the relative price difference between real and synthetic yearly futures prices between 1.8.2003 and 1.12.2008 in percentage points, averaged for each week of the year. M+1 in the graphical illustration denotes $\frac{F_{t,(M+1)}-sF_{t,(M+1)}}{F_{t,(M+1)}}$, and M+2 denotes $\frac{F_{t,(M+2)}-sF_{t,(M+2)}}{F_{t,(M+2)}}$. The price data was received from the Economics department at the Aalto University School of Business, originally published by NASDAQ OMX Commodities.



7.5.4. Summary of the price differentials and their economic significance

To summarize these findings in this section, it seems that synthetic futures prices show good correspondence with the observed market prices in the case of yearly futures, which is consistent with the findings of Kristiansen (2007), and some correspondence in the case of quarterly futures, but significantly lower correspondence with regards to the monthly futures, contradicting the results by Wimschulte (2010). These results suggest that the relationship between the real market prices and synthetic prices is more accurate with longer time periods to the beginning of the delivery period and decreases with the maturity of the futures.

A potential explanation could be that the short-term developments in the market environment (e.g. weather conditions, electricity demand and supply, water reservoir levels, coal price etc.) can have a large impact on short-end futures prices, but their effects are diluted towards longer forecasting horizons, on which the short-term shocks in the system do not have significant effect. For example, as shown earlier in Section 7.2. of this thesis, low water reservoir levels, coal price and electricity demand have a significant impact on the electricity spot price and on the short-maturity futures prices, but the impact decreases when the contract maturity increases, which is also reflected in the behavior of the futures premium. This is a natural conclusion, considering that the market participants can assume that current conditions driving the market prices do not prevail for longer periods of time and that, for example, the water reservoir levels can be expected to follow their historical averages on the following year, it is hard to argue that the impact on year-ahead futures would be of similar magnitude as it is for the weekly futures.

This can similarly be viewed to influence the price differences between synthetic and real futures, as the synthetic futures are constructed using a portfolio of shorter maturity futures that are more prone to react to changes in the physical state of the market, thus causing the price deviations to increase for short-maturity contracts.

Hence, in overall it may be concluded that price discrepancies between futures prices observed in the market and synthetic prices do exist, and the price spread increases as the futures’ maturity decreases, being the smallest for yearly futures and largest for monthly futures. These results are similar to the previous analysis by Kristiansen (2007), and thus do not lend support to Kristiansen’s (2007) prediction that these price discrepancies would decrease over time as the market becomes more mature. However, the results contradict the findings by Wimschulte (2010), who finds that for the one-month futures the hypothesis of a zero mean price differential cannot be rejected. Furthermore, Wimschulte (2010) incorporates transaction costs into his analysis, finding that the observed price differentials lack economic significance when transaction fees and bid-ask –spreads are taken into account.

The transaction fees in Nord Pool are volume-dependent (see Nord Pool, 2004; and Wimschulte, 2010), and Wimschulte (2010) estimates them to be below 0.02€/MWh for a combination of buy and sell orders for larger market participants. The transaction fees alone do not explain the price differences between the real and synthetic futures prices, as for example a 0.02€/MWh transaction fee would represent 2% and 6% of the observed mean price difference for the 1- and 2-month futures, respectively. Therefore, the bid-ask –spreads have to also be accounted for, and in his study Wimschulte (2010) examines the bid-ask –spread for his sample of the monthly futures to be on average 0.25 €/MWh, or 0.65% of the futures price, and thus he concludes that the overall transaction costs prevent straight forward arbitrage in the light of his results.

Unfortunately the actual bid-ask –data was not available for this study, but comparing the mean price differences between actual and synthetic futures with the transaction costs, i.e. the combination of transaction fees of a buy and sell order and the bid-ask –spread, totaling 0.70% of the actual futures prices as observed by Wimschulte (2010), can be used as an indicative test for the economic significance of the price differential.

Total transaction costs of 0.70% would prevent an arbitrage with the yearly contracts, as the price differentials are -0.04% and -0.25% for the 1- and 2-year contracts, respectively. This would also be the case for the 2-quarter and 2-month futures with average price differences of 0.21% and 0.69%, respectively. However, the transaction costs of 0.70% of the futures price would not rule out arbitrage opportunities for the 1-quarter and 1-month contracts, where the observed price differentials are 1.62% and 2.01%, respectively. Hence, assuming total transaction costs of 0.70%, arbitrage profits would be available for an arbitrageur using synthetic contracts, representing 0.05€//MWh or 0.92% of the futures price for the front-quarter contract and 0.14€//MWh or 1.31% of the futures price for the month-ahead contract. However, these theoretical arbitrage profits should be considered merely indicative, as no actual data on transaction fees or bid-ask spreads was available for this analysis, and thus the actual transaction costs might differ from the ones reported by Wimschulte (2010).

In conclusion, the hypothesis that futures prices would equal synthetic futures prices cannot be accepted without reservations. With yearly futures the futures prices observed in the market are on average almost equal to the synthetic futures prices, as is also the case with the 2-quarter futures, although the results for the 1-year and 2-quarter futures are not statistically significant. However, with regards to the quarter-ahead and 1- and 2-month futures, the hypothesis cannot be accepted, as real market prices do not equal the corresponding synthetic futures prices. Furthermore, for 1-quarter and 1-month futures the price differential seems to be, on average, greater than the transaction costs used by Wimschulte (2010). This leads to the conclusion that synthetic and actual futures prices in the Nordic electricity market are, on average, not equal with all futures even when accounting for an estimate of the transaction costs, thus opening windows for arbitrageurs to take advantage of the mispricing in the market. However, on average, the economic significance of the arbitrage returns remains quite modest, making their economic significance rather low in comparison to other sources of risk-free returns on the markets.

8. DISCUSSION AND CONCLUSIONS

This thesis studies the existence of the futures premium in the Nordic electricity market, together with analyzing the factors affecting the behavior of electricity spot and futures prices and the futures premium. The analysis is further deepened by testing the forecasting ability of electricity futures over the future spot price, and finally opportunities for arbitrage are examined by comparing futures prices in the market to synthetic futures prices. This section first presents the main findings of the study, proceeding to summarize their implications, and finally concludes with suggestions for future research.

8.1. Main Findings

8.1.1. The existence of a futures premium in the Nordic electricity market

The results presented in Section 7.1 of this thesis show that the basis – i.e. the futures premium – is, on average, nonzero and positive in the Nordic electricity market, ranging from 1.96% to 21.16%, being the smallest for short-maturity futures and increasing with the contract maturity.

Thus, the Nordic electricity market seems to conform a contango-relationship with futures prices above spot prices. This is consistent with the previous findings by Botterud et al. (2002), Mork (2006), Botterud et al. (2010), Gjolberg and Brattested (2011), Lucia and Torro (2011), and Huisman and Kilic (2012). These results imply that the hedging needs between buyers and sellers in the Nordic electricity market are not balanced, but rather suggest that purchasers of power face greater hedging pressure and are willing to pay a premium to the sellers of power for fixing the prices into the future.

8.1.2. The factors affecting electricity spot and futures prices in the Nordic electricity market

The supply of power in the Nordic electricity market is dominated by hydropower, but coal also plays an important role in the market as electricity price is often determined by coal-fired generation either directly or indirectly, as discussed in Secion 2.2. Thus, the influence of hydropower supply and coal price on the electricity spot and futures prices are of particular interest in the Nordic power market.

The results from the regression analysis in Section 7.2. show that coal price has a strong positive relationship with electricity spot and futures prices. Increases in coal price – i.e. in the cost of producing electricity with coal – have a positive relationship with electricity prices, which is consistent with Redl et al. (2009) and Kauppi and Liski (2008). This highlights the role of coal in determining electricity prices in the Nordic market, a dimension often understated by the dominant role of hydropower generation in the region.

As expected, the results also show that deviations from historical water reservoir levels have an inverse effect on electricity spot and futures prices, i.e. above average water reservoir levels that reflect ample supply of cheaper hydropower have a negative relationship with electricity prices and vice versa. These results are consistent with the previous literature on electricity spot and futures prices’ behavior in the Nordic electricity market (see for example Botterud et al., 2002; Botterud et al., 2010; Gjolberg and Brattested, 2011; Lucia and Torro, 2011; Huisman and Kilic, 2012). Hence, it is safe to conclude that water reservoir levels and especially deviations from their historical median levels have an inverse relationship with electricity spot and futures prices.

In addition, the results also show that electricity demand has a positive relationship with electricity prices in the Nordic market, following a natural rationale that prices increase with demand. These results are consistent with the prediction of the theoretical model by Bessembinder and Lemmon (2002), and also lend further support to the findings by Botterud et al. (2010) – that were not statistically significant – that electricity demand is positively related to electricity prices, the results in this thesis being also mostly statistically robust.

Furthermore, the results also show that the influence of water reservoir level deviations from historical median levels, coal price, and electricity demand on electricity prices seems to decline when the time to maturity of the futures contract increases, presenting the strongest influence on short-maturity contracts and the smallest impact on long-maturity contracts. This is a natural result, as short-term developments in water reservoir levels, coal price and electricity demand can be assumed not to prevail for longer periods of time, which also seems to be reflected in futures pricing in the market.

8.1.3. The factors affecting futures premium in the Nordic electricity market

Contradictory to my original hypothesis, the influence of the physical factors in the market – i.e. water reservoirs, coal price and electricity demand – on futures premium are opposite to their effects on electricity prices. This is because their influence is greater for the shorter maturity instruments than for the contracts with longer maturities, resulting in an inverse relationship with the futures premium compared to their effects on electricity prices.

Hence, deviations from historical water reservoir levels are actually positively correlated with the futures premium, and coal price exhibits a negative relationship with the futures premium similarly to electricity demand. Furthermore, the relationship between these physical factors and the futures premium seems to increase with contract maturity, inversely to what was observed with their impact on electricity prices. These results are natural, when considering that the futures premium represents the price difference between the current futures price and the spot price. This emphasizes how the volatility of these physical factors affects the market, suggesting that temporary changes in the physical state of the system have a greater influence on short-term prices than on the long-term prices.

8.1.4. The forecasting ability of electricity futures

The results presented in section 7.4. of this paper show that electricity futures in the Nordic electricity market possess forecasting power over the future electricity spot price, and the results are statistically significant for futures contracts in all maturities. Thus, the results lend strong support to the findings presented by Huisman and Kilic (2012), providing further evidence on the forecasting power of electricity futures in the Nordic electricity market. On a more general level, the results are also in accordance with Fama and French (1987), who found that the futures basis contains power to forecast the future spot price in commodities with high perishability or high storage costs relative to their value.

Furthermore, the results in section 7.5. of this thesis present no evidence of time-varying risk premiums in the Nordic electricity market, which is also consistent with the findings of Huisman and Kilic (2012).

8.1.5. Comparison of real and synthetic electricity futures prices

The comparison of synthetic futures' prices with futures prices observed in the market in section 7.5. shows that these price discrepancies are different for contracts with different maturities. For yearly futures the results are consistent with the previous research by Kristiansen (2007) as the synthetic futures prices show good correspondence with the observed market prices, the deviations at maximum being around 25 basis points on average. This price difference is greater for the quarterly futures, observed futures prices being on average 0.21% to 1.62% above the synthetic prices. With monthly futures this average price difference is as high as 2.01% for the month-ahead future and 0.69% for the 2-month contract, suggesting that opportunities for arbitrage would exist in the Nordic market, contradictory to Wimschulte (2010). However, when incorporating an estimate of transaction cost into the analysis, it appears that only 1-month and 1-quarter contracts exhibit large enough price discrepancies to yield an arbitrage profit. On a more general level, transaction costs above 2 percent would mean that, on average, no opportunities for arbitrage would exist in the Nordic market.

These results also indicate that the relationship between the real market prices and synthetic prices is more accurate with longer time periods to the beginning of the delivery period, decreasing with the maturity of the futures. This might be attributable to the behavior of the electricity prices and the futures premium discussed in the previous section, i.e. because the factors affecting the electricity prices have a larger impact on the short-maturity contracts than on the longer-maturity futures.

All in all, the results suggest that although there seems to be a rather good correspondence with actual and synthetic futures prices in the Nordic electricity market on average, the existence of opportunities for arbitrage cannot be ruled out even with the inclusion of transaction costs. However, the economic significance of the arbitrage profits is rather small, and larger profits could probably not be realized with the current trading volumes or without affecting the market prices, but at least on paper some arbitrage opportunities seem to be present in the market, although their economic significance is relatively low in comparison to other risk-free sources of return available in the financial markets.

8.2. Conclusions and implications

On a general level, the findings in this thesis provide information on the fundamentals in the Nordic electricity market. The role of the marginal production method or coal price in influencing the electricity spot and futures prices and the futures premium in the Nordic market has received little attention in the previous literature, and I contribute to shed light on the role of coal price in determining electricity prices the Nordic market.

The findings in this thesis show that coal price has a relatively large influence on electricity spot and futures prices, and thus, it may be concluded that it is of at least equal importance to market participants to examine coal price developments and the factors affecting it than it is to follow the hydro reservoir level developments. Even though the majority of the electricity in the Nordic market is produced by the dominant hydropower, at the end it is the marginal cost of power generation that determines the electricity price in the market, and therefore coal price also plays an important role in the market as the marginal electricity price is often determined by coal-fired generation either directly or indirectly.

The results also provide further support to the generally accepted view that water reservoir levels have a negative influence on electricity prices in the Nordic market and that the overall electricity demand has a positive influence on electricity prices. Furthermore, the results show how the magnitude of the impact of the physical factors on electricity prices decreases when the contract maturity increases. Therefore it becomes important for a market participant to account for these fundamental variables and their behavior when considering different purchase or supply strategies and their timings – especially because the behavior of some of these variables could possibly be predicted with econometrical models. Water reservoir levels seem to follow similar seasonal patterns over time, as also does the temperature – a key component in determining electricity demand levels – and industrial power demand is driven by economic activity. There is ample of data available on these factors, and an informed market participant could potentially benefit from combining these features into the power purchase or sales strategy.

In addition, the findings in this thesis show that the futures premium on average is positive, suggesting that the hedging demand in the electricity market is unbalanced so that it is higher on the purchaser-side than on the power generator-side, contributing to the positive futures premium. From the purchasers' perspective this can be seen to incur a cost that inflates their cost of power by 1.96% to 21.16% on average, depending on the hedging strategy and the maturities of contracts used in hedging. If the long-term average cost of hedging is on this range, a question arises whether it is economically reasonable. Discussions with practitioners revealed that most of the hedging on the buy-side is conducted using long-term futures contracts, which according to my findings seem to have the largest futures premiums – a natural result, as the forecasting horizon is long and especially if the hedging demand is higher in these maturities. From a speculators' point of view, on the other hand, this can be seen as an opportunity to earn profits by assuming the risks of price spikes on behalf of the power purchasers, which would call for comprehensive understanding about the fundamentals driving the electricity prices in the market in order to price these risks correctly.

Furthermore, as the results also suggest that futures contracts in the Nordic electricity market possess forecasting power over the future spot price, this underlines the information content in electricity futures, thus implying that practitioners could use the futures prices in their estimations of electricity price developments in the future.

Finally, synthetic futures contracts present opportunities both from purchasers' and speculators' viewpoints. Purchasers of power can use synthetic futures to decrease their average hedging costs, as my results show that monthly and quarterly synthetic futures prices with exactly the same exposure as the real futures, are 0.69% - 2.01% below the actual futures prices. From a speculator's perspective the highly variable price differences between real and synthetic futures prices as well as the long-term average price difference might open up windows for arbitrage, if the transaction costs remain below the available arbitrage profits. Unfortunately, I was unable to conduct a more detailed analysis on these strategies due to the lack of bid-ask and trade volumes data, and therefore I leave it for future research to study in a more detail.

8.3. Suggestions for further research

The focus of this thesis is in analyzing the relationship between the electricity futures prices and the Nord Pool system price, and the factors affecting their behavior. Thus, the behavior of electricity prices on a regional level or in different countries in the Nord Pool region – that all have their own characteristics with regards to temperature, electricity demand and supply structure, and the proportion of imports of electricity – has not been examined in a more detail. Therefore a further examination of the influence of congestion in transmission capacity on regional electricity prices and contracts for difference (CfDs) would be a welcome addition to the existing literature.

In addition, the trading applications and strategies that were originally planned to be tested in this thesis were not conducted due to the lack of bid-ask price data and trading volume data. Access to this data would enable a detailed analysis on whether the windows for arbitrage that open due to price differences between real and synthetic futures prices could actually be utilized with sufficient volumes and prices to earn a risk-free profit, or are these price deviations that occur on paper inaccessible for practitioners in the market. Furthermore, combining temperature and weather derivatives data to the data about the physical state of the market - i.e. water reservoir levels, electricity demand, coal spot and futures prices - could be helpful in further examining the electricity market behavior, and also possibly help in forecasting electricity spot and futures price developments.

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