PRICING OF ELECTRICITY FUTURES BASED ON LOCATIONAL PRICE DIFFERENCES: EMPIRICAL EVIDENCE FROM FINLAND

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ABSTRACT

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Abstract

Competitive electricity markets in a particular geographical area usually have a reference spot price representing the benchmark price level of the wholesale electricity, and setting the underlying price for derivatives market. However, due to physical transmission congestion local prices may differ substantially from the reference price. In the Nordic market Electricity Price Area Differentials (EPADs) are used to hedge the basis risk between a bidding area and the Nordic reference (system) price. In this thesis I analyze the relationship between Finnish EPADs and the underlying area price difference for the Finnish bidding area. Since electricity is a non-storable commodity, common view is that an appropriate pricing model for electricity futures is based on the expected spot price and a risk premium instead of storage and convenience yield. First, I compute the monthly ex-post bias of Finnish monthly EPADs from January 2006 to January 2016. Second, I attempt to resolve whether the bias can be attributed to a risk premium or market inefficiency. The results imply that on average the futures prices before the delivery period have exceeded the Finnish area spot price difference in the respective delivery period. However, the bias seems to vary between seasons, and is significantly different from zero only when excluding extreme observations of winter 2009 - 2010 from the sample. Both risk considerations and market inefficiency seem to explain the bias. I document little support for the findings of previous studies that have linked the bias to different kind of risk proxies, but find some evidence that the bias has increased after 2012. This could be attributed to the decrease in Russian imports, which may have widened the imbalance between electricity consumers and generators that naturally hedge the Finnish area price leading to a positive premium in the futures market. Finally, I document bi-directional causality between the Finnish area price difference and the EPADs, which could hint that the bias may also be influenced by a somewhat inefficient, backward-looking futures market.

futures, electricity futures, EPAD, Nordic electricity market, locational price difference

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Tiivistelmä

Tietyn maantieteellisen alueen kilpailullisilla sähkömarkkinoilla on yleensä viitespot-hinta, joka kuvastaa yleistä hintatasoa tukkumarkkinalla, ja jota käytetään johdannaisten viitehintana. Paikallisten markkinoiden hinnat saattavat kuitenkin poiketa tästä viitehinnasta siirtoyhteyksien rajallisuuden takia. Pohjoismaisilla sähkömarkkinoilla ns. systeemi- ja tarjousalueen aluehinnan väliseltä basis-riskiltä suojaudutaan ns. aluehintaero-johdannaisilla (eng. Electricity Price Area Differential, EPAD). Tutkin tässä pro gradu-työssä Suomen tarjousalueen EPAD-tuotteiden ja vastaavan aluehintaeron yhteyttä. Koska sähkö ei ole varastoitavissa, yleisen näkemyksen mukaan sopiva sähköfutuurien hinnoittelumalli perustuu odotuksiin tulevasta spot-hinnasta ja riskipreemioon ns. convenience yieldin ja varastoteorian sijasta. Ensin lasken toteutuneen kuukausittaisen futuuriharhan Suomen kuukausi-EPAD:eille tammikuusta 2006 tammikuuhun 2016. Tämän jälkeen pyrin selvittämään, aiheutuuko harha riskipreemiosta vai markkinoiden tehottomuudesta. Tulosten mukaan EPAD-futuurien hinnat ennen toimituskuukauden alkua ovat olleet keskimäärin korkeammat kuin toteutunut aluehintaero. Harhassa näyttää kuitenkin olevan kausivaihtelua ja se poikkeaa tilastollisesti merkitsevästi nollasta ainoastaan, kun havaintoaineistosta jätetään pois 2009 – 2010 talven selvästi poikkeavat havainnot. Sekä riskinäkökulma että markkinoiden tehottomuus näyttävät selittävän harhaa. Havaitsen vain vähän tukea aikaisemmille tutkimuksille, jotka ovat löytäneet yhteyden harhan ja erilaisten riskiä mittaavien muuttujien välillä. Sen sijaan löydän jonkin verran tukea sille, että harha on kasvanut vuoden 2012 jälkeen. Tämä voi johtua vähentyneestä sähköntuonnista Venäjältä, mikä on saattanut kasvattaa liiketoimintaansa suojaavien sähkön tuottajien ja kuluttajien välistä määrällistä epäsuhtaa johtaen positiiviseen preemioon futuurimarkkinalla. Tulokset myös osoittavat EPAD-hintojen ja aluehintaeron välillä olevan kaksisuuntainen kausaalisuus, mikä kielii siitä, että harha voi johtua jossain määrin tehottomasta, historiaa peilaavasta futuurimarkkinasta.

futuuri, sähköfutuuri, pohjoismainen sähkömarkkina, aluehintaero

Säilytyspaikka Jyväskylän yliopiston kauppakorkeakoulu

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1 INTRODUCTION

Electricity markets around the world have undergone a wave of deregulation and liberalization since the 1990s. The Nordic electricity market is a typical example of this development. In the Finnish and Nordic markets vertically-integrated monopolies, that used to manage production, transmission and sales of electricity, have been restructured. Nowadays production and sales operate under free competition, while nation-wide transmission and communal-level distribution networks remain regulated natural monopolies. For academic research the restructuring has provided an interesting new research theme. Spodniak et. al (2014) note that market power and efficiency of restructured wholesale and retail markets have been studied quite extensively (see for example Fridolfsson and Tangerås (2009), Hellmer and Wårell (2009), Giuletti et. al (2010), Lehto (2011) and Borenstein & Bushnell (2015)).

Natural extension to restructured wholesale markets has been the development of derivatives markets, since electricity is a homogenous commodity in a given geographical area with sufficient transmission network and capacity and similar power system. Well-functioning derivatives market is of high importance for market participants, since electricity is practically non-storable, and hence subject to extreme price volatility. Similar to retail and wholesale markets, pricing of derivatives written on different reference prices has gained notable academic interest. The focus of research has unsurprisingly been on the derivatives in the largest and most mature markets, such as the ones in particular states in the U.S., the Nordic countries, and Germany/Austria. These are studied in Bessembinder and Lemmon (2002), Redl, Haas, Huber & Böhm (2009), Gjolberg and Brattested (2011), and Fleten and Hagen (2015) among others.

Due to physical transmission congestion local prices may, however, differ substantially from the reference prices leading market participants to incur locational basis risks. The Nordic market has been divided to 15 bidding areas based on transmission capacities between the areas, and Finland composes one area. Electricity Price Area Differentials (EPADs) are used to hedge price differences between a bidding area and the Nordic system price.

Marchoff and Wimschulte (2009) note that explicit exchange-listed derivatives on the area prices do not exist, since the market was designed on purpose so that overall liquidity would not split among several products. In the bidding areas where area prices differ significantly from the system price hedging has to be done with two separate contracts, which together yield an implied futures contract on the area price, that is using 1) a futures contract based on the system price and 2) futures contract, commercially known as an EPAD, based on the area price difference.

Contrary to futures on electricity reference prices, such as the Nordic system price, literature on EPADs is scarce. To my knowledge only three papers (Marchoff and Wimschulte, 2009; Kristiansen, 2004a; Kristiansen, 2004b) on

EPADs pricing have been published in recognized journals. More recently EPADs have been studied by Spodniak et. al (2014) and Spodniak (2015) in conference papers. The main contribution of my thesis is to provide additional literature on EPADs pricing. All the previous studies have focused on the relationship between EPADs and respective area price difference or the ex-post futures premium, and I also follow that approach in my thesis. However, unlike Marchoff and Wimschulte (2009) Spodniak et. al (2014) or Spodniak (2015) this thesis attempts to link the ex-post futures premium of EPADs also to abnormal supply and demand conditions as has been done in the previous, more general electricity futures literature.

1.1 Research motivation, problem and scope

Electricity prices (and associated costs) are of particular importance to the competitiveness of Finnish economy due to Finland's cold climate and energy-intensive industry's large share of GDP that cause Finland to have one of the largest energy intensities (the ratio of gross inland energy consumption to GDP) in EU[1].

Electricity spot price in Finland has differed substantially from the Nordic system price. For example in 2015 Finnish monthly area spot price exceeded the Nordic system spot price on average by 54.6% exposing a Finnish market participant to significant basis risk. As can be seen from table 1, the year 2015 was certainly no outlier; between 2006 and 2015 the system price and the area spot prices of Norway, Sweden and Denmark have been on average by 10.47%, 5.97%, 10.72% and 2.86% lower than the spot price in Finland, respectively. Furthermore, the Finnish area price difference has widened during the last years.

A natural question for the Finnish market participants is whether the area price differences are reflected in the EPAD prices. Self-evidently, this question is of interest for market participants hedging future electricity consumption, and generation. Speculators alike are interested to discover whether there are profitable trading strategies to be exploited.

Prices of derivatives have also wider ramifications. In a market economy they provide price signals, which are essential for an efficient allocation of resources. Applied to EPADs the prices could, for example, provide signals for investments in transmission capacity, or production planning of energy-intensive industry or electricity generators.

Regulatory point of view has to be considered as well. EU is harmonizing the European electricity market, and EPADs are under review. Regulators are inclined to discover, whether EPADs can efficiently be used to hedge against the area price difference, or should there be established an alternative market

[1] European Energy Agency: http://www.eea.europa.eu/data-and-maps/indicators/total-primary-energy-intensity-2/assessment

structure, where transmission system operators (TSOs) would for example issue financial transmission rights (FTRs) (Spodniak et. al, 2014).

TABLE 1 Annual spot prices (€/MWh) (system (SYS), Sweden (SE), Finland (FI), Norway (NO) and Denmark (DK)) and the relative average differences compared to Finland. Swedish, Norwegian and Danish prices are computed as averages of the area prices within the countries. (Nord Pool)

	SYS	SE	FI	NO	DK
2006	48.59	48.12	48.57	49.10	46.36
2007	27.93	30.25	30.01	27.64	32.71
2008	44.73	51.12	51.02	44.93	56.54
2009	35.02	37.01	36.98	34.64	37.97
2010	53.06	56.82	56.64	55.05	51.72
2011	47.05		49.30	46.80	48.69
2012	31.20	32.51	36.64	30.30	36.95
2013	38.10	39.44	41.16	38.17	39.29
2014	29.61	31.59	36.02	29.37	31.41
2015	20.98	21.81	29.66	20.40	23.70
Aver. diff.	-10.47 %	-5.97 %		-10.72 %	-2.86 %

Following this motivation, I attempt to shed light on the following issues:

- how large is the futures bias for Finnish EPADs, or how biased forecasts do the EPAD futures prices provide for the realized difference between the Finnish area and the Nordic system price?
- which market factors can help to explain the observed bias, or alternatively expressed, is the observed bias a consequence of market inefficiency, a risk premium, or a combination of them?

The scope of this thesis is limited to the relationship between the Finnish EPADs and the underlying Finnish area price difference, since as described earlier Finland has had considerably higher area price difference than the rest of the three Nordic countries. Thus I do not study EPADs of other bidding areas. Nor do I examine the explicit formation of the underlying area price difference.

1.2 Theoretical framework, methodology and data

Commodity futures are conventionally priced based on no-arbitrage condition between the spot and futures market, or assuming that futures price has to be equal to the price of a replicating portfolio. However, electricity is non-storable and therefore markets are incomplete. Hence, expectations theory is most often used to price electricity futures. It states that prior to maturity, the futures prices converge to the risk-adjusted expected future spot price. (Hull, 2009; Vehviläinen, 2002)

In this thesis I first compute the ex-post future bias for monthly Finnish EPADs or the difference between the realized area spot price and futures price for the corresponding delivery period. The sample period consists of monthly observations between January 2006 and January 2016. Futures price data were obtained from a third party that have received it from Nasdaq OMX Commodities exchange, whereas spot prices were obtained from Nord Pool, the physical power exchange in the Nordic market.

As discussed by Fama & French (1987) and Gjolberg and Brattested (2011) among others, the observed ex-post bias may result from a risk premium, market inefficiency or forecast errors. In order to shed light on the determinants of Finnish EPAD futures bias, I use similar ordinary least squares regressions as the authors that have examined the bias of electricity futures written on reference prices in larger markets. The set of explanatory variables includes water reservoir levels and temperature that proxy for supply and demand conditions, as well as skewness and variance of the area price difference that can be regarded as alternative proxies for risk.

1.3 Findings

The results imply that on average there has been a positive bias in monthly Finnish EPADs, or that the futures price before the delivery period has exceeded the spot price difference in the respective delivery period. However, the bias is significantly different from zero only when excluding extreme observations from the sample. Furthermore, the bias seems to exhibit seasonality being highest during autumn and winter, and lowest and even negative during summer.

Both risk considerations and market efficiency seem to explain the bias. I document little support for the findings of Bessembinder & Lemmon (2002) or Marchoff and Wimschulte (2009), but find some evidence that the bias has increased after 2012. This could be attributed to a 63% decrease[2] in Russian imports, which may have widened the imbalance between electricity consumers and generators that naturally hedge the Finnish area price leading to a positive premium in the futures market. Finally, I document a feedback mechanism or bi-directional causality between the Finnish area price difference and the EPADs, which could hint that the futures market may be inefficient to some extent.

The rest of this thesis is organized as follows. In chapter two I present an overview of the Nordic market. Chapter three provides theoretical framework of my thesis and presents previous empirical literature. Chapters four and five describe the data and methodology I utilize in this thesis, while chapter six exhibits and discusses the results. Finally, chapter seven concludes and provides suggestions for future research.

[2] Computed as the relative change between the average monthly import from the periods 2006 - 2011 and 2012 - 2016. See figure 12.

2 OVERVIEW OF THE NORDIC ELECTRICITY MARKET

In this chapter I provide an overview of the Nordic electricity market, in which Finland is included. First, I explain briefly the history of the common market, since it is useful to understand how it was formed, and which major changes have occurred after the introduction. Second, I describe the current market structure, which can be divided to short-term physical and longer-term financial market. This provides for example the details needed to understand how reference spot prices are formed, how financial derivatives are traded and what kind of products there are available as well as how trading volumes for specific products have evolved. The last two sub-chapters discuss the fundamentals of the Nordic, and Finnish markets. This is useful reference for the empirical section, and guides the selection of exogenous variables in the empirical models.

2.1 Brief history

History of the common Nordic market dates back to 1991, when Norway deregulated its wholesale electricity market. This formed a model for Sweden, Finland, and Denmark, that joined the common exchange Nord Pool, in 1996, 1998 and 2000, respectively. Estonia, Lithuania and Latvia joined the exchange in 2010, 2012 and 2013, and in 2014 Nord Pool was coupled with Western European spot markets. In practice this implies that a single algorithm is used to compute spot prices across the involved exchanges and to allocate cross-border capacities. Currently the physical exchange is owned by the Nordic and Baltic transmission system operators (TSOs). (Nord Pool, 2015a and b)

The first financial contracts on the system price were introduced in 1997, while trading of EPADs, or CfDs (contracts for differences) as they were called then, were launched in 2000. In 2002 the physical and financial exchanges were demerged into separate companies, and in 2008 the financial exchange was acquired by Nasdaq OMX and merged into Nasdaq OMX Commodities (Nasdaq OMX, 2015).

2.2 Wholesale markets in the Nordic countries

Wholesale markets in the Nordic countries can be divided into the short-term physical market, and the longer-term financial market. Market participants in the physical market include retailers and large industrial consumers, generators and trading houses. They have to be physically connected and to have a balance agreement with the TSO in the bidding area they are residing, as the physical market balances supply and demand of electricity at every instant.

Figure 1 exhibits the different markets and their relation to the electricity supply and purchase. In the day-ahead spot market participants purchase and sell electricity for each hour for the next day according to their preliminary supply or consumption plans, which yields the spot prices for each hour. In the secondary market trading is continuous, and participants can manage unanticipated imbalances or optimize their supply or purchase plans up to an hour before a delivery hour. Finally, the ancillary market maintained by the TSOs balances the power system in real-time, maintains system security and yields balance prices, which are used in settling imbalances, i.e. the difference between actual generation (consumption) and electricity sold (purchased). The TSO of Finland is Fingrid.

The financial market in turn allows market participants to hedge their generation or consumption in longer-term and provides market access also to financial players, such as banks or hedge funds.

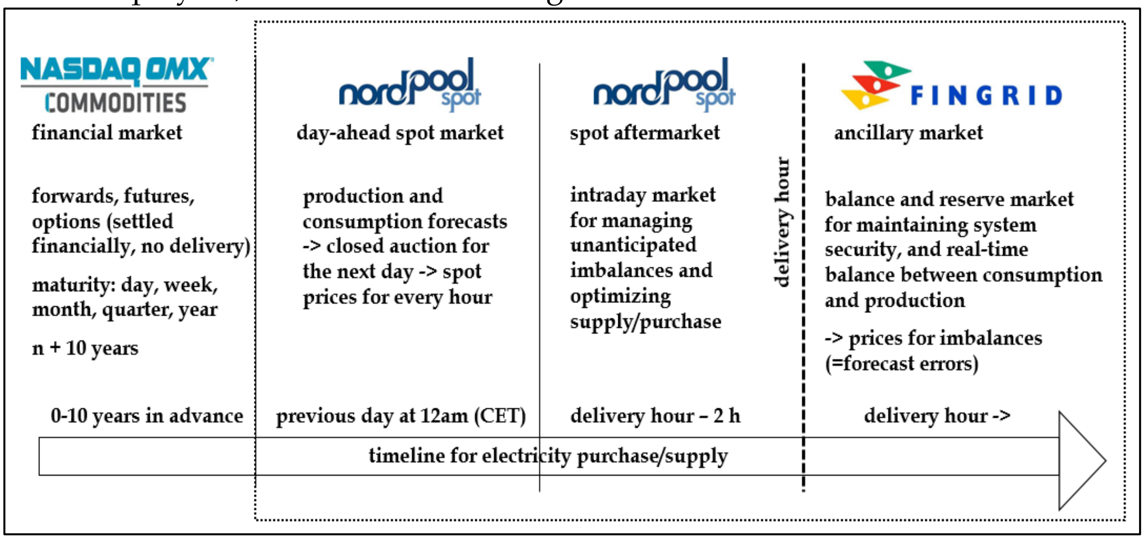

FIGURE 1 Different markets in the Nordic model. Nord Pool (2015c, p 16-17), Nasdaq OMX (2016), Fingrid (2016)

The Nordic market is one of the largest and was among the first liberalized electricity markets. Moreover, measured by generation capacity, four largest producers owned 50% of the generation capacity in 2013 (NordReg, 2014, p. 34). Consequently, efficiency and exploitation of market power in it have been intriguing objects of empirical research[3]. Bask, Lundgren and Rudholm (2011, 1035) find evidence of "small, but statistically significant market power", which however has decreased as the market has expanded, while Fridolfsson & Tangerås (2009) review numerous empirical studies on the market power in the Nordic market and conclude that there seems to be no evidence of system-wide

[3] This discussion refers to the efficiency and market power in the physical market. The efficiency of the financial market is discussed in chapter 3.

exploitation of market power by generators. However, they note that transmission congestion may yield regional market power.

2.2.1 Physical market

This thesis focuses on the Finnish area price difference, and futures written on it. Thus, within the physical market I only cover the day-ahead market and will not discuss further the aftermarket and the ancillary market.

Trading in the day-ahead physical market can be done bilaterally in OTC or in Nord Pool. Figure 2 depicts trading turnover in Nord Pool Spot divided by the consumption in the common market from 1997 to 2013. The share of trading via exchange has been increasing and in 2013 nearly 90% of the total consumption was traded through the Nord Pool.

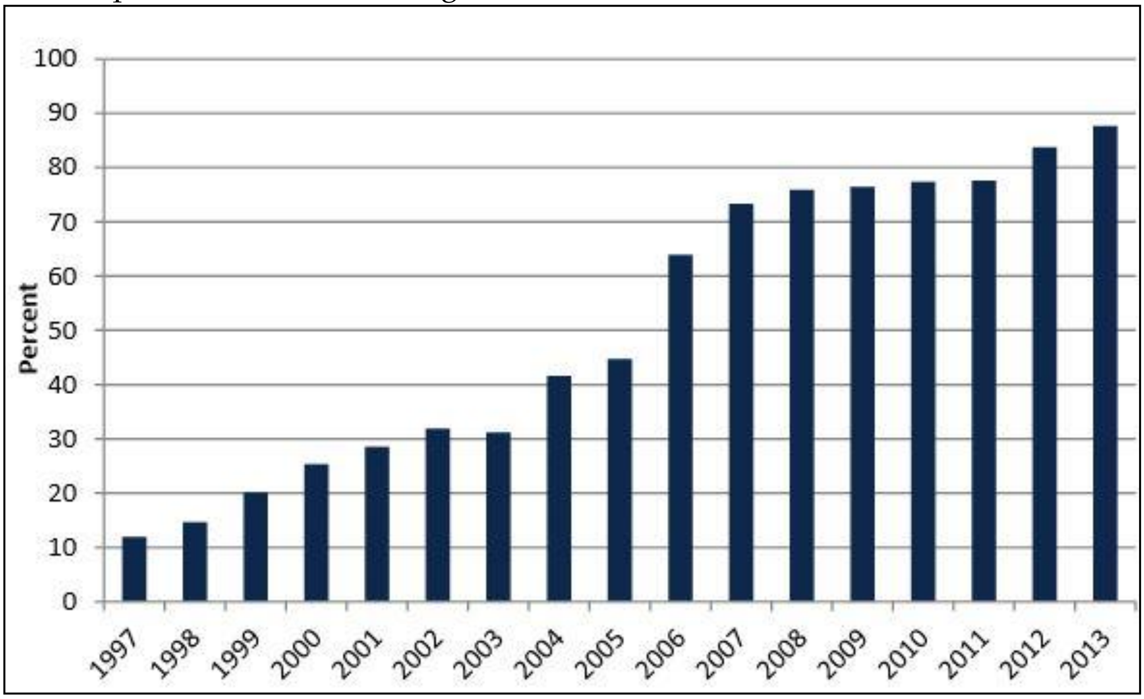

FIGURE 2 Turnover/consumption in Nord Pool. (NordReg 2014, 36)

The physical spot market is operational 365 days in a year and produces spot prices for each hour. Over 300 market participants from the Nordic and Baltic countries submit daily their bids to Nord Pool before 12:00 CET. Bids are like individual demand and supply curves: they reveal the quantity demanded and supplied at a given price. Nord Pool aggregates the bids to market-wide supply and demand curves for each hour and spot price clears off the market. The individual orders are fulfilled if price at which quantity demanded (supplied) is above (below) the spot price. This procedure is repeated for each hour yielding a spot price for every hour, and results for the next day are published normally before 13:00 CET. Daily, weekly, monthly, quarterly and annual spot prices are computed as simple averages from the hourly prices.

The system price is computed from the aggregated supply and demand curves assuming no transmission constraints yielding a reference price for the whole Nordic area. In a competitive market the clearing spot price then represents the marginal cost of the last generation unit needed to meet the given, highly inelastic demand (figure 3). The characteristics of supply and demand in the Nordic market are elaborated in chapter 2.3.

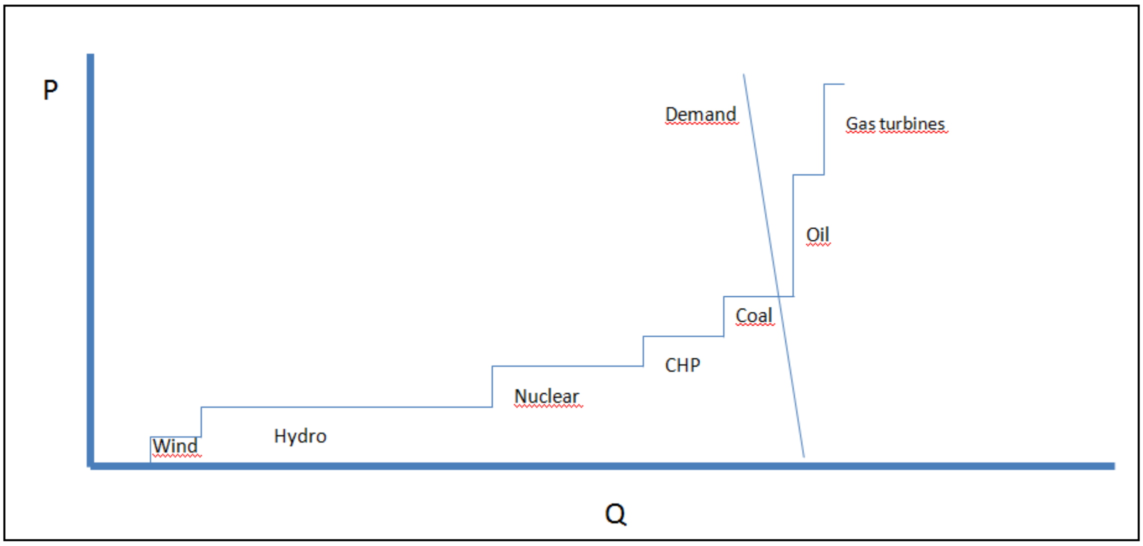

FIGURE 3 A stylized illustration of the so called merit order: the spot price equals the marginal cost of the last generation unit needed to meet the demand on a given hour.

The area spot prices are computed similarly for each hour but now the exchange aggregates the orders only for each bidding area, and takes into account the available transmission capacity, which is determined by the TSOs. The flow of power is directed from the surplus (lower price) area to deficit (higher price) area and the transmission capacity between them is utilized to the maximum: aggregated supply (demand) curve in the deficit (surplus) area is shifted parallelly right to the extent of maximum transmission capacity, which increases (decreases) the price in the surplus (deficit) area. If transmission computed by Nord Pool exceeds the available capacity set by TSOs for example from SE1 bidding area to Finland, higher spot price clears the Finnish market. Conversely, if the computed flow of power in all areas is within the limits set by TSOs, then the entire market has one common price, called the system price. (Nord Pool, 2015b)

The formation of area spot prices is depicted in figure 4 whereas figure 5 presents the bidding areas as well as maximum transmission capacities between the areas.

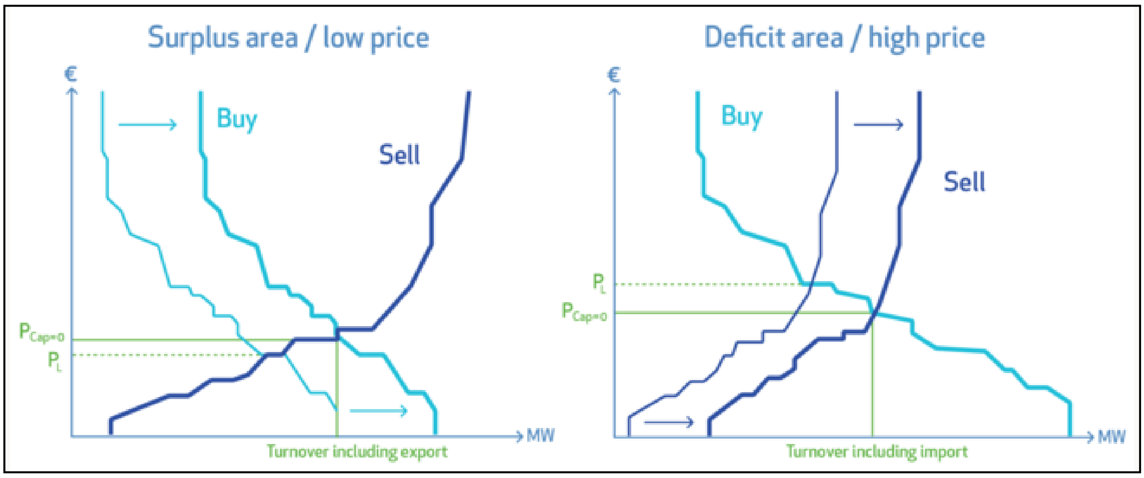

FIGURE 4 Formation of area prices. (Nord Pool, 2015b)

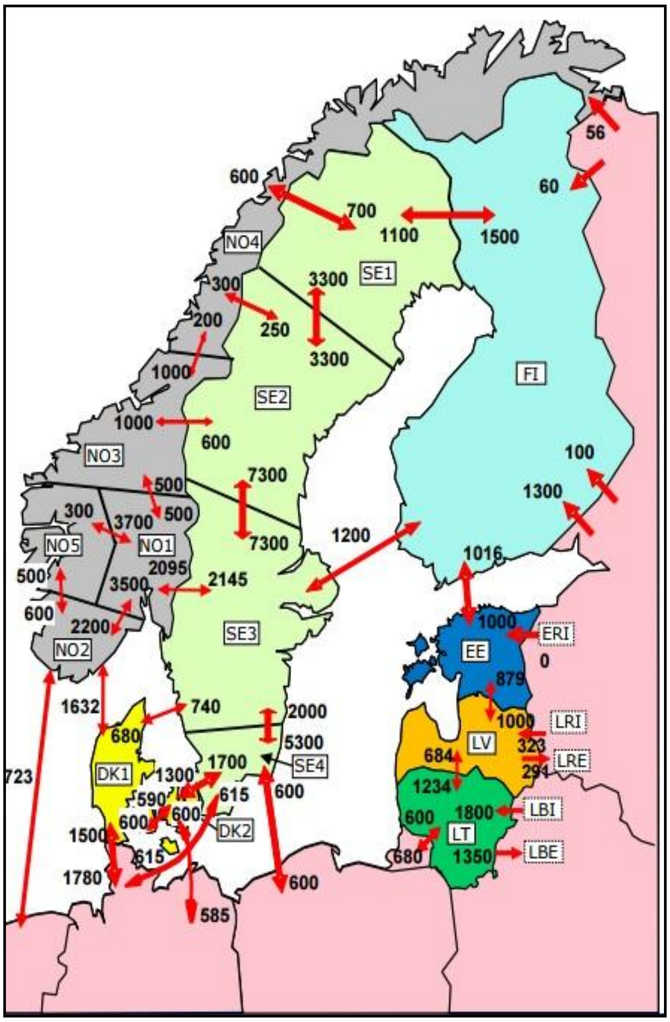

FIGURE 5 Bidding areas and main transmission capacities (MW) in the Nordic market. (Entso-E, 2015)

2.2.2 Financial market

In the Nordic market longer-term hedging can be either done over-the-counter (OTC) or in Nasdaq OMX Commodities (NOC) exchange, where standardized futures, forwards (commercial name deferred settlement (DS) futures) and options are listed and traded on weekdays from 08:00 am to 16:00 (CET). NOC also provides clearing services, and in fact significant amount of OTC trades are cleared in NOC.

Futures include contracts with delivery period from one day to week, whereas forwards' delivery period is one month, quarter or year. Before their expiry year contracts are cascaded into quarter contracts, and quarter contracts to month contracts. Neither forwards nor futures lead to physical delivery of electricity: they are cash-settled in the delivery (or settlement) period.

EPADs' delivery period ranges from one week to one year. However, in practice the week contract is illiquid and hence impractical for hedging. Month EPADs are listed for four months, quarter EPADs for four quarters, and year EPADs four years prior to the delivery period.

Futures and forward contracts differ by their settlement. Forwards are settled only during the delivery period, whereas futures are settled also on a daily basis during the trading period. In theory this has some implications for their pricing, as the cash flows occur at different times. However, in practice this issue is negligible. If interest rates are a given function of time, i.e. not stochastic, futures and forward prices are equal (Hull, 2009, 110). In this thesis I make no distinction between them and from now on refer to both of them as "futures".

All the contracts in NOC are quoted as €/MWh (with minimum tick size 0.01€) and refer to a baseload of one MW during the delivery period, which varies from 24 to 8760 hours. For a system futures contract the underlying price is the arithmetic average of hourly system spot price during the delivery period, whereas for an EPAD, the underlying price is the arithmetic average of the difference between the hourly area and system spot prices during the delivery period.

To understand how different futures can be used in hedging consider a simple example. A Finnish industrial consumer with constant electricity consumption of one MWh per hour participates on the wholesale markets and intends to fix the purchase price for the next year (=delivery period). It purchases one MWh per each hour from the spot market, one year contract written on system price, and one year EPAD written on Finnish area price difference.

Now suppose the futures prices are fixed at 25€/MWh for the system future, and 7€/MWh for the Finnish EPAD, and that next year the average system and Finnish spot price materializes at 26€/MWh and 35€/MWh respectively. The realized area price difference is then 9€/MWh. Thus the cash flows for the consumer will be the following (see equation 3.1. for the payoff of futures):

- 8760h*(-1MW)*35€/MWh = -306 600€ for the spot delivery
- 8760h*(1MW)*(26-25)€/MWh = 8 760€ for the long position in a system futures contract
- 8760h*(1MW)*(9-7)€/MWh = 17 520 € for the EPAD

The total cost equals then 306 600€ - 8760€ - 17 520€ = 280 320€, and the purchased volume being 8760MWh the average purchasing price realizes at

- 280 320€/8760MWh = 32€/MWh, which is the sum of the two hedges.

Liquidity among different products and maturities varies greatly. Figures 6 and 7 exhibit the development of trading volumes in the past years for futures on system price and Finnish EPADs for trades conducted or cleared at the Nasdaq OMX Commodities. Comparing annual turnovers, it is evident that Finnish EPADs are far less liquid than the system futures. In 2015 turnover of Finnish EPADs (traded or cleared at Nasdaq) constituted barely half the consumption in Finland, whereas for the system futures and the respective consumption in the Nordic and Baltic region the same ratio in 2013 was nearly four. Trading of Finnish EPADs is concentrated on year contracts, and usually done at OTC[4].

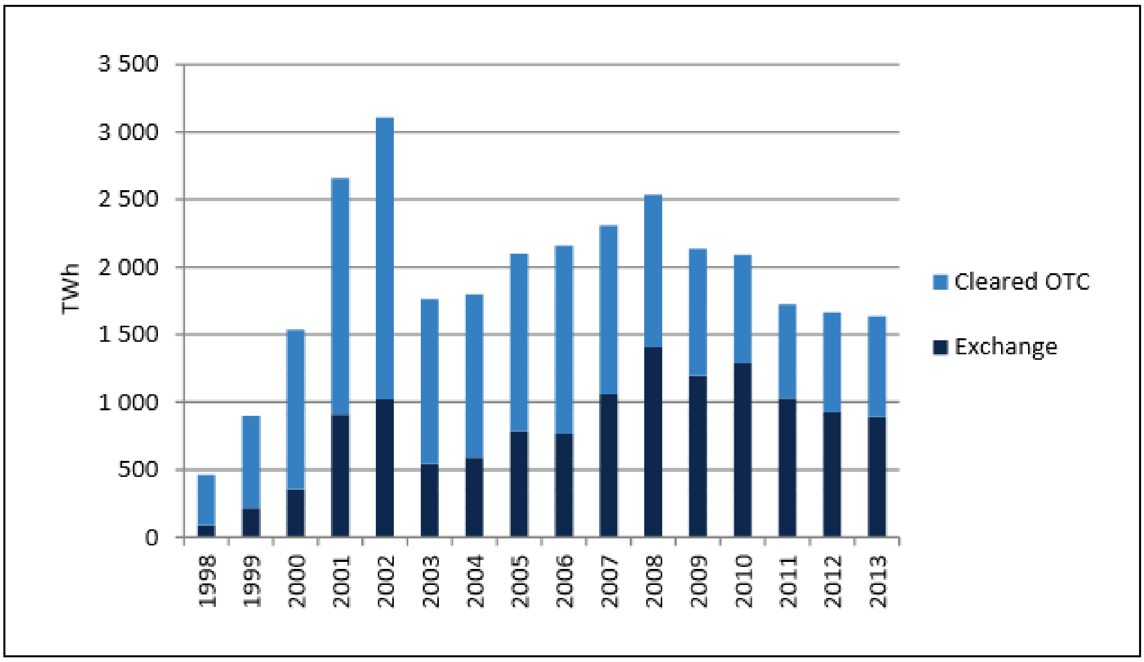

FIGURE 6 Trading volumes (TWh) for Nordic system futures in 1998-2013. (NordReg 2014, p. 46)

[4] Note that the data in figure 7 do not include OTC volumes not cleared in Nasdaq.

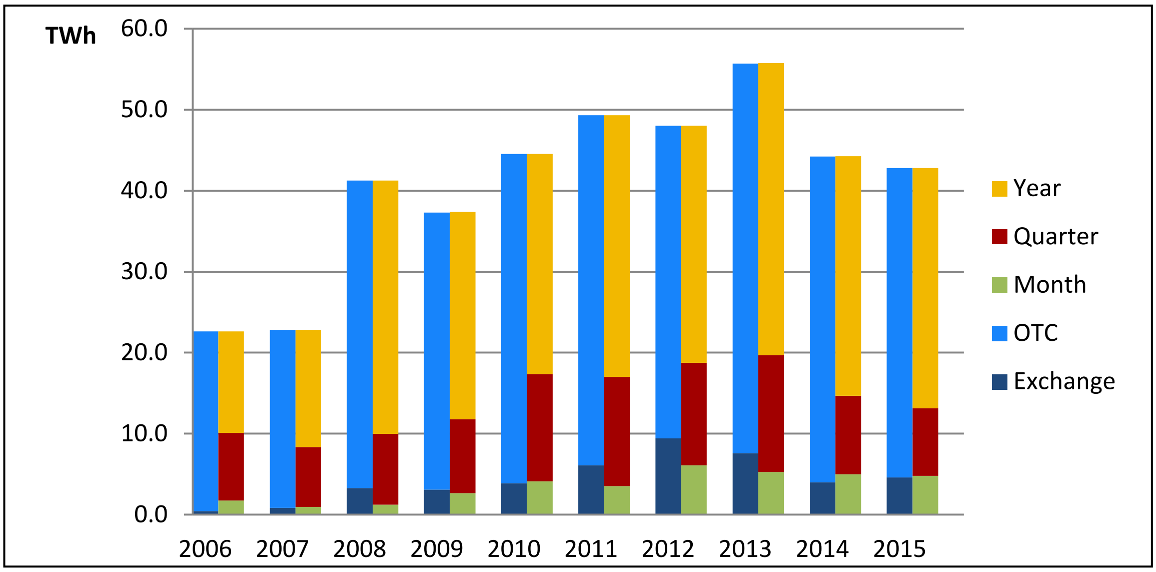

FIGURE 7 Trading volumes (TWh) for Finnish EPADs in 2006-2015. (Nasdaq OMX Commodities, 2015).

2.3 Nordic market fundamentals

The Nordic market is characterized by large amount of hydro power generation, and consumption that depends heavily on temperature and energy-intensive industry. Water reservoir levels are affected by precipitation and melting of snow. Consumption varies seasonally depending on the temperature, since electricity is used in heating and (to a lesser extent) cooling. In addition to heating, another considerable source for electricity demand in the Nordic countries is the industrial use of electricity. It varies in accordance with fluctuations in the global[5] economic-activity. The global economy affects also electricity supply owing to fluctuating fuel prices.

Due to its predominant role in the generation mix (figures 7 and 8), hydro power has a significant part in price determination in the Nordic market. Short-term marginal cost for a hydro power generator is referred as the water value, which represents the expected marginal value of storing the water for future purposes. In other words, it is an opportunity cost, which equals the discounted future expected spot price. (Fridolfsson & Tangerås, 2009) Thus, it is a function of expected reservoir levels, the costs of alternative generation and demand. When reservoir levels are high, the water value decreases as the possibility of spillages increases, whereas low reservoir levels increase the water value.

Generation types that have low marginal costs are on the left end of the supply curve, i.e. first on the merit order. The run-on-river hydro power plants cannot store the water. Thus, their marginal cost is near zero and they are offered to the market as independently of the price. Other price independent gen-

[5] The end products of electricity-intensive industries tend to be bulk products, such as pulp and paper and steel exported to global markets.

eration includes wind and nuclear power as well as combined heat and power (CHP) generation, which depends on demand for heating in district heating systems and industrial processes.

Regulated hydro power with large reservoirs and condense power plants (mostly run with coal, peat, biomass and natural gas) in turn act as marginal generation that balances variation in supply of renewable power and demand. Peak demand is covered by gas turbines and condense power plants run by oil.

Generation and consumption differ greatly within counties in the Nordic market, as is evident from figure 8. Although Norway and Sweden consume the most electricity in the Nordic market, they are still net exporters[6] due to vast hydro power resources. Finland, in contrast, covers significant amount of consumption by imports. Similarly, Denmark and the Baltic countries together are net importers. The Nordic market is connected to other markets with transmission links between Norway and Netherlands; Sweden, Denmark and Germany; Sweden and Poland; Finland (+ Baltic countries) and Russia.

Generation in Norway is dominated by regulated hydro power, while in Sweden nuclear and hydro power each constitute approximately 40% of the generation. Hydro power in Sweden consists of both unregulated and regulated assets. Denmark relies on wind power and conventional thermal power plants, and Finland has a generation mix of nuclear, fossil and biofuels and mainly unregulated, run of river hydro power, whereas in the Baltic countries electricity is mainly generated with fossil fuels.

Similar to supply, demand also varies within different countries. The percentage shares of different sectors within each country are, however, not totally dissimilar. Electricity is mostly consumed in residential, services and industry sectors each representing 26% (30%), 22% (26%) and 34% (40%) percentage of the gross (net) electricity consumption in the Nordic and Baltic area, respectively. Sweden, Norway and Finland are the largest consumers owing to cold climate, and energy-intensive industries, such as pulp and paper, and metal industries. In Denmark and the Baltic countries consumption is more tilted towards residential and services sector.

Supply and demand vary not only within countries but also seasonally (figure 9). Demand exhibits strong seasonal component being highest during winter and lowest in summertime. Furthermore, demand slumped considerably in 2008 – 2009, as industrial consumption declined as a consequence of the financial crisis, while the winter of 2014-2015 was particularly mild[7]. Nuclear power provides a relatively stable source of power throughout the year, while hydro power fluctuates being the highest at winter and lowest at summer, as hydro power producers maximize their profits from regulated hydro assets. The Nordic-wide thermal power generation in turn varies similarly as thermal power generation in Finland (see figure 9).

[6] However, in dry years it is possible that they are net importers.

[7] See for example figure 14 in chapter 4.

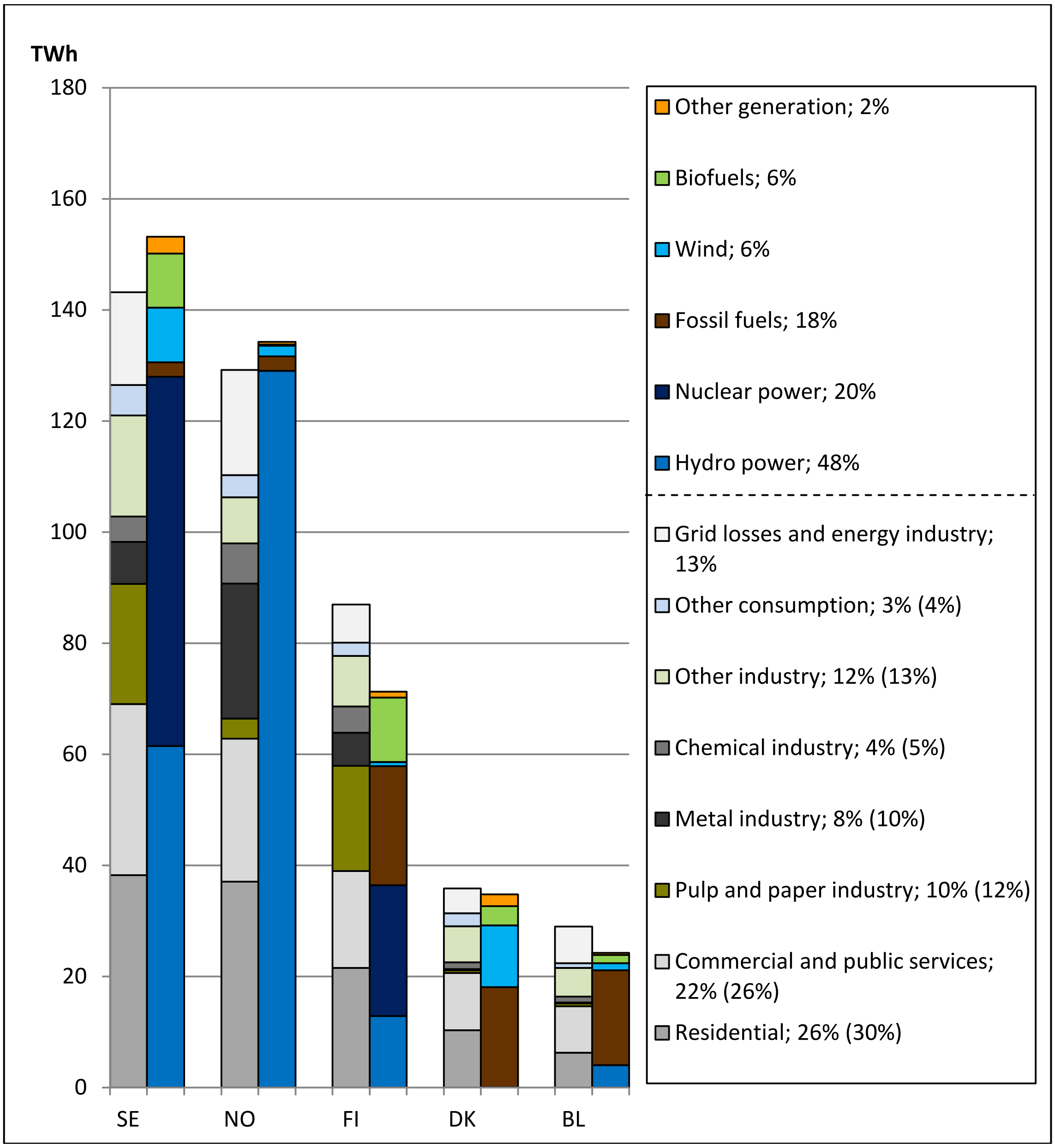

FIGURE 8 Gross electricity generation and consumption in the Nordic countries and Baltic area in 2013. The share of net consumption in parenthesis. (Compiled from Eurostat and International Energy Agency, 2015).

The development of the monthly system spot price (together with Finnish area price and area price difference) is depicted in figure 10. In the past years the system price has been historically low as price independent renewable (mainly wind) production has increased due to subsidies, prices of fossil fuels have decreased, weather has been relatively mild during winters and hydro-power availability has not been particularly tight. On the other hand, the sharp increases in the system price during winters 2009 – 2010 and 2010 - 2011 can at least partially be attributed to the facts that weather was colder than average and hydropower availability was below-average.[8]

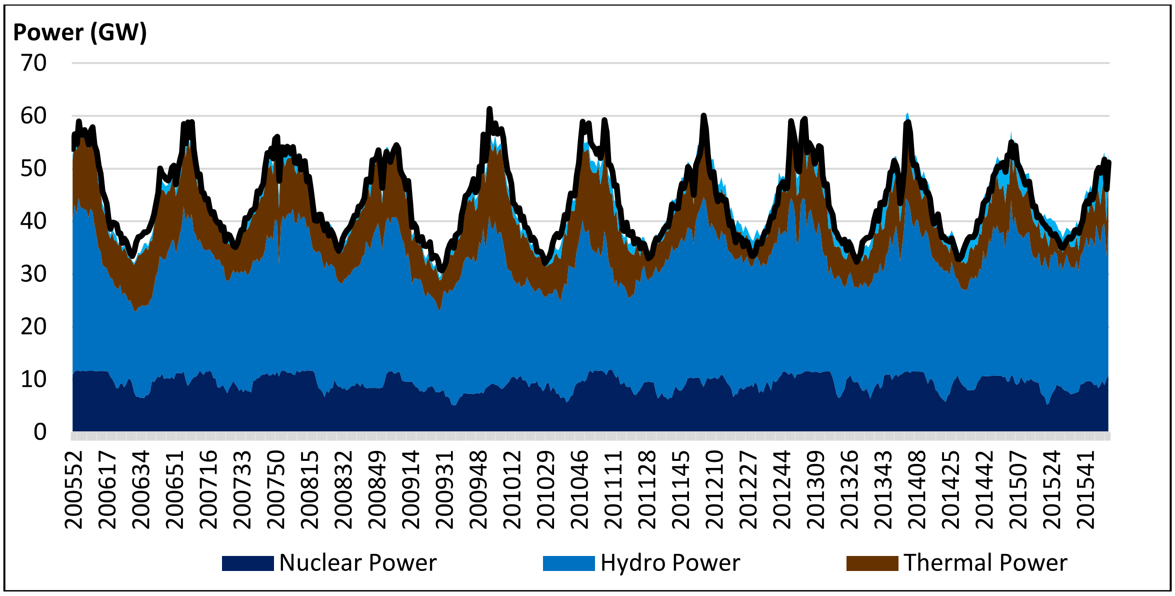

FIGURE 9 Power generation and consumption (average power per week) in the Nordic area 2006 - 2015 (SKM Market Predictor, 2016)

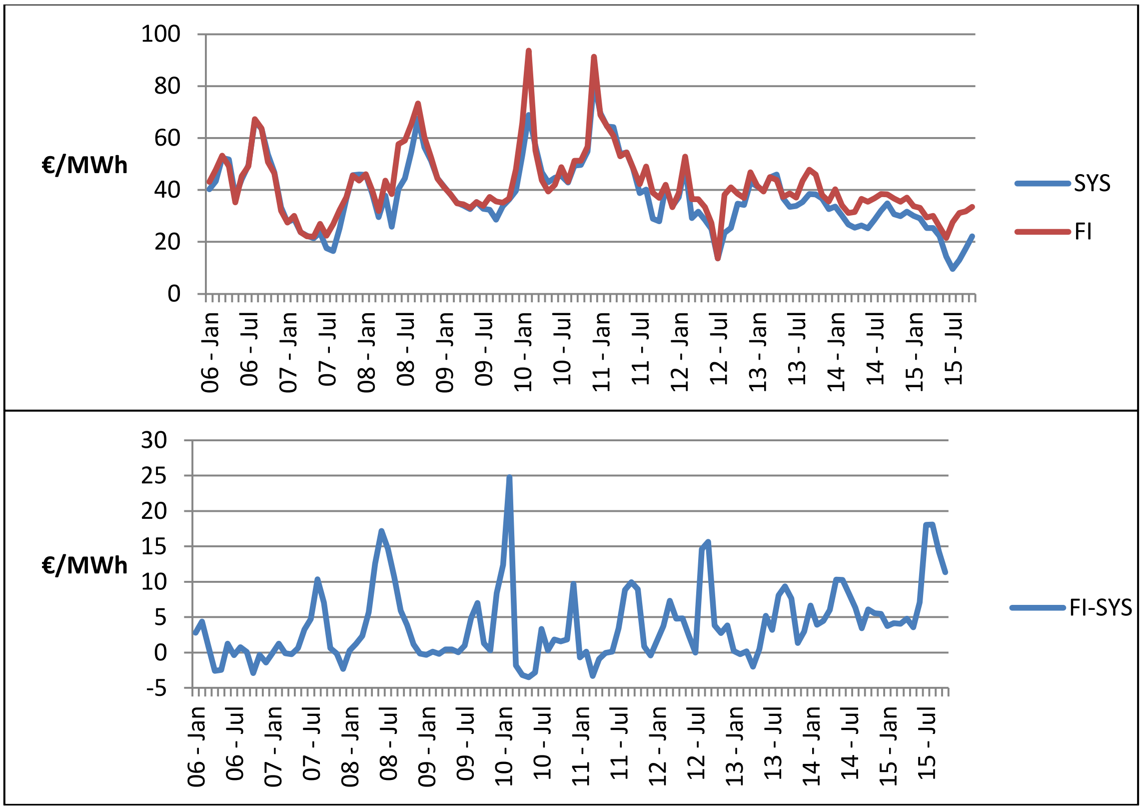

FIGURE 10 Monthly Nordic system price, Finnish spot price and the difference between them (FIN-SYS area price difference) Jan 2006 – Jan 2016.

[8] Data on water reservoir levels In Finland, Sweden and Norway as well as temperatures in Helsinki and Oslo are presented in chapter 4.

2.4 Finnish market fundamentals

The Finnish market has a number of important characteristics compared to the whole Nordic market (see figure 11). First, although nuclear and hydropower production constitute considerable share of the generation mix also in Finland, the share of hydropower is much lower than in the Nordic market and relatively larger share of it is based on unregulated, run-on-river hydro assets. Second, Finland also has less renewable and more fossil fuels based generation especially in the form of CHP generation. The amount of plain condense generation has decreased as it has become less profitable due to decreasing spot prices. Finally and most importantly, as can be seen from the continuous difference between consumption and generation values, Finland is a net importer of electricity throughout the year.

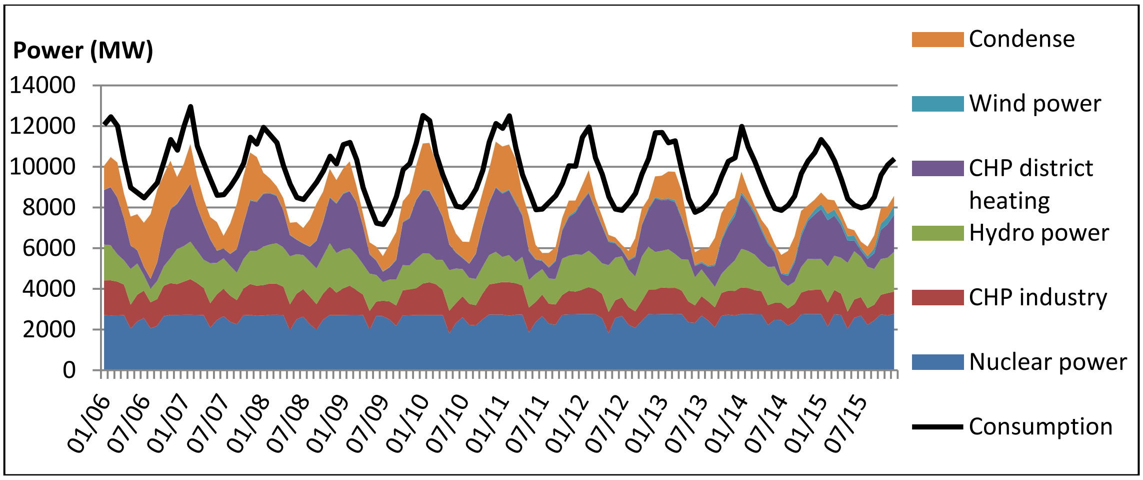

FIGURE 11 Generation and consumption (average power per month) in Finland 2006 – 2015. (Finnish Energy Industries, 2016a, 2016b)

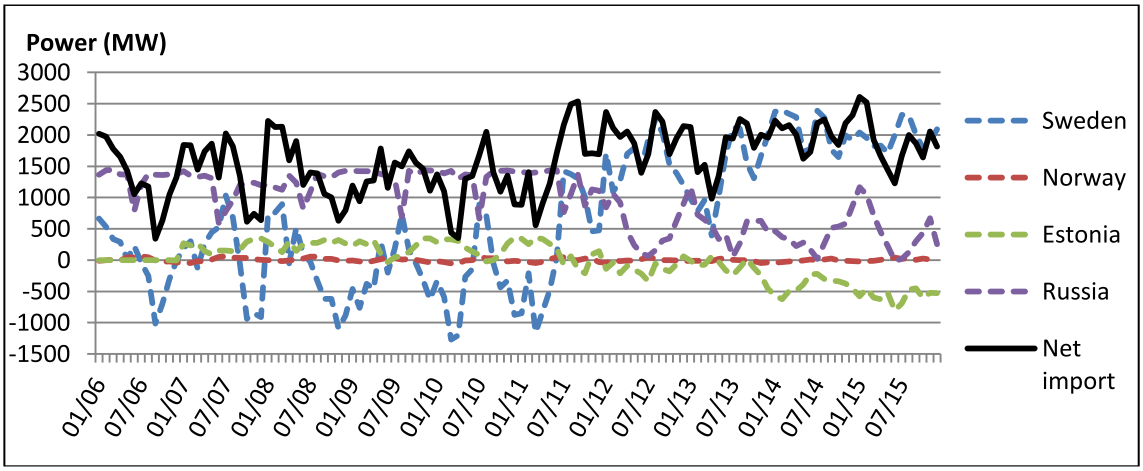

FIGURE 12 Net import and export (average power per month) from and to Finland 2006 – 2015. (Finnish Energy Industries, 2016a)

Until 2011 Finland both exported and imported electricity to Sweden on a monthly basis and imports from Russia were relatively stable (figure 12). However in late 2011 Russia introduced capacity tariffs on its market and as a consequence imports from Russia decreased on weekdays during the peak hours. Reduced imports have primarily been replaced by exports from Sweden and increased price difference between Sweden and Finland (table 1). While the price difference between the Finnish and Nordic system price has not increased notably in absolute terms, in relative terms the difference has widened substantially.

3 THEORETICAL FRAMEWORK

In this chapter I lay out the theoretical framework for electricity (and EPAD) futures, as this will form the basis for my empirical research in the consecutive chapters. I first explain the general definition of futures. Second, I briefly review the literature regarding traditional futures pricing. Hull (2009) provides easily accessible review of the traditional, and most common pricing theory of futures in his seminal book, and I follow his approach reviewing it. Third, I examine an alternative pricing theory, which is slightly more controversial and based on risk premium and expected spot price, and particularly suitable for electricity as a non-storable commodity. On this occasion I also discuss problems related to its empirical testing, and how it is linked to the efficient market hypothesis. Fourth, I address the issues of electricity futures pricing in more detail[9]. Finally, I define the concept of risk premium, since it has been used inconsistently in the electricity futures literature, and review the empirical evidence of pricing the electricity futures and EPADs (risk premium and market efficiency).

3.1 Futures pricing

A buyer (seller) of a futures contract is said to go long (short), and agrees to purchase (sell) the underlying asset at a fixed price at maturity. The payoff at maturity for a trader holding a long position can be written as

$$p_F = S_T - F_{t,T} \tag{3.1}$$

where S_T is the spot price at maturity and $F_{t,T}$ the futures prices agreed upon at time t for a contract maturing at time T. For a short position the payoff is the negative of equation (3.1). Note that for electricity futures T is defined as the *delivery period* rather than a single point of time, since electricity is a flow commodity.

Hedgers use futures to manage price risks, for example to reduce the variance of cash-flows, be it revenue, or input costs, while speculators use them simply for betting the future price development of the asset in question without having an offsetting position in the underlying asset.

Literature on hedging from the point of corporate finance view is vast. Hedging can, for example, decrease expected bankruptcy costs, or expected tax liabilities, increase debt-capacity or improve managerial incentives (Berk and

[9] Since the underlying price of EPAD is actually a linear combination of two electricity spot prices, reviewing general framework for electricity futures pricing serves also the purpose of this thesis, i.e. to examine the pricing of EPADs.

DeMarzo 2011, p. 955). Since electricity prices are particularly volatile, hedging is likely to benefit companies in the power industry (Bessembinder and Lemmon, 2002) or, by the same logic, companies in electricity-intensive industries. Futures also serve important purposes for the broader market economy: liquid trading and markets provide price signals, which in turn are crucial for investment decisions, and hence for efficient allocation of resources.

3.1.1 Theory of storage and cost of carry

Similar to practically all financial instruments, traditional approach to futures pricing is based on no-arbitrage conditions, i.e. the futures price has to be equal to the price of a replicating portfolio[10]. Generally futures price F_t at time t for delivery at time $t+T$ for an asset that provides no other income can be written:

(3.2) $$F_t = S_t e^{rT}$$

where F_t is futures price, S_t spot price at time t, r risk-free interest rate and T time to maturity. The logic behind equation (3.2) is the following: to own the asset at time T, investors can either go long in the futures contract at price F_t, hold it to maturity and take the delivery, or purchase the asset at spot price S_t. Futures contract saves the opportunity cost of tying capital before the maturity, hence its price has to be higher to satisfy the no-arbitrage condition between spot and futures price. Suppose that $F_t > S_t{*}e^{rT}$, then investors will short the futures contract, purchase the asset and hold it to maturity and earn a risk-free profit. Similarly if $F_t < S_t{*}e^{rT}$, investors will short the asset, and go long the futures contract. (Hull, 2009)

Hull (2009) notes that in the pricing of futures contracts it is crucial to separate investment and consumption assets. He argues that investment assets, such as bonds and stocks, are held by a significant number of investors for investment purposes, while consumption assets, such as copper or agricultural commodities, are held primarily for consumption purposes.

Equation (3.2) can be elaborated for assets that face storage costs, provide income or convenience yield, which refers to possible benefit from physical possession of the asset. As an example, consider possibility for a producer to profit from temporary local shortages. For an investment asset that provides known income y, equation (3.2) becomes:

(3.3) $$F_t = S_t e^{(r-y)T}$$

while for a consumption asset requiring storage costs u, and providing convenience yield and known income y:

---

[10] This is subject to several assumptions such as that there are no transaction costs, market participants can borrow and lend at the same risk-free interest rate and that they can take advantage of the arbitrage conditions.

(3.4) $$F_t = S_t e^{(r+u-y)T}$$

The exponential term $r+u-y$ (or its variants) describes cost of carry, which represents net opportunity cost of holding inventory compared to having position in the corresponding futures contract. (Hull, 2009)

3.1.2 Theory of expected spot price and risk premium

The second theory – often called as the expectations theory - views the futures price as a function of expected spot price, and a risk premium and can be traced to Keynes (1930). Following Hull (2009) futures price at time t for delivery at time T, can be written

(3.5) $$F_{t,T} = E_t(S_{t+T})e^{(r-k)T}$$

where $E_t(S_{t+T})$ is the expected spot price at time $t+T$, r is risk-free interest rate, k risk-adjusted discount rate and T denotes time to maturity. Denoting $(k-r)=P$, which can be interpreted as a risk premium, and substituting it into equation 3.5 yields

(3.6)[11] $$F_{t,T} = E_t(S_{t+T})e^{(-P)T}$$

Hull (2009) argues that the modern approach explaining the expectations theory is based on risks and returns in the whole economy, i.e. capital asset pricing model. Investors require higher returns for risks that cannot be eliminated by diversifying. In other words, when the return of the futures contract in question is positively correlated with overall stock market (or well-diversified market portfolio) return, investors will require a risk premium for holding that futures position and futures price will be below the expected future spot price. Conversely, when the two returns are negatively correlated, the future price will exceed the expected future spot price. Note that this approach is suitable for investment assets, which are held by a significant amount of investors, but not necessarily for consumption assets.

According to Hull (2009) another approach dates back to Keynes (1930) and Hicks (1939). They argued that the risk premium is determined by market microstructure. They viewed that producers of commodities tend to be more risk-averse, and their relative hedging need exceeds that of consumers. This will then decrease the futures price below the expected spot price. Speculators then take the other side of the trade provided that their expected return (risk premium) is sufficient.

Anderson and Danthine (1982) extend this view further theoretically by constructing hedging models based on micro-foundations, rational expecta-

[11] In a linear form the equation 3.6. is often presented as $F_{t,T} = E_t(S_{t+T}) - P$

tions[12] equilibrium, and different settings for hedgers' choices and uncertainty they face. They conclude that the sign of risk premium "depends upon characteristics of the hedgers involved", and only when consumers and producers face symmetric problems, the net hedging tends to be balanced, and the risk premium (in rational expectations equilibrium) zero. Thus unlike Keynes and Hicks, they conclude that the futures price can as well exceed expected spot price.

Fama and French (1987) note that the theory of storage is widely accepted in the literature, whereas the theory involving expected future price and risk premium is more controversial. He studies various commodities and finds that for highly perishable commodities (broilers, cattle, eggs, hogs and pork bellies) expectations theory help explain better the relationship between spot and future prices, whereas for precious metals (gold, platinum), that are more durable and have low storage costs, theory of storage explains the relationship better.

Finally Fama and French (1987) remark that it is difficult to determine, whether it is risk premium or bias in predicting the future spot prices, that causes futures prices to differ from spot prices ex-post. Gjolberg and Brattested (2011) also highlight this issue in the electricity futures literature noting that assuming rational expectations, the observed bias or error may be an average of a time-varying risk premium. Closely related concept to futures pricing is the efficient market hypothesis, which is briefly presented next.

3.2 Efficient market hypothesis

Literature on the efficient market hypothesis (EMH) is vast, and dates to 1970s or even before. The EMH has been stated in different ways. In the famous paper by Fama (1970) it is described as "a market in which prices always fully reflect available information is called efficient". Jensen (1978, 3) in turn expresses it as following:

"A market is efficient with respect to information set θ_t if it is impossible to make economic profits by trading on the basis of information set θ_t."

Jensen notes further that here economic profits mean "the risk adjusted returns net of all costs." (1978, 3)

Fama (1970) distinguishes three forms of the theory based on available information set:

- weak form: information set is historical prices
- semi-strong form: information set is all publicly available information

[12] Theory of rational expectations in this context assumes that market participants are perfectly forward-looking, and on average can predict the spot prices accurately, i.e. the average forecast error is zero. However, deviations from the expected outcome can occur due to unforeseen shocks. See (Muth, 1961) for further reference.

- strong form: information set is all relevant information - be it publicly or privately available

Note that the EMH does not state that the current futures price should be equal to the future spot price. The risk premium can exist, and is fully compatible with the EMH. Instead, the EMH implies that in the absence of risk premium, futures price should (on average) be equal to the future spot price (given information set available before the delivery period). In the foreign exchange market the biased futures or forwards are often explained rationally by the so called peso problem[13]: market participants expect or fear a significant, yet infrequent event and bid up insurance against it. Ex-ante this behavior might seem as irrational, but when the risk is realized, it becomes rational.

3.3 Electricity futures and EPADs pricing

This section connects the previous discussion of futures pricing to electricity futures. As Marckhoff and Wimschulte (2009) note, a long (short) EPAD contract can be regarded as a combination of two electricity futures contracts: a long (short) position in an implied area contract[14], and a short (long) position in the Nordic system price contract. Hence, theoretical framework of ordinary futures can be applied to EPADs as well.

Vehviläinen (2002) discusses in detail the basic pricing of electricity derivatives in competitive market. He notes that "electricity that is delivered at any given future time is a separate asset from the electricity that is delivered now" and that "the non-storability of electricity makes the electricity market different from the financial and other commodity markets" (Vehviläinen, 2002, 49)

Due to non-storability he lists two unique features of the electricity futures pricing compared to other commodities. First, he notes that electricity spot price, i.e. the underlying price for futures, is subject to spikes and volatility, because supply and demand has to be in balance all the time. Hence, they are difficult to model. Second, Vehviläinen (2002, 47) adds that "at no time it is allowed to own spot electricity as an asset" meaning that market is incomplete, since it is not possible to hedge financial futures by creating a replicating portfolio with a bank account and physical spot electricity. Based on previously mentioned arguments, Vehviläinen (2002) presents that in a competitive market electricity futures prices converge to risk-adjusted expected future spot price, as described by equation 3.6.

[13] The term is said to originate from 1970s. Mexican peso had been successfully pegged to the US dollar for an extended period. However, Mexican bank deposits yielded more than comparable US deposits offering possibilities for carry trade. Eventually the peso was allowed to float and devaluate. The interest rate gap, or risk premium, can be seen to stem from the concern of devaluation.

[14] Implied area futures are hypothetical futures on an area price – a combination of a system future and an EPAD.

Botterud, Kristiansen and Ilic (2010) provide a different view. They argue that in the Nordic market, where hydropower constitutes a significant share of production capacity, one can apply the theory of storage, since they view water reservoirs as electricity storages. Huisman and Kilic (2012) on the other hand separate imperfect direct and imperfect indirect storability with fuels such as coal, and natural gas representing the former, and renewable energy depending on weather the latter[15]. They note that traders can sell an electricity futures contract, purchase the needed amount of fuel at liquid spot markets, store it and convert the fuel to electricity in the delivery period to fulfill their delivery commitment[16]. However, they note that the availability of hydropower (that is based on water reservoirs) depends at least in the long-run on exogenous, unexpected weather conditions, which reduces the flexibility of storage. Huisman and Kilic (2012) note that this applies even more drastically to wind, solar, or hydropower on run-on rivers without reservoirs, which all depend heavily on weather, and lack storage possibilities.

As noted before the risk premium in the expectations theory can be explained in two ways. For an investment asset Hull (2009) explains it as correlation between the returns of a futures contract in question and a broader, well-diversified stock and bond portfolio. However, to electricity markets, and EPAD pricing the approach by Anderson and Danthine (1982) that considers the microstructure of the market seems more appropriate or as Gjolberg and Brattested (2011, 4) note "in a balanced market i.e., a market where short hedging demand is exactly matched by long demand, the futures price should equal the expected spot price" and that "in a well-functioning market with unbalanced hedging demand, the futures price deviates from the expected spot price by the risk premium".

Electricity markets are local, and small by turnover compared for example to global stock and bond markets. Even in the Nordic market, it seems plausible that it is industry participants, not outside, diversifying investors, who are the dominant traders in the futures market. Bessembinder and Lemmon (2002) argue similarly. More importantly, it is certain that the dominant role of industry participants and speculators, and the absence of institutional, diversifying investors apply especially well to Finnish EPADs' market due to its illiquidity and uniqueness.

In conclusion, the expectations theory as presented by Vehviläinen (2002) seems a more appropriate framework to electricity futures pricing than the theory of storage. This is also assumed in the vast majority of the literature. In this context, and assuming rational-expectations the risk-adjusted futures price equals the expected spot price, which in turn depends on expectations of future marginal cost to satisfy the expected demand.

[15] Although CHP is based on fossil fuels, it represents indirect storability, as it depends on heating demand, i.e. temperature.
[16] It is important to recall that in the Nordic market financial and physical market are separated so that a futures contract do not lead to delivery commitment

The risk premium in turn is determined by the preferences of the market participants. In the EPAD market (and certainly to some extent also in wider electricity market(s)) the participants can be described as producers, consumers, and investors, of which most are probably speculators, who care less about correlations with broader capital markets. Thus, the risk premium can be explained by asymmetric relative hedging needs of electricity producers and consumers, and this is discussed further in the next chapter.

3.4 Empirical evidence on pricing of electricity futures and EPADs

Empirical evidence of electricity futures pricing is concentrated to using data from the Nordic, US, and Western European markets. They are not only the largest markets, but also among the ones which were deregulated first. Despite the fact that these markets are still relatively young they have been studied quite extensively. On the contrary, literature regarding the EPADs is scarcer. Hence, what follows is that first focusing on the Nordic market I review the main literature regarding ordinary electricity futures. This literature review might seem a bit exhaustive given the actual research problem is related to Finnish EPADs, but it serves to highlight the key methods, and reasoning used in the empirical analysis. Hedging behavior of consumers and producers in broader electricity markets can then be reflected to EPADs. Finally, I review the few available studies on EPADs and summarize the chapter.

Empirical studies on electricity futures pricing can be broadly divided to two lines of research. It is possible to study futures pricing per se, and test for example the weak form of efficient market hypothesis, i.e. whether past information on prices can be used to explain the futures prices.

Nevertheless, more literature seems to be concerned with the relationship between future spot and futures prices, and factors that explain it. This line of research can be further divided to ex-post, and ex-ante methods. Of these the ex-post method, i.e. replacing the expected spot price with realized spot price, is more commonly used in the electricity futures literature. Its drawback, as discussed by Fama (1987) and Fleten & Hagen (2015) among others, is the fact that it is difficult to identify the forecast error and the risk premium components of the estimated bias. However, it circumvents the main problem associated with the ex-ante method. Ex-ante method requires that the researcher has to make a subjective choice for spot price expectation, and consensus for the appropriate model is unambiguous (Fleten & Hagen, 2015).

Some authors assume that expectations are formed rationally so that the fact that futures prices deviate from the realized spot prices is caused by the risk premium. However, a more fruitful approach in my opinion is presented by Gjolberg and Brattested (2011). They make no explicit assumptions regarding the risk premium and market efficiency in advance. Instead they study the bias, and use logical reasoning with support of empirical evidence, in order to determine whether the fact that futures and future spot prices differ from each other ex-post can be explained by risk premium, or market inefficiency.

Before reviewing the literature further, it is worth clarifying the definition of risk premium used in the literature, as many authors use it loosely and inconsistently (Weron and Zator, 2014). Here I follow Weron and Zator (2014) and define the ex-ante risk premium at time t to be realized at time T as

$$RP_{t,T} = \ln\left(E_t(S_T)\right) - \ln\left(F_{t,T}\right) \tag{3.7}$$

and its negative as futures premium:

$$FP_{t,T} = -RP_{t,T} = \ln\left(F_{t,T}\right) - \ln\left(E_t(S_T)\right) \tag{3.8}$$

For ex-post premiums, the expected spot price $E_t(S_T)$ is replaced with realized price S_T. To obtain respective relative premiums equations (3.7) and (3.8) are divided by expected or realized spot price at time T.

Defined this way, the risk premium has similar interpretation as the market price of risk, which is commonly used in the financial literature (Weron and Zator, 2014). Some authors use the definitions above interchangeably, while some use the term bias (not every author uses logarithmic prices). Additionally, some distinct them, but define the signs the opposite way. Therefore, for the sake of clarity and consistency, I review the literature using the sign rules above, and not necessarily the way they are originally used in the particular piece of literature.

As an example consider Lucia and Torro (2011). They define the risk premium as in equation 3.8. Thus, when referring fox example to their study, I use the term futures premium. Finally, the reader is advised to recall that although the term "premium" is widely used in the literature, it can be explained by unforeseen forecast errors and market inefficiency in addition to pure risk component. I will mention explicitly which view the authors take.

3.4.1 Electricity futures

In a widely cited paper Bessembinder and Lemmon (2002) examine optimal hedging and equilibrium futures pricing using daily data from April 1997 to July 2000 in the PJM (Pennsylvania, New Jersey and Maryland) and from April 1998 to July 2000 in the CALPX (California) market.

They first construct a structural, equilibrium model for the expected spot price by considering risk-averse producers and retailers who face uncertainty. Then their model for futures pricing implies that the market participants use risk considerations to price futures. Their model implies that the ex-ante futures premium (based on their model for expected spot price) depends on variance and skewness of the expected spot prices:

(3.9) $$F_{t,T} - E(S_T) = b_1 + b_2 Var(E(S_T)) + b_3 Skew(E(S_T))$$

so that b_2 is expected to be negative, while b_3 positive. Furthermore, they note that although their "primary testable implications are stated in terms of power prices, the underlying state variable is power demand" (Bessembinder and Lemmon, 1362). Using regression analysis they find evidence to support the model: futures premium is positive in summer, when demand and demand risk are high and respectively negative in spring and fall. As their sample period is rather short, they note that results should be interpreted cautiously. Nevertheless their study has become a popular benchmark and is widely cited in later literature, where their testable model is often modified so that $E(S_T)$ is replaced by realized spot price S_T, so the regression equation is:

(3.10) $$F_{t,T} - S_T = b_1 + b_2 Var(S_T) + b_3 Skew(S_T) + \varepsilon_t$$

Some authors also use the variance and skewness during time t instead of delivery period T as a proxy for expected variance and skewness.

Redl et al. (2009) study the futures pricing in the Nord Pool and Central European (EEX) market using data from 2003 to 2008. First, they examine the determination of year-ahead futures prices. They find evidence that year-ahead futures prices in both markets depend on current spot prices and year-ahead generation costs, that is, year-ahead prices for natural gas, coal and CO_2 allowances. They attribute the significance of current spot prices to adaptive expectations of market participants, which could indicate inefficiencies in the market. Moreover, they note that the role of year-ahead generation prices is in line with economic theory, as in competitive markets the price formation depends on marginal costs. At first, it would seem that they lack control variable for the year-ahead hydro availability in the Nordic market. However, this is reasonable since predicting longer-term hydro-power availability is imprecise and affected by current reservoir levels, which are reflected in current spot prices.

Second, Redl et al. (2009) use unrestricted vector autoregressive (VAR) model, and find that for EEX peak load and Nord Pool base load contracts the lagged values of spot prices explain futures prices, while opposite is not true, which would suggest the markets to be inefficient, and trading strategies of market participants would rely on current spot prices.

Third, they compute ex-post an average future premiums for monthly contracts using the average futures prices during the last month of trading and prices from the last trading day. They find positive premiums on average for both the EEX and Nord Pool contracts. Additionally, they find evidence that premiums are less in absolute terms for the last trading day than for the monthly average. They argue that this could indicate that the forecast error is a meaningful component of the premium as market participants have more information available at the last trading day, and this is reflected in the futures prices. They also note that the sign of premium varies over time, which they argue, provides further support for the presence of forecast errors.

Finally, Redl et al. (2009) test the Bessembinder and Lemmon model and expand it to include factors that proxy for supply and demand shocks in the delivery period. Their demand shock variable is the ratio between actual consumption and its long-term average in the relevant area. In the same manner, they construct the supply shock variable incorporating generation data for hydro and nuclear power.

The results they find are somewhat mixed. In EEX market they find partial support for the basic Bessembinder and Lemmon model: skewness of the spot prices explains the premium, but variance does not. For Nord Pool they find no support for the model, and attribute this to fundamentals of the Nordic market, i.e. high amount of flexible hydropower, which yields less skewed spot prices. They conclude that positive future premiums arise from risk assessment of market participants and unforeseen shocks may help to explain the forecast error, and yet market inefficiency cannot be ruled out.

The Nordic market is also studied in Lucia and Torro (2011), Huisman and Kilic (2012,) Gjolberg and Brattested (2011) as well as Weron and Zator (2014) among others. Lucia and Torro (2012) investigate the futures premium of weekly Nordic system futures from 1998 to 2007. They find evidence of time-varying, premiums that are positive on average, and vary over the year being the largest in winter and close to zero in summer. Moreover, they document that the relationship between unexpectedly low availability of hydro power and futures premium is positive. Although they find only partial support from 1998 to 2002 for the explicit Bessembinder and Lemmon (2002) model based on spot price variance and skewness, they argue that the results confirm that tighter market conditions, which increase the risk of price spikes (i.e. skewness), impact futures pricing.

Gjolberg and Brattested (2011) examine the "forecasting performance"of weekly Nordic system futures, and, unlike most authors, abstain from using the terms risk or futures premium. They document that future prices exceed spot prices (or ex-post futures premium equals) 7.4%-9.3% on average on a monthly basis. They argue that for a number of reasons this cannot be explained solely based on risk considerations but also hints towards market inefficiency. First, they note that the magnitude of error is suspiciously large and that the correlation of ex-post forecast error with different ex-post risk measures is zero. Moreover they argue that the seasonality in forecast errors would indicate the presence of risk premium, as demand-risk varies seasonally. However, unlike Lucia and Torro (2012) they find that the forecast error does not exhibit clear seasonality. Finally, they interestingly discover that the forecast error has actually increased as the market has matured.

Huisman and Kilic (2012) study futures pricing by comparing two different markets with imperfect indirect storability (Nordic) and imperfect direct storability (Dutch) dominating production. In both markets they find evidence that future prices predict spot prices. However, only in the Dutch market they observe time-varying premiums.

Weron and Zator (2014) study weekly futures in the Nordic market, and document negative futures premium for the front contract, and positive futures premiums for the contracts of three and six weeks from the maturity. They extend some results of Lucia and Torro (2011) finding that the effect of unexpected availability of hydro power is not restricted only to low water reservoir levels. They document that the relationship between the risk (futures) premium and deviations in water reservoir from mean levels is positive (negative). Moreover, their regression implies a weak positive relationship between the risk premium and unexpectedly high consumption. For the Bessembinder and Lemmon model they find no evidence that would support nor contradict it. Finally, they conclude that since fundamental factors can explain the premium to some extent, it represents more likely the price of risk than market inefficiency.

All the previously discussed studies define the risk or futures premium based on realized (or expected) spot price during the delivery period, and the futures price in the trading before the delivery period. Fleten and Hagen (2015) utilize a different approach. As noted before, they view that the ex-post risk premium is hard to interpret. Furthermore, they argue that it measures the risk that does not need to be held. According to them the risk premium is determined by hedging needs of retailers and producers as well as actions of traders, who have no incentive to hold futures over the delivery period. Even if they had, Fleten and Hagen argue that traders could offset the position with shorter maturity. Moreover, they highlight the same issue, as Fama and French (1987), namely the possible forecast error component of the ex-post risk premium. Therefore, they conclude, that methods based on delivery price are inappropriate.

Instead, Fleten and Hagen (2015) study the risk premium and its determinants overnight during the trading period using data from January 2002 to September 2012 from the German and Nordic market. Similar to Gjolberg and Brattested (2011) they hypothesize that producers hedge longer-term, while retailers short-term, as their volume forecasts become more accurate. They find support for this: on average the risk premium for a contract is positive before it becomes a front contract (that nearest to maturity), and negative when it is front contract. This supports findings of Benth et. al. (2008) who study also the German market, and note that futures premium is decreasing in time-to-maturity due to different hedging strategies of producers and consumers.

The overnight approach by Fleten and Hagen would indeed seem more reasonable than the one based on ex-post delivery price given their focus is on risk premium of speculators, who close their positions before the delivery period. Their research provides also further support for relevance of time-to-maturity in pricing of electricity futures. However, in this thesis my emphasis is on the delivery period risk premium for the reasons mentioned in the introduction. Therefore, in the empirical section I stick to the ex-post approach.

3.4.2 EPADs

Whereas the Nordic system futures and electricity futures in other markets have been studied extensively, the literature regarding EPADs is scarce. To my knowledge no study focuses only to Finnish EPADs and the literature even for other areas is limited to few studies.

Recall that an EPAD can be considered as a combination of two electricity futures contracts: a long (short) position in an implied area contract, and a short (long) position in the Nordic system price contract. Hence, a priori factors that increase (decrease) the ex-post futures premium for an implied area future (a system future), increase the ex-post futures premium for an EPAD.

Kristiansen (2004a) examines EPADs preliminary. Using data from 2000 to 2002 he computes the average prices for various seasonal products[17] during the trading period, and the respective realized spot prices. He finds that on average Oslo (NO1) and Copenhagen (DK2) EPADs exhibit negative futures premium, while Stockholm (SE), Helsinki (FI) positive. Moreover, Helsinki has clearly the highest positive premium. He attributes these results to different market structure. For example the Oslo area is dominated by lower spot prices and by risk-averse hydropower producers, who want to hedge their area price exposure. Conversely one can conjecture that spot prices and risk of price spikes are higher in Finland, and as a consequence retailers are risk-averse, while thermal producers are not that concerned hedging the area price difference. Kristiansen (2004a) notes that the sample size is limited. Therefore, the inference should be treated cautiously.

Marckhoff and Wimschulte (2009) provide a more throughout study on the pricing of EPADs using methods common in the broader electricity futures literature. They use data over the period 2001 to 2006 and study also the implied area futures. Seasonal contracts constitute significant share of the data they had available (quarterly and monthly products were introduced after 2003). Like Kristiansen (2004a), they use futures prices from the whole trading period instead of the last trading day or shorter period. Their main findings are:

- EPAD prices contain significant ex-post futures premium, whose sign and size vary between the different areas and delivery periods
- the relation between ex-post futures premium and time-to-maturity is not uniform for EPADs, but clearly negative for implied area futures. For the Finnish EPAD the effect of time-to-maturity seems to be negligible for monthly, and yearly contracts, and positive for seasonal and quarterly contracts.
- the skewness and variance of the underlying system and area prices have explanatory power over the ex-post futures premium of EPAD and implied area futures, which provides support for the Bessembinder and Lemmon (2002) model

Similar to Kristiansen (2004a) they attribute the sign and size of futures premium to the different production structure and the resulting transmission congestion between different areas, i.e. asymmetric hedging needs of producer

[17] Back then there were season products, for spring, summer, autumn and winter, and EPADs were called CFDs.

and consumers. They explain the negative relation between futures premium and time-to-maturity for the implied area futures the same way as Fleten and Hagen (2015) for the Nordic and German system futures: producers hedge for longer-term, while retailers for short-term. For the Helsinki EPADs they compute the average futures premium for different contracts (yearly, quarterly, seasonal, and monthly) and find that they range from -1.34€/MWh to 2.79€/MWh and that positive premium occurs significantly more often than negative. They document also that the futures premium for Finnish EPADs is higher for winter contracts, compared to summer contracts, which could indicate asymmetric hedging demand between seasons. For the Bessembinder and Lemmon (2002) model no inference exclusively for Finland is available, because they pool the data from all the areas when testing the model.

Finally, Marckhoff and Wimschulte (2009) hypothesize that the realized area price differences are affected by the level of hydropower production since the production in the Nordic market is dominated by it. They test this hypothesis by regressing weekly realized area price differences for each area on the difference between current weekly water reservoir levels of Finland, Sweden and Norway, and deviation from their historic medians. Unsurprisingly they find that the above-median water reservoir levels in Norway increase the area price spread in other areas, while for example above-median levels in Sweden and Finland, decrease the realized spread in Finland and Sweden. They note that the intuition behind this is trivial: high hydropower production in Norway lowers the system price, but since transmission capacities are limited, the cheap price applies only to Norway, and cannot spread to other countries.

It should be noted that the studies by Marchhoff and Wimschulte (2009) and Kristiansen (2004a) cover only the earlier period after the introduction of the current spot market model. This means that market participants were probably still learning to price the new products. Moreover, the market fundamentals have changed significantly since then. For example, the share of renewable production has increased substantially, the common spot market has expanded to Baltics, Sweden has been divided to four different price areas, and there has been the introduction of emission allowances scheme. Daslakis and Markellos (2009) provide evidence that futures premium in the Nordic market and emission allowances are positively correlated. Viljainen et al. (2012) in turn find evidence that a structural change occurred in the Nordic market after the emission trading began in 2005. It seems intuitive that these effects are also diffused to spot area prices and EPADs[18]. Hence, the results of earlier studies on EPADs' future bias should be interpreted cautiously and new literature is welcome.

More recent conference paper by Spodniak et al. (2014) focuses on the same issues as Marchhoff and Wimschulte (2009) with some additional analysis and much longer sample period (2000-2013). First, they compute also the realized ex-post futures premium for each area and notice that its sign and size vary between different areas and delivery periods. According to their results

[18] This should apply especially well for the Finnish market, since in Finland a significant amount of production capacity is based on fossil fuels.

Helsinki area monthly contracts tend to have on average minor positive futures premium of 0.15€/MWh and ranging from -2.41€/MWh (2010) to 1.76€/MWh (2012), while quarterly and yearly contracts exhibit on average negative premiums of 0.53€/MWh and 0.84€/MWh respectively.

Second, Spodniak et al. (2014) study the determinants of futures premium of EPADs. Similar to Marchoff and Wimshulte (2009) their results vary between bidding areas. For the Finnish EPADs their results indicate a negative relationship of time-to-maturity for month and year contracts. They confirm the findings of Marckhoff and Wimschulte (2009) that the availability of hydropower in different areas affects the realized area price differences.

Finally, similarly to Redl et al. (2009) they model the dynamic relationship between spot and future prices for area price differences with vector autoregressive model to study the efficiency of EPADs pricing. For all the areas except Sweden 4 (Malmö) and Norway 3 (Tromso) they find evidence for bi-directional Granger causality. Their interpretation of market efficiency differs substantially from that of Redl et al. (2009). Spodniak et al. (2014, 27) argue that bi-directional Granger causality, i.e. that lagged spot prices predict futures prices and vice versa, implies that the market is efficient since then the prices "send proper signals to each other". It should be noted that they use daily spot prices and closing price of monthly EPADs, whereas Redl et al. (2009) use monthly EPEX and Nord Pool spot prices and monthly averages of the respective monthly futures prices. I discuss the interpretation of the vector autoregressive model more in chapter 5.

I summarize the discussion on the theoretical framework for the electricity futures, and EPADs pricing with a few conclusions. First, the very nature of electricity makes the electricity market, and futures pricing different from most of other commodities. Second, the most plausible approach to pricing is the expectations theory and risk premium. Same approach can be applied also to EPADs as they are a combination of two conventional electricity futures. Third, if rational expectations hold and the futures market is efficient, any ex-post deviation of future price from the realized spot price can be explained solely by the risk premium, which depends on the asymmetric hedging demand by the hedgers.

In practice, however, it is not straightforward to determine, whether it is the risk premium or systematic forecasting errors (market inefficiency) or both, that causes the spot prices to differ from futures prices ex-post: if the market is efficient, past information should not be useful in predicting the futures prices. Finally, in the electricity market, the role of outside investors is probably small compared to industry participants and speculators. Hence, (assuming rational expectations) risk premium is determined mostly by asymmetric hedging demand of producers and consumers, and speculators risk appetite within the industry. This should apply especially well to Finnish EPADs. Considering that Finland is net importer of electricity, hedging demand by the consumers should exceed that of the generators and futures bias for Finnish EPADs is expected to be positive.

Empirical electricity futures literature have previously been focused on markets in the US, central Europe and Nordic countries, and futures written on their reference spot prices. The starting point for most of the studies is expectations theory, and the common approach is to study the futures bias ex-post despite its shortcomings. Studies seem to document that the ex-post futures bias or premium tends to be positive more often than negative, and that time-to-maturity of a futures contract affects the bias negatively. Yet there seems to be no consensus on determinants of the bias. Some studies link it to risk factors, such as seasonality, market supply and demand conditions, and expected spot price variance and skewness, while some have highlighted that current spot prices contain information about futures prices hinting towards market inefficiency.

The literature on EPADs consists only of few studies, and they tend to document positive bias for the Finnish EPADs. However, some of the studies are out-dated, and the determinants of the bias remain largely unclear. This underscores the need for more research.

4 DATA

In this chapter I present the data used in the empirical analysis. The primary data consist of spot and futures prices data from December 2005 to January 2016 and was obtained from Nord Pool and Nasdaq respectively, whereas data on temperature and water reservoir levels was retrieved from several sources.

Although monthly contracts are less liquid than quarter and year contracts, monthly data was selected to increase the amount of observations and to mitigate the effect of the forecast error. January 2006 was selected as the sample start to allow the market to adapt to the new contracts[19].

4.1 Spot prices, Finnish EPADs prices and future premium

Monthly system and Finnish spot price (computed from hourly averages) data were retrieved from Nord Pool web page for the period of January 2006 – January 2016. The area price difference $S_t^{FIN-SYS,T}$ for each month T was then obtained by subtracting the system price $S_t^{SYS,T}$ from the Finnish area price $S_t^{FIN,T}$:

(4.1) $$S_t^{FIN-SYS,T} = S_t^{FIN,T} - S_t^{SYS,T}$$

The monthly average prices for EPADs were computed as the average of daily closing prices of the last five trading days prior to the contract's delivery month T:

(4.2) $$F_t^{T-1,T} = (\textstyle\sum_{n=-5}^{-1} F_{n,T})/5$$

Thus, for example futures price for delivery in October 2015 equals the average of daily closing prices of 09/30/2015, 09/29/2015, 09/28/2015, 09/25/2015 and 09/24/2015. The daily closing prices were obtained from a database of a third party that has received the data directly from Nasdaq[20].

The ex-post futures premium PR for the delivery month T is then obtained as the difference between the futures price and the realized spot price difference defined in equations 4.1 and 4.2:

(4.3) $$PR_T = F_t^{T-1,T} - S_t^{FIN-SYS,T}$$

[19] The month contracts were introduced in 2003 so that the earliest delivery month was in January 2004.

[20] The original intention was to use volume-weighted average of the actual trades during the last five trading days which would have included also the OTC trades cleared in the exchange. However, the actual trade data proved to be somewhat unreliable, since in the first years of the sample there were months in which volume-weighted average prices of the five last trading days could not be computed due to lack of trading.

Figure 13 depicts the area price difference, futures prices and futures premium.

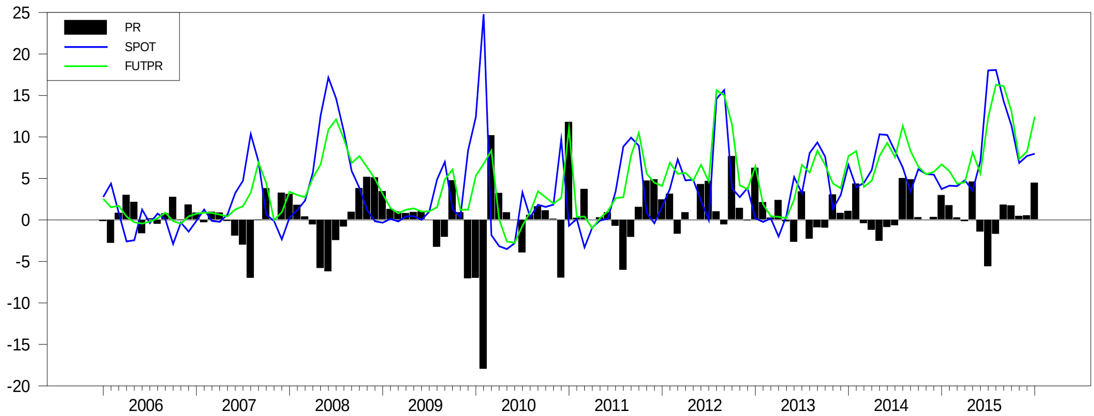

FIGURE 13 Monthly area price difference (SPOT), respective futures prices and (FUTPR) futures premium (PR) (€/MWh) January 2006 – January 2016.

By visual inspection the futures prices seem to lag behind the realized spot price difference. The spike in the area price difference in February 2010 and the resulting large negative premium is notable. On 22nd February 2010 spot prices in Finland, Eastern Denmark and Sweden exceeded 1000€/MWh for several hours while the system price remained at 300€/MWh or below and prices in Southern Norway and Western Denmark well below 100€/MWh. Similar spikes (yet on fewer hours) occurred also on 17th December 2009 and 8th January 2010. The spikes in winter are unprecedented as excluding December 2009, January 2010 and February 2010 observations the maximum hourly area price difference in Finland has been 275.04 €/MWh during the period from January 2006 to January 2016.

The spikes have been explained by below-average temperatures, low availability of Swedish nuclear power plants as well as outages from transmission lines from Norway to Sweden, which increased the area prices in Sweden, Eastern Denmark and Finland (NordReg, 2011, 11-17). Moreover, hydropower availability was below-average (figure 14).

The following example describes the effect of the spikes to the Finnish area price difference and the resulted premium. Assuming that no such spikes would have occurred (that transmission capacities would have been sufficient and all the area prices had been equal to the system price on those days), the realized Finnish area price differences on December 2009, January 2010 and February 2010 would have been 2.26€/MWh, 5.82e/MWh and 11.53€/MWh, respectively, and respective future premiums -1.01€/MWh, 0.49€/MWh and -4.78€/MWh.

Descriptive statistics for the area spot price difference, futures prices and premiums are presented in table 2 (for different seasons in Appendix table A1). As expected, the variance of the area price difference exceeds that of monthly EPAD price since electricity cannot be stored in the same way as numerous other commodities and the underlying spot price has to clear the market without inventories. The traded EPAD price has exceeded the FINSYS spot price by 0.52€/MWh. This result is in line with Spodniak et. al (2014) who document an average premium of 0.15€/MWh for the Finnish month EPADs from 2004 to 2013, although they computed the average premium using the daily closing prices from the whole trading period. However, it is different from zero only at 88% confidence level. After excluding the observations from December 2009, January 2010 and February 2010, the average realized premium is almost 0.30€/MWh higher and different from zero at 99% confidence level, while the variances of the area price difference and futures premium decrease. This emphasizes the effect of the spikes to sample statistics.

TABLE 2 Descriptive statistics of the primary variables. *** marks statistically different from zero at 99% confidence level.

	N	Mean	Median	Variance	St. dev	Min	Max
Monthly EPAD (€/MWh)	121	4.53	4.18	16.81	4.10	-2.76	16.3
FIN-SYS spot diff. (€/MWh)	121	4.01	3.22	26.94	5.19	-3.51	24.78
Futures premium (€/MWh)	121	0.52	0.6	12.96	3.6	-18.03	11.79
Excl. 12/2009 – 2/2010							
Monthly EPAD (€/MWh)	118	4.53	4.13	17.11	4.14	-2.76	16.30
FIN-SYS spot diff. (€/MWh)	118	3.72	2.88	23.09	4.81	-3.51	18.07
Futures premium (€/MWh)	118	0.81***	0.80	9.27	3.05	-7.06	11.79

Recalling the discussion about asymmetric hedging need in chapter 3.3 and that Finland is net importer of electricity, the fact that the realized future premium has been positive is not surprising. However, the premium seems to vary between seasons. Table A1 in the appendix exhibits descriptive statistics within seasons. Futures premium seems to be highest in autumn and lowest, even negative in summer. Furthermore, excluding again the spikes during the 2009 - 2010 winter, the premium becomes statistically significant also in winter exceeding that of autumn.

A possible reason for the seasonality in the premium might be that electricity consumption varies seasonally which might cause the mismatch of hedging demand between natural sellers and buyers of Finnish EPADs to vary also. Alternatively, the market participant's perceived risk is greater in autumn and winter than in summer leading to positive premium during winter and autumn and negative in summer. Lucia and Torro (2011) document that weekly Nordic futures have smaller futures premium in summer than in winter and attribute this to the seasonally varying electricity demand and risk of price spikes.

Partial autocorrelation (PAC) and autocorrelation (AC) coefficients of the primary variables are presented in table 3. PAC, that controls for the effect of all the shorter lags, suggest that both monthly EPAD and FINSYS series depend considerably on their first lagged values, suggesting they could be modeled as an autoregressive process of order one (AR(1)). Moreover, AC values indicate that monthly EPAD and FINSYS spot prices price exhibit rapidly decaying serial correlation. For FIN-SYS the coefficient decays after two lags, whereas for monthly EPAD autocorrelation seems more persistent up to six lags.

TABLE 3 Partial autocorrelation (PAC) and autocorrelation (AC) coefficients of the primary variables.

Autocorrelation	N	1	2	3	4	5	6
Monthly EPAD (€/MWh)	121	0.73	0.5	0.36	0.31	0.23	0.14
FIN-SYS spot diff. (€/MWh)	121	0.62	0.29	0.08	-0.01	0.02	-0.06
Futures premium (€/MWh)	121	0.15	0.01	-0.12	-0.12	0.03	-0.04
Partial autocorrelation	N	1	2	3	4	5	6
Monthly EPAD (€/MWh)	121	0.73	-0.08	0.06	0.1	-0.08	-0.04
FIN-SYS spot diff. (€/MWh)	121	0.62	-0.15	-0.06	0.01	0.08	-0.18
Futures premium (€/MWh)	121	0.15	-0.02	-0.12	-0.09	0.06	-0.07

Decaying AC suggests that both of the series are stationary, or that neither contain unit roots. This is supported by the Dickey-Fuller and Phillips-Perron unit roots tests, whose results are given in table 4. All the test values are more negative than the respective 1% significance level critical levels. This result is in line with findings of Redl et al. (2009) who document that monthly Nordic system futures and spot prices are stationary.

TABLE 4 Dickey-Fuller and Phillips-Perron unit roots tests.

	N	test variable	1%	5%	10%
Dickey-Fuller Unit Root Test					
Monthly EPAD (€/MWh)	121	-3.90	-3.49	-2.89	-2.58
FIN-SYS spot diff. (€/MWh)	121	-5.19	-3.49	-2.89	-2.58
Phillips-Perron Unit Root Test					
Monthly EPAD (€/MWh)	120	-3.82	-3.49	-2.89	-2.58
FIN-SYS spot diff. (€/MWh)	120	-5.16	-3.49	-2.89	-2.58

4.2 Water reservoir level and temperature

As discussed in chapter 2, the demand and supply conditions in the Nordic market are significantly affected by climate and weather. Whereas hydro-power has a crucial impact on the supply, demand is affected by the temperature.

The impact of the hydropower availability to the risk premiums in the Nordic electricity market has been studied at least in Lucia and Torro (2011) and Weron and Zator (2014). Lucia and Torro (2011) study weekly system futures and spot prices and show that below-average water reservoir levels prior to the delivery period increase the futures premium. Similarly, Weron and Zator (2014) document that the relationship between the ex-post risk (futures) premium and deviations in water reservoir from mean levels prior to the delivery period is positive (negative).

The time series of water reservoir level data (as a fraction of the total capacity) for Finland and Sweden were retrieved from Datastream, while both Datastream and Norwegian Water Resources and Energy Directorate provided the data for Norway. Datastream included daily data (from weekly observations) from 11.1.1990 onwards for Sweden and Finland and from 3.1.2002 for Norway. For Norway the period between 11.1.1990 and 2.1.2002 was completed using data from Norwegian Water Resources and Energy Directorate. Finally the monthly values were then computed averaging the daily values. Pearson correlation coefficients of the realized water reservoir levels are presented in table A5 in the Appendix. They reveal that the water reservoir levels of each country are strongly correlated.

Since the water reservoir levels vary seasonally, the market participants focus on the deviations from the historical average levels (Lucia and Torro, 2011). Therefore, following Lucia and Torro (2011) the historical monthly average values were computed for the sample period January 2006 – January 2016 for each month (with $T = 1,..,12$) and year (with $y=2006,..2016$) so that for a given month in a given year the historical value was computed using the observations from 1990 to year y-1. Descriptive statistics of the observed values and deviations from the historical average are depicted in table A2 in the appendix.

The historical and observed values are plotted in figure 14. The seasonal pattern is evident. As Weron and Zator (2014) note, water *inflows* lead the reservoir levels; the largest inflows to the reservoirs occur in the spring and early summer as snow begins to melt. Vice versa, the inflows decrease in the autumn as temperature decreases below zero. As a result, the water reservoir levels are the highest in autumn and lowest in the early spring.

To my knowledge previous research has not examined the effect of temperature to future bias directly. Redl et al. (2009) and Weron and Zator (2014) included to their models electricity consumption indices (deviations from the long-term averages). As presented in chapter 2, electricity demand varies considerably within seasons in the Nordic countries and Finland. Thus, temperature (being more stable than consumption over longer periods) deviations from the long-term average seem as a viable proxy for demand shocks especially in Finland.

January 1971 – January 2016 monthly observed average temperatures were obtained for Helsinki from the Finnish Meteorological Institute. Similar to water reservoir data, the historical monthly average values were computed for the sample period January 2006 – January 2016 for each month (with $T = 1,..,12$) and year (with $y=2006,..2016$) so that for a given month in a given year the historical value was computed using the observations from 1971 to year y-1. Historical and observed values are plotted in figure 15.

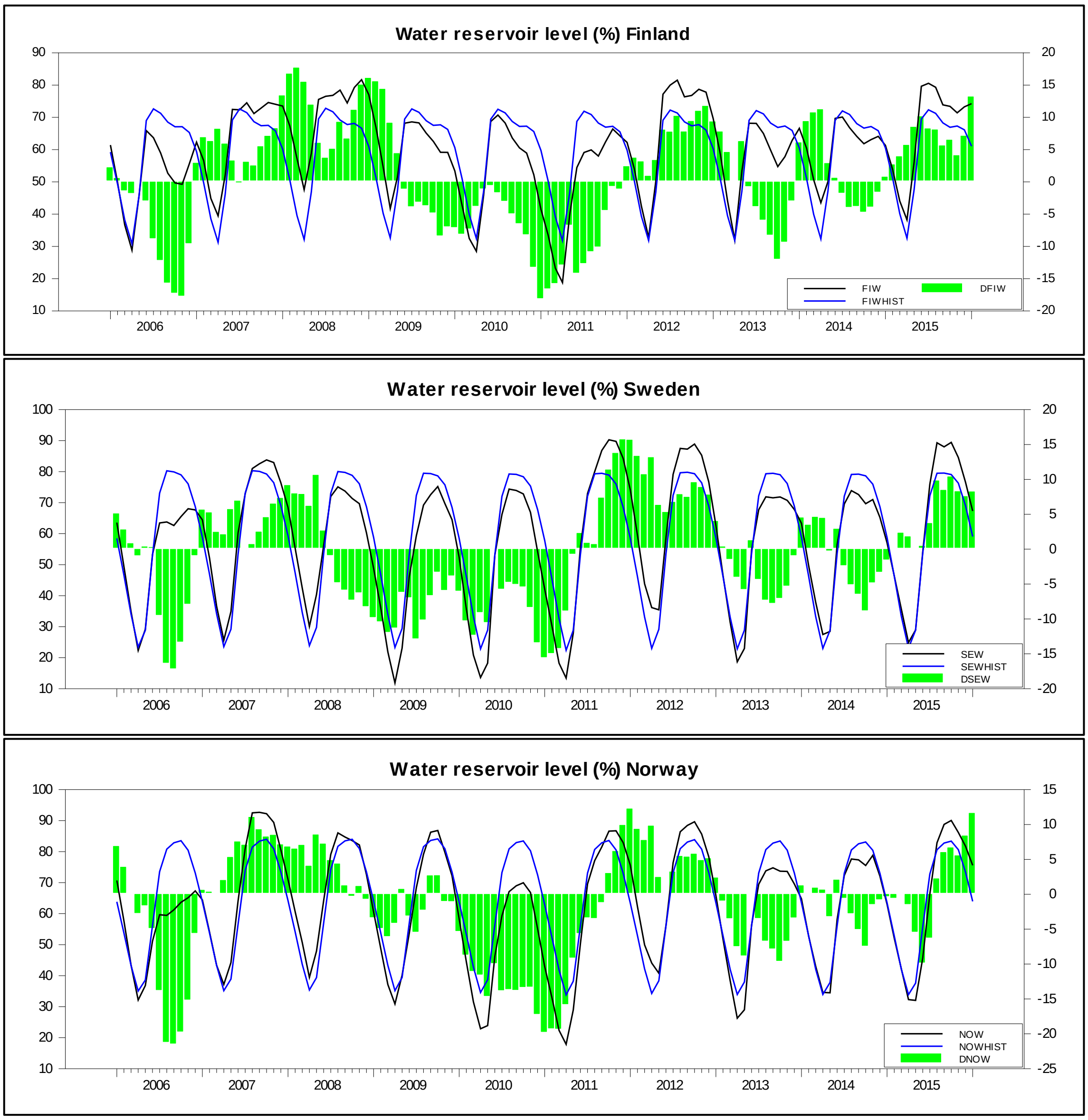

FIGURE 14 Observed and historical water reservoir levels (left axis) and their difference (green bars) (right axis) in Finland, Sweden and Norway from January 2006 to January 2016.

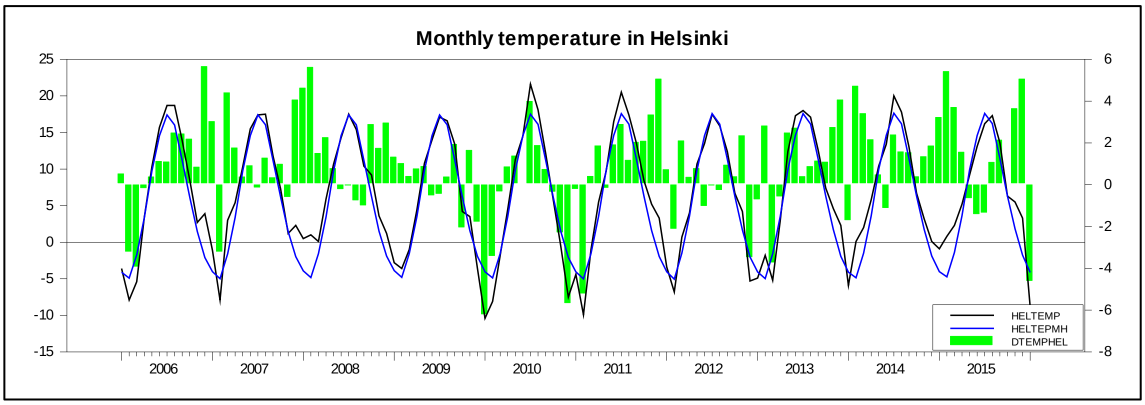

FIGURE 15 Observed (TEMP) and historical (TEMPH) monthly temperatures (left axis) and their difference (DTEMP) (right axis) in Helsinki January 2006 – January 2016.

5 METHODOLOGY

From the previous chapter we already know that Finnish EPADs are (depending on the sample period) somewhat positively biased estimates of the underlying area price difference and that the bias varies between seasons. In this chapter I present the methodology used to examine the research problems of this thesis. I follow Marchhoff and Wimschulte (2009) and Weron and Zator (2014) and test the Bessembinder and Lemmon (2002) model that hypothesizes that the bias depends on skewnesss and variance of the underlying spot price, that are proxies for risk in the model. Moreover, following Weron and Zator (2014) I also test whether the bias can be explained by exogenous variables that are proxies for supply and demand shocks. Finally, similar to Redl et al. (2009) I examine the dynamics of the futures and spot prices by vector autoregressive (VAR) model.

As the notation of the key variables in the previous literature is somewhat ambiguous, I clarify the notation I use throughout the empirical analysis in figure 16. S_t^T denotes the spot price in the delivery month T and $F_t^{T-1,T}$ the futures price whose settlement occurs in the delivery period T. Note that the futures price is observed at *T-1*, that is before the delivery period *T* in the end of the previous month.

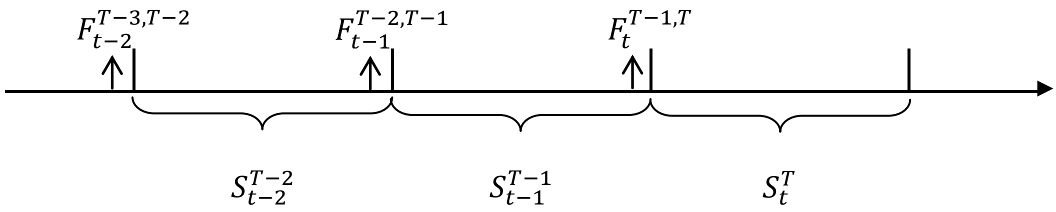

FIGURE 16 The lag notation of futures and spot price series.

5.1 Bessembinder and Lemmon (2002) model

Bessembinder and Lemmon (2002) model has become a popular benchmark in the electricity futures literature and was later tested by Marchhoff and Wimschulte (2009) and Weron and Zator (2014) among others. The model can provide indirect evidence on the determinants of the premium, or more specifically, whether the premium can be explained by proxies for risk (variance and skewness).

Recall from section 3.6.1. that the model suggests that the ex-ante futures premium depends negatively on the variance and positively on the skewness of the expected spot prices. Using the variance and skewness during time *T-1*[21] as a proxy for the expected variance and skewness, the model becomes:

$$(5.1)\quad F_t^{T-1,T} - S_t^{FIN-SYS,T} = a + b_1 Var S_{t-1}^{FIN-SYS,T} + b_2 Skew\left(S_{t-1}^{FIN-SYS,T}\right) + \varepsilon_t$$

or following Marchhoff and Wimschulte (2009) for EPADs using separately skewness and variance of system spot and Finnish area spot price instead of their difference:

$$(5.2)\quad F_t^{T-1,T} - S_t^{FIN-SYS,T} =$$
$$a + b_1 Var\left(S_{t-1}^{SYS,T-1}\right) + b_2 Skew\left(S_{t-1}^{SYS,T-1}\right)\, c_1 Var\left(S_{t-1}^{FIN,T-1}\right) + c_2 Skew\left(S_{t-1}^{FIN,T-1}\right) + \varepsilon_t$$

Marchhoff and Wimschulte (2009) note that *a priori* the coefficient on $Skew(S_{t-1}^{FIN,T-1})$ is expected to be positive (price spikes in previous month increase the Finnish EPADs prices and futures premium if the market participants view that the possibility of further price spikes has increased) while the coefficient on $Skew(S_{t-1}^{SYS,T-1})$ should be negative and the coefficient on variances should be opposite to the signs of the coefficients on skewness.

5.2 Exogeneous variables

Following Weron and Zator (2014) the realized futures premium can also be regressed against other exogenous variables (Z and X), so the general form of the regression equation would be

$$(5.3)\ F_t^{T-1,T} - S_t^{FIN-SYS,T} = a_2 + b_1 Z_{t-1} + b_2 X_{t-1} + \varepsilon_t.$$

The set of additional variables includes water reservoir level at time *t-1* (from the period prior to the delivery period) to examine whether abnormal demand and supply conditions affect the ex-ante premium (assuming rational expectations and forecast error of zero). I use also the water reservoir variable but replace the consumption variable by the temperature as the electricity demand may have changed structurally over the years due to changes in industrial demand. Hence, the temperature variable provides a proxy for purely exogenous demand shocks as electricity demand depends on the temperature during the heating season.

Following Weron and Zetor (2014) I decompose the observed water reservoir level variable to seasonal (historical), and stochastic (deviation from mean) components. Similar decomposition is done also for the temperature variable. The decomposition mitigates the problem that the water reservoir level (or

[21] Variance and skewness are computed from daily spot prices during month T-1 (one month prior to the delivery period)

temperature) exhibits strong seasonality and thus captures the effects of all omitted, seasonal variables, whereas the stochastic component reflects the real effect of the varying water reservoir level or temperature (Weron and Zetor, 2014). The historical temperature in Helsinki is also omitted as it exhibits strong seasonality, which is already captured by the historical water reservoir level.

The model then becomes:

(5.4) $F_t^{T-1,T} - S_t^{FIN-SYS,T} = a_1 + b_1 NOW_{t-1} + b_2 dNOW_{t-1} + b_3 dTEMP_{t-1}^{HEL} + \varepsilon_t$

where NOW_{t-1} is the historical water reservoir level in Norway, $dNOW_{t-1}$ water reservoir level deviation from the average in Norway and $dTEMP_{t-1}^{HEL}$ temperature deviation from average in Helsinki one month prior to the delivery period.

Only the water reservoir level variables from Norway were included since Norway has the largest hydro-reserves and as documented in chapter 4, the water reservoir levels in Finland and Sweden are correlated with Norway's levels which would potentially lead to multicollinearity. Similarly, only the temperature in Helsinki is included in the model as it has the highest impact on the Finnish area price difference.

Weron and Zetor (2014) document that below(above)-average water reservoir level increases (decreases) the futures premium of system futures. For Finnish EPADs the impact should be opposite: below-average water reservoir levels in Norway decrease the possibility of widening area price difference and hence decrease the futures premium. The temperature coefficient should in turn have a negative sign: below-average temperature in Helsinki increases electricity demand in Finland and the risk of widening area price difference, which should increase the futures premium.

Finally I also extend the regression model 5.4 by introducing a dummy variable for the time period after 2011 (so that Y2012 equals 1 for January 2012 and after it) since Russian imports decreased after 2011 autumn. This regression model reads as

(5.5) $F_t^{T-1,T} - S_t^{FIN-SYS,T} = a_1 + b_1 NOW_{t-1} + b_2 dNOW_{t-1} + b_3 dTEMP_{t-1}^{HEL} + b_4 Y2012 + \varepsilon_t$

5.3 Vector-autoregressive model

Vector-autoregressive (VAR) model is a popular method to study the relationship between a set of potentially endogenous variables. Redl et al. (2009) use an unrestricted VAR model to examine EEX peak load and Nord Pool base load contracts. I use the same methodology for Finnish area price difference and EPADs prices.

The vector autoregressive model can be defined as

(5.6) $$y_t = A_0 + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + \varepsilon_t$$

where

$$y_t = \begin{bmatrix} S_t^T \\ F_t^{T-1,T} \end{bmatrix}, A_0 = \begin{bmatrix} a_{10} \\ a_{20} \end{bmatrix}, A_1 = \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix} \text{ and } \varepsilon = \begin{bmatrix} \varepsilon_{10} \\ \varepsilon_{20} \end{bmatrix}$$

S_t^T is the spot price in month *T*, $F_t^{T-1,T}$ is the futures prices at *T-1* for delivery in month *T* as defined in chapter 4. Since both $F_t^{T-1,T}$ and S_t^T are stationary, the VAR model is employed in levels. Impulse responses and variance decomposition of the estimated VAR model can be used to examine the dynamic behavior between the two series.

To account for possible outliers in the cold winter of 2009 – 2010 with supply disruptions and the decrease in the Russian imports after 2012 I add two dummy variables *Y2012* that obtains the value of 1 after *T*=01/2012 and 0 before that and *W0910* (=1, when, *T*=12/2009, 01/2010 or 02/2010, and 0 otherwise). Inserting these into 5.6 yields:

(5.7) $$y_t = A_0 + A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + BY2012 + CW0910 + \varepsilon_t$$

where

$$y_t = \begin{bmatrix} S_t^T \\ F_t^{T-1,T} \end{bmatrix}, A_0 = \begin{bmatrix} a_{10} \\ a_{20} \end{bmatrix}, A_1 = \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix}, \varepsilon = \begin{bmatrix} \varepsilon_{10} \\ \varepsilon_{20} \end{bmatrix}, B = \begin{bmatrix} b_{11} \\ b_{12} \end{bmatrix} \text{ and } C = \begin{bmatrix} c_{11} \\ c_{12} \end{bmatrix}$$

5.4 Granger causality

Granger (1969) proposed a statistical test to examine whether one time series can be used to forecast another. More specifically, consider two stationary time series of variables *X* and *Y*. If *Y* can be forecast better using the past Y and past *X* values than just the past values of *Y*, *X* is said to Granger cause *Y*. Granger (1969, 430) emphasized that this definition of causality refers to predictable causality and that "the flow of time clearly plays a central role in these definitions". The simple causal model can be written:

(5.8a) $$Y_t = a_1 + \sum_{j=i}^{m} b_j X_{t-j} + \sum_{j=i}^{m} c_j Y_{t-j} + \varepsilon$$

(5.8b) $$X_t = a_2 + \sum_{j=i}^{m} d_j Y_{t-j} + \sum_{j=i}^{m} e_j X_{t-j} + \varepsilon$$

Within these models, X_t Granger causes Y_t, if some b_j differs from zero. Similarly Y_t Granger causes X_t, if some d_j is not zero. If both occur, there is a feedback relationship or bi-directional Granger causality between X_t and Y_t. The model can also be extended to include an instantaneous term:

(5.9) $$Y_t = a_1 + fX_t + \sum_{j=i}^{m} b_j X_{t-j} + \sum_{j=i}^{m} c_j Y_{t-j} + \varepsilon_t$$

Redl et al. (2009) link the Granger causality to the market efficiency, which was discussed in chapter 3. They test the model with one lag for monthly EEX and Nord Pool contracts. Using (5.8) their model can be written (applying the same notation I have used so far) as

(5.10a) $$F_t^{T-1,T} = a_2 + d_1 S_{t-1}^{FIN-SYS,T-1} + e_1 F_{t-1}^{T-2,T-1} + \varepsilon_t$$

(5.10b) $$S_t^{FIN-SYS,T} = a_1 + b_1 F_{t-1}^{T-2,T-1} + c_1 S_{t-1}^{FIN-SYS,T-1} + \varepsilon_t$$

They find that both the spot and futures prices can be explained by their lagged values. In addition, they find that spot prices Granger cause futures prices (d_1 is significantly different from zero) but futures prices do not Granger cause the spot prices (b_1 is not significantly different from zero). Redl et al. (2009, 361) conclude that "spot prices in the trading period of the forward contracts are relevant for price formation of the forwards whereas the opposite is not true" and therefore argue that "there is strong evidence that the predictive power of the forward price is weak".

Closer look at the results of Redl et al. (2009) reveals, why they are not as striking as would seem at the first glance and why their conclusion can be criticized. First, note the time denotation of the futures term in the equation 5.10b. The term $F_{t-1}^{T-2,T-1}$ refers to the price of futures contract, whose delivery period is *T-1*. Hence, it should be no surprise that it does not explain well the spot price at *T*. The more fruitful approach will be to replace $F_{t-1}^{T-2,T-1}$ with an "instantaneous" term $F_t^{T-1,T}$ so that the set of equations will be:

(5.11a) $$F_t^{T-1,T} = a_2 + d_1 S_{t-1}^{FIN-SYS,T-1} + e_1 F_{t-1}^{T-2,T-1} + \varepsilon_t$$

(5.11b) $$S_t^{FIN-SYS,T} = a_1 + b_1 F_t^{T-1,T} + c_1 S_{t-1}^{FIN-SYS,T-1} + \varepsilon_t$$

Second, Redl et al. (2009) argue that their results imply that the futures market might not be efficient, since spot prices in the trading period affect futures (whose delivery period is the next month) prices. This would certainly be a valid conclusion if the spot prices of the consequent months would not be strongly correlated. However, spot prices are auto-correlated as is evident from the significance of c_1 in their results. Therefore, it is not completely surprising that the market participants' expectations (the futures price) of the next month's spot price are affected by the spot price in the preceding month. Nevertheless, in an efficient market one should *a priori* expect the coefficient d_1 to be less significant and further away from unity than the coefficient b_{1^*}.

6 RESULTS AND DISCUSSION

The data presented in chapter 4 confirmed that Finnish EPADs are to some extent biased estimates of the monthly area spot price difference. In this chapter I present the results of the OLS regressions, VAR analysis and Granger causality tests and attempt to answer the remaining research problems.

6.1 Results from the analysis of the Bessembinder and Lemmon (2002) model

Empirical results based on equations 5.1 and 5.2. are presented in tables 5 and 6.

TABLE 5 Regression results of eq. 5.1.

$$F_t^{T-1,T} - S_t^{FIN-SYS,T} = a + b_1 VarS_{t-1}^{FIN-SYS,T} + b_2 Skew\left(S_{t-1}^{FIN-SYS,T}\right) + \varepsilon_t$$

The Newey-West correction was used to obtain the autocorrelation and heteroscedasticity consistent standard errors. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.
H(0): α=0, β_i=0. t-stastistics in parenthesis.

Sample	a	b_1	b_2	n	R-bar^2
Full	0.68***	1x10^{-3}	-0.40*	121	0.02
	(2.56)	(0.78)	(1.69)		
Excl. (12/2009-3/2010)	0.55*	0.01	-0.16	116	0.00
	(1.81)	(0.91)	(0.97)		

TABLE 6 Regression results of eq. 5.2.

$$\begin{aligned} F_t^{T-1,T} - S_t^{FIN-SYS,T} &= a + b_1 Var\left(S_{t-1}^{SYS,T-1}\right) + b_2 Skew\left(S_{t-1}^{SYS,T-1}\right) + c_1 Var(S_{t-1}^{FIN,T-1}) \\ &+ c_2 Skew(S_{t-1}^{FIN,T-1}) + \varepsilon_t \end{aligned}$$

The Newey-West correction was used to obtain the autocorrelation and heteroscedasticity consistent standard errors. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.
H(0): α=0, β_i=0, c_i=0. t-stastistics in parenthesis.

Sample	a	b_1	b_2	c_1	c_2	n	R-bar^2
Full	0.73***	-3x10^{-3}	0.60*	1x10^{-3}	-0.80*	121	0.00
	(2.57)	(0.46)	(1.77)	(0.31)	(1.75)		
Excl. (12/2009-2/2010)	0.83**	-4x10^{-3}	0.67**	-4x10^{-3}	-0.25	116	0.00
	(2.27)	(0.25)	(2.13)	(0.24)	(0.60)		

The results show no support for the Bessembinder & Lemon (2002) model, or the findings of Marchhoff and Wimschulte (2009) with respect to the coefficients of the risk variables. In the regression 5.1 the coefficient of skewness is statistically significant but of the opposite sign than expected. Since extreme price spikes in winter December 2009, January 2010 and February 2010 yielded extreme levels of skewness, variance and futures premium, I run the regression also excluding those observations from the sample. This yields also the coefficient of skewness to be statistically insignificant.

In the regression 5.2 the risk variables are calculated based both on the system spot and Finnish area price. The coefficients of variances are again insignificant. Meanwhile, the signs of skewness coefficients are opposite than expected but statistically significant, which seems a bit puzzling, since this would imply that the Finnish EPAD futures are more overpriced, the higher was the system price risk (as measured by skewness of the distribution of daily system price) during the preceding month. Moreover, R^2-value of the regression is low. I also regressed the premium against kurtosis but similar to skewness the sign of the kurtosis coefficients were opposite than expected and insignificant.

Possible reason for the results could be that the market participants view the risk of higher Finnish area prices as temporary[22] and not overbid the next month's futures price despite the elevated risk in the previous period. Moreover, the correlation between $Skew\left(S_{t-1}^{SYS,T-1}\right)$ and $Skew(S_{t-1}^{FIN,T-1})$ is rather high (0.70) which might lead to collinearity problem and distort the results. Hence, the results of equation 5.1 seem more robust and as such, it seems that risk considerations (at least measured by skewness, variance or kurtosis of the daily area price difference) are not meaningful for monthly Finnish EPADs pricing. It should also be noted that Marchhoff and Wimschulte (2009) aggregated the futures premium of all the EPADs when they obtained results supporting the model. Thus their results are not directly comparable to the results of this thesis.

However, the constant is statistically significant and positive in both regressions. The positive constant indicates a positive futures premium, or in other words, that the futures price has been on average higher than the respective realized area price difference, and that short selling of the futures before the delivery period would have produced positive returns. This result is in line with Marchoff and Wimschulte (2009) for the pooled EPADs contracts and Redl et al. (2009) for the monthly EEX and Nord Pool contracts, since they also document positive constants in their Bessembinder and Lemmon (2002) regressions.

[22] Finnish area prices often spike due to sudden, yet relatively short failures or outages in transmission capacity from Sweden or nuclear power plants. This applies especially to the period after 2012 (decreased Russian imports).

6.2 Regression results from the model with exogeneous variables

The results from the equation 5.4 are presented in table 7. Contrary to findings of Weron and Zetor (2014) only seasonal component of the water reservoir variable NOW_{T-1} seems significant. It captures all the seasonal effects so that the higher is the absolute water reservoir level, the higher is the futures premium. This is consistent with the fact that the premium has been highest during autumns and lowest during summers as presented in chapter 4.

TABLE 7 Regression results of eq. 5.4.

$$F_t^{T-1,T} - S_t^{FIN-SYS,T} = a_1 + b_1 NOW_{t-1} + b_2 dNOW_{t-1} + b_3 dTEMP_{t-1}^{HEL} + \varepsilon_t$$

The Newey-West correction was used to obtain the autocorrelation and heteroscedasticity consistent standard errors. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.
H(0): α=0, β_i=0. t-stastistics in parenthesis.

Sample	a	b1	b2	b3	n	R-bar²
Full	-1.26	0.03*	0.00	0.12	120	0.00
	(1.29)	(1.72)	(0.00)	(0.41)		
Excl. (12/2009-3/2010)	-1.52*	0.04**	0.01	-0.09	116	0.03
	(1.73)	(2.62)	(0.28)	(0.54)		

TABLE 8 Regression results of eq. 5.5.

$$F_t^{T-1,T} - S_t^{FIN-SYS,T} = a_1 + b_1 NOW_{t-1} + b_2 dNOW_{t-1} + b_3 dTEMP_{t-1}^{HEL} + b_4 Y2012 + \varepsilon_t$$

The Newey-West correction was used to obtain the autocorrelation and heteroscedasticity consistent standard errors. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively
.H(0): α=0, β_i=0. t-stastistics in parenthesis.

Sample	a	b1	b2	b3	b4	n	R-bar²
Full	-1.69*	0.03*	-0.01	0.10	0.95*	120	0.005
	(1.69)	(1.76)	(0.35)	(0.37)	(1.64)		
Excl. (12/2009-3/2010)	-1.81**	0.04***	0.00	-0.09	0.63	116	0.03
	(2.03)	(2.63)	(0.03)	(0.57)	(1.17)		

The results from the regression taking into account the period after 2012 are shown in table 8. The dummy variable is statistically significant at the 10% level and implies that the premium has been 0.95€/MWh higher after 2012 after controlling for seasonality, and water reservoir and temperature variables. The result is intuitive as the Russian importers might have been natural sellers of Finnish EPADs and as imports from Sweden have increased, the "deficit" between natural buyers and sellers of Finnish EPADs has widened further. Otherwise, the results do not change after adding the *Y2012* control variable. However, the sign of constant term is now negative in the regressions 5.4 and 5.5 in contrast to the regressions 5.1 and 5.2. Weron and Zetor (2014) and Redl et al. (2009) obtain a similar result in their regressions that include both fundamental and risk variables. After excluding the winter of 2009-2010 from the sample, the statistical significance of *Y2012* dummy variable decreases substantially, but otherwise the results do not change meaningfully.

Regression equation 5.5 may still suffer from an omitted variable bias. Important variables that may affect market participants' perception of risk include expected availability of transmission lines from Sweden to Finland, and availability of nuclear power in Finland. Both of them affect the area price risk in Finland. Unfortunately data on them was not available, and thus they could not be included in the regression.

6.3 Results from the VAR analysis

The optimal lag length for the vector autoregressive model was assessed using the Akaike information criterion (AIC) and optimal lag structure selection procedure in RATS. It suggested that the proper lag length, or VAR order, is two. I also run the regressions with a lag length of one to compare the results to those of Redl et al. (2009). The results for the basic VAR are presented in table 9 and 10.

The results have multiple implications. First, they reveal the autocorrelation structure of the both series; the lagged values explain the current values of both series. For the spot price series both lags are significant whereas for the futures prices only the first lag. This is confirmed by the F-tests. Second, the lagged spot prices (especially the first lag) are significant in explaining the current futures prices. This is also confirmed by the F-tests, which indicate that *S* Granger-causes *F*. This implies that the previous spot price affects the market's expectation of the next month's spot price, that is, the futures price for the next month's delivery period, and provides evidence that the futures pricing may be inefficient at least to some extent. However, it is not possible to state that the market is completely inefficient although the past prices help explain the futures prices. As the consecutive area spot differences are autocorrelated, the market is not totally irrational when it resorts to the previous realized spot price difference in estimating the next month's area price difference.

TABLE 9 The results of the basic VAR(2) model. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.

$$\begin{bmatrix} S_t^{FIN-SYS,T} \\ F_t^{T-1,T} \end{bmatrix} = \begin{bmatrix} a_{10} \\ a_{20} \end{bmatrix} + A_1 \begin{bmatrix} S_{t-1}^{FIN-SYS,T-1} \\ F_{t-1}^{T-2,T-1} \end{bmatrix} + A_2 \begin{bmatrix} S_{t-2}^{FIN-SYS,T-2} \\ F_{t-2}^{T-3,T-2} \end{bmatrix} + \varepsilon$$

H(0): α=0, β_i=0. t-stastistics in parenthesis.

Variable	$S_t^{FIN-SYS,T}$	$F_t^{T-1,T}$
constant	1.262** (2.15)	0.984*** (3.19)
$S_{t-1}^{FIN-SYS,T-1}$	0.603*** (5.75)	0.478*** (8.68)
$S_{t-2}^{FIN-SYS,T-2}$	-0.308** (2.38)	-0.259*** (3.81)
$F_{t-1}^{T-2,T-1}$	0.437** (2.21)	0.522*** (5.04)
$F_{t-2}^{T-3,T-2}$	-0.089 (0.61)	0.080 (1.05)
Durbin-Watson stat.	2.01	2.01
Observations	119	119

F-Tests. Dependent variable $S_t^{FIN-SYS,T}$

Variable	F-Statistic	Signif
S	17.8205	0.000
F	2.5169	0.085

F-Tests. Dependent variable $F_t^{T-1,T}$

Variable	F-Statistic	Signif
S	41.1952	0.000
F	19.0134	0.000

Finally, the results over the predictive power of lagged futures prices on the spot prices are mixed. In the VAR(1) setup the *previous* futures price (one month ago) does not have predictive power over the next month's spot price. This result should be no surprise and is in line with that of Redl et al. (2009) (who studied different market), although their interpretation is different. They argue that the result provides evidence that the futures market does not predict the spot price, but as discussed in chapter 5, closer look at the notation reveals that this interpretation is misleading. In contrast, in VAR(2) setup, which was estimated to be optimal lag structure and has Durbin-Watson statistic closer to two, also the futures price one month ago help explain the next month's area price difference.

TABLE 10 The results of the basic VAR(1) model. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.

$$\begin{bmatrix} S_t^{FIN-SYS,T} \\ F_t^{T-1,T} \end{bmatrix} = \begin{bmatrix} a_{10} \\ a_{20} \end{bmatrix} + A_1 \begin{bmatrix} S_{t-1}^{FIN-SYS,T-1} \\ F_{t-1}^{T-2,T-1} \end{bmatrix} + \varepsilon$$

H(0): α=0, β_i=0. t-stastistics in parenthesis.

Variable	$S_t^{FIN-SYS,T}$	$F_t^{T-1,T}$
constant	1.402** (2.51)	1.232*** (4.08)
$S_{t-1}^{FIN-SYS,T-1}$	0.592*** (5.65)	0.451*** (7.94)
$F_{t-1}^{T-2,T-1}$	0.058 (0.44)	0.341*** (4.69)
Durbin-Watson stat.	1.77	1.556
Observations	119	119

F-Tests. Dependent variable $S_t^{FIN-SYS,T}$

Variable	F-Statistic	Signif
S	31.96	0.000
F	0.19	0.660

F-Tests. Dependent variable $F_t^{T-1,T}$

Variable	F-Statistic	Signif
S	63.11	0.000
F	21.96	0.000

I run the VAR models also with time dummies to control for periods in December 2009 – February 2010 and after 2012. The results are presented in tables 11 and 12 and do not change meaningfully from the basic models, although they indicate the significance of the respective periods.

TABLE 11 The results of the VAR(2)-X model. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.

$$\begin{bmatrix} S_t^{FIN-SYS,T} \\ F_t^{T-1,T} \end{bmatrix} = \begin{bmatrix} a_{10} \\ a_{20} \end{bmatrix} + A_1 \begin{bmatrix} S_{t-1}^{FIN-SYS,T-1} \\ F_{t-1}^{T-2,-1T} \end{bmatrix} + A_2 \begin{bmatrix} S_{t-2}^{FIN-SYS,T-2} \\ F_{t-2}^{T-3,T-2} \end{bmatrix} + \begin{bmatrix} b_{11} \\ b_{12} \end{bmatrix} Y2012 + \begin{bmatrix} c_{11} \\ c_{12} \end{bmatrix} W0910 + \varepsilon$$

H(0): $\alpha=0$, $\beta_i=0$. t-stastistics in parenthesis.

Variable	$S_t^{FIN-SYS,T}$	$F_t^{T-1,T}$
constant	0.707 (1.31)	0.911*** (3.02)
$S_{t-1}^{FIN-SYS,T-1}$	0.510*** (5.27)	0.4889*** (9.01)
$S_{t-2}^{FIN-SYS,T-2}$	-0.252** (2.03)	-0.181** (2.60)
$F_{t-1}^{T-2,T-1}$	0.460** (2.40)	0.395*** (3.68)
$F_{t-2}^{T-3,T-2}$	-0.180 (1.30)	0.003 (0.04)
Y2012	1.763** (2.08)	1.565** (3.30)
W0910	11.054*** (5.05)	-0.34 (0.28)
Durbin-Watson stat.	1.85	1.97
Observations	119	119

F-Tests. Dependent variable $S_t^{FIN-SYS,T}$

Variable	F-Statistic	Signif
S	14.9733	0.000
F	3.0951	0.049

F-Tests. Dependent variable $F_t^{T-1,T}$

Variable	F-Statistic	Signif
S	42.0593	0.000
F	7.3890	0.001

TABLE 12 The results of the VAR(1)-X model. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.

$$\begin{bmatrix} S_t^{FIN-SYS,T} \\ F_t^{T-1,T} \end{bmatrix} = \begin{bmatrix} a_{10} \\ a_{20} \end{bmatrix} + A_1 \begin{bmatrix} S_{t-1}^{FIN-SYS,T-1} \\ F_{t-1}^{T-2,-1T} \end{bmatrix} + \begin{bmatrix} b_{11} \\ b_{12} \end{bmatrix} Y2012 + \begin{bmatrix} c_{11} \\ c_{12} \end{bmatrix} W0910 + \varepsilon$$

H(0): α=0, β_i=0. t-stastistics in parenthesis.

Variable	$S_t^{FIN-SYS,T}$	$F_t^{T-1,T}$
constant	0.708 (1.34)	0.98*** (3.33)
$S_{t-1}^{FIN-SYS,T-1}$	0.519*** (5.30)	0.481*** (8.81)
$F_{t-1}^{T-2,T-1}$	0.041 (0.30)	0.198** (2.59)
Y2012	1.942** (2.42)	1.90*** (4.24)
W0910	10.720** (2.25)	-0.440 (0.34)
Durbin-Watson stat.	1.61	1.57
Observations	119	119

F-Tests. Dependent variable $S_t^{FIN-SYS,T}$

Variable	F-Statistic	Signif
S	28.1104	0.000
F	0.0915	0.762

F-Tests. Dependent variable $F_t^{T-1,T}$

Variable	F-Statistic	Signif
S	77.69	0.000
F	6.72	0.011

As discussed in chapter 6.3 the inference of VAR setup was to some extent ambiguous owing to the fact that it includes no contemporary futures price. To shed more light on the pricing dynamics I regress the spot price against its lags and lagged and *contemporary* futures prices, since the spot price and futures price for the same delivery period constitute perhaps the most interesting relationship between the two series. The results are presented in tables 13 and 14.

Both of these modified tests indicate that the contemporary futures price has significant predictive power over the spot price difference for the respective delivery period. The F-tests confirm that when contemporary futures price is included, the futures prices Granger cause the spot price. This mitigates the relevance of the earlier results that suggested the market may be inefficient as it used previous prices in futures prices for the next period.

TABLE 13 Regression results of eq. 5.11b.

$S_t^{FIN-SYS,T} = a_1 + b_1 F_t^{T-1,T} + c_1 S_{t-1}^{FIN-SYS,T-1} + \varepsilon_t$

The Newey-West correction was used to obtain the autocorrelation and heteroscedasticity consistent standard errors. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.

H(0): α=0, β_i=0, c_i=0. t-stastistics in parenthesis.

Sample	a	b_1	c_1	n	R-bar^2
Full	-0.07	0.81***	0.110	120	0.52
	(0.18)	(3.82)	(0.50)		

F-Tests. Dependent variable $S_t^{FIN-SYS,T}$

Variable	F-Statistic	Signif
F	14.56	0.000

TABLE 14 Regression results of modified eq. 5.11b with two lags.

$S_t^{FIN-SYS,T} = a_1 + b_1 F_t^{T-1,T} + c_1 S_{t-1}^{FIN-SYS,T-1} + d_1 F_{t-1}^{T-2,-1T} + e_1 S_{t-2}^{FIN-SYS,T-2} + \varepsilon_t$

The Newey-West correction was used to obtain the autocorrelation and heteroscedasticity consistent standard errors. *, ** and *** mark the significance of parameter estimates at 10, 5 and 1 % risk levels, respectively.

H(0): α=0, β_i=0, c_i=0, d_i=0. t-stastistics in parenthesis.

Sample	a	b_1	c_1	d_1	e_1	n	R-bar^2
Full	0.194	0.879***	0.204	-0.115	-0.124	119	0.53
	(0.41)	(4.34)	(0.85)	(0.51)	(1.62)		

F-Tests. Dependent variable $S_t^{FIN-SYS,T}$

Variable	F-Statistic	Signif
F	18.51	0.000

In conclusion, there is a clear bi-directional causality between the futures and spot prices. This is illustrated in figure 17. On one hand, $S_{t-1}^{FIN-SYS,T-1}$ (the previous spot price) influences $F_t^{T-1,T}$(the futures price, or market's expectation for the spot price in next month's delivery period), and on the other hand $F_t^{T-1,T}$ also has predictive power over $S_t^{FIN-SYS,T}$ (the next month's spot price). The connecting link seems to be the fact that the spot prices are autocorrelated. This implies that the market's expectation of the next month's spot price may be at least partially influenced by the spot price in the previous period and at the same time the futures market need not be as inefficient as would seem at the first glance.

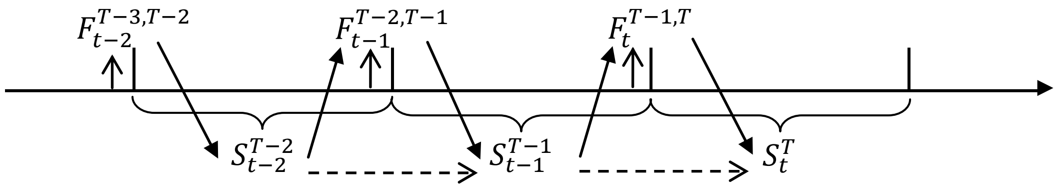

FIGURE 17 A stylized figure describing the bi-directional relationship between the spot and futures prices.

The strong bi-directional relationship might to some degree contribute to the seasonality observed in the ex-post futures premium; the realized Finnish area price has been on average the lowest in spring and highest in summer, while the ex-post premium has been the lowest in summer and highest in autumn. Thus, it is possible that the lower area price difference in spring affects the market perceptions of the area price difference in summer leading to underbidding of the summer futures contracts and respectively, the higher area price difference in summer raises the expectations of autumn prices. It should be emphasized that this (naive) explanation cannot possibly explain wholly the observed seasonality in the ex-post futures premium. Rather, it should be viewed as weak evidence that the strong bi-causal relationship may not be completely irrelevant to the observed seasonality.

7 CONCLUSIONS

In recent years, the electricity spot prices have been systematically higher in Finland than in the other Nordic countries. This has exposed the Finnish market participants to significant basis risks when using only the Nordic system futures for hedging. This thesis has examined the pricing of Finnish EPADs that are used to hedge the price difference between the Finnish spot price and the Nordic system price. More specifically, I have analyzed whether the monthly EPADs prices are biased estimates of the future area price difference and whether the bias can be attributed to market inefficiency or a risk premium.

The results imply that on average the futures prices before the delivery period have exceeded the Finnish area spot price difference in the respective delivery period. This result is intuitive as Finland is a net importer of electricity and as a consequence, there are less natural sellers of Finnish EPADs than buyers and since the area price difference risk is biased to upside. The positive bias is also in line with the results from Redl et al. (2009) or Lucia and Torro (2011) from different electricity markets.

The bias seems to vary between seasons, and is significantly different from zero only when excluding extreme observations of winter 2009 - 2010 from the sample. Again, Lucia and Torro (2011) obtained a similar result for the weekly Nordic system futures. A possible reason for the seasonality might be that electricity consumption varies seasonally which might cause the systematic mismatch of hedging demand between natural sellers and buyers of Finnish EPADs to vary also. Alternatively, the market participant's perceived risk may be greater in autumn and winter than in summer leading to positive premium during winter and autumn and negative in summer.

Both risk considerations and market inefficiency seem to explain the bias. However, I document little support for the findings of previous studies, that have linked the bias to abnormal electricity supply and demand conditions (Weron and Zator, 2014) or different kind of risk proxies derived from realized spot price distributions in the preceding period (Marchhoff and Wimschulte, 2009).

Instead I discover some evidence that the bias has increased after 2012. This could be attributed to the decrease in Russian imports, which may have widened the imbalance between the electricity consumers and generators that naturally hedge the Finnish area price leading to a positive futures premium in the futures market. The fact that the bias, similar to electricity consumption pattern, exhibits seasonality, might also suggest that it may to some extent be explained by risk considerations.

Finally, I document bi-directional causality between the Finnish area price difference and the EPADs, which could hint that the bias may at least partly stem from a somewhat inefficient, backward-looking futures market that utilizes realized area spot price difference to estimate the next period's area spot price difference. Redl et al. (2009) found similar results for the Nordic system and EEX futures. The bi-directional relationship might also contribute to the seasonality of the futures premium as the area price difference exhibits also some seasonality. However, due to the fact that the area spot price differences are autocorrelated it is impossible state that the futures market is completely inefficient even when it incorporates past information to futures prices for the next's period price.

The results show that the Finnish market participants should pay attention to their area price hedging policies and timing as the futures market has somewhat positive bias that varies within seasons, and since the market may be somewhat backward-looking. Due to the fact that this thesis has solely focused on Finnish EPADs and monthly contracts and the EPADs are unique to each bidding area which by themselves has unique fundamentals, it is unclear how widely the results can be generalized to other bidding areas. However, it seems reasonable to assume that they may well exhibit similar peculiarities for example in terms of past spot prices affecting the futures market.

Future research could focus on different areas. For example, it would be productive to examine the Finnish EPADs futures pricing during the trading period of the futures contract. This approach would also enable to concentrate in greater detail to the liquid annual and quarterly contracts as the sample size would increase. On the same occasion, the efficiency of the plain futures market could be studied by constructing synthetic portfolios of contracts with different maturity and analyze whether there are price discrepancies between for example quarter and synthetic quarter contracts (constructed from monthly contracts). Another interesting line of research could focus on the area price differences in itself and, for example, attempt to shed light how different kind of supply and demand shocks affect the area price differences in the Nordic market.

APPENDIX

TABLE A1 Descriptive statistics of Monthly EPAD, FIN-SYS spot price difference and futures premiums within different seasons. . *** and * mark statistically different from zero at 99% and 90% confidence levels for future premiums.

	N	Mean	Median	Variance	St. dev	Min	Max
spring							
Monthly EPAD (€/MWh)	30	2.59	1.31	8.73	2.95	-2.60	8.37
FIN-SYS spot diff. (€/MWh)	30	1.78	0.47	16.25	4.03	-3.51	12.57
Futures premium (€/MWh)	30	0.81	0.60	7.00	2.65	-5.89	10.19
summer							
Monthly EPAD (€/MWh)	30	5.00	3.01	26.47	5.14	-2.76	16.30
FIN-SYS spot diff. (€/MWh)	30	6.10	4.79	35.12	5.93	-2.80	18.07
Futures premium (€/MWh)	30	-1.09*	-0.92	9.48	3.08	-7.06	5.03
autumn							
Monthly EPAD (€/MWh)	30	6.12	6.22	17.70	4.21	-0.45	16.13
FIN-SYS spot diff. (€/MWh)	30	4.57	3.62	20.59	4.54	-2.90	15.65
Futures premium (€/MWh)	30	1.55***	1.06	5.44	2.33	-2.14	7.68
winter							
Monthly EPAD (€/MWh)	31	4.41	3.82	9.75	3.12	0.36	12.46
FIN-SYS spot diff. (€/MWh)	31	3.60	2.77	28.39	5.33	-2.34	24.78
Futures premium (€/MWh)	31	0.81	1.76	26.90	5.19	-18.03	11.79
winter excl. 12/2009 – 2/2010							
Monthly EPAD price (€/MWh)	28	4.41	3.76	10.23	3.20	0.36	12.46
FIN-SYS spot diff. (€/MWh)	28	2.36	1.45	9.62	3.10	-2.34	9.69
Futures premium (€/MWh)	28	2.05***	1.82	10.51	3.24	-7.04	11.79

TABLE A2 Descriptive statistics of realized monthly water reservoir levels and deviation variables (realized – historical average) in Finland, Sweden and Norway January 2006 – January 2016.

	N	Mean	Median	Variance	St. dev	Min	Max
Water reservoir level FIN (%)	121	60.15	62.25	195.92	14.00	18.80	81.67
Water reservoir level SWE (%)	121	57.69	63.47	445.13	21.10	11.86	90.28
Water reservoir level NOR (%)	121	61.84	64.46	375.29	19.37	17.87	92.68
Water reservoir level diff. FIN (%)	121	0.89	2.20	73.47	8.57	-18.23	17.67
Water reservoir level diff. SWE (%)	121	-0.61	0.07	60.20	7.76	-17.29	15.71
Water reservoir level diff. NOR (%)	121	-1.82	-0.72	64.43	8.03	-21.60	12.24

TABLE A3 Descriptive statistics of the realized monthly temperature and deviation variables (realized – historical average) in Helsinki January 2006 – January 2016.

	N	Mean	Median	Variance	St. dev	Min	Max
Temperature Helsinki (°C)	121	6.54	5.80	66.05	8.13	-10.40	21.60
Temperature diff. Helsinki (°C)	121	0.93	1.06	5.33	2.31	-6.36	5.99

TABLE A4 Autocorrelation (AC) and partial autocorrelation (PAC) coefficients of the water reservoir level and temperature deviation variables.

Autocorrelation	N	1	2	3	4	5	6
Water reservoir level diff. FIN (%)	121	0.91	0.77	0.61	0.44	0.31	0.23
Water reservoir level diff. SWE (%)	121	0.89	0.75	0.60	0.46	0.34	0.24
Water reservoir level diff. NOR (%)	121	0.89	0.75	0.62	0.49	0.37	0.26
Temperature diff. Helsinki (°C)	121	0.27	0.11	0.15	-0.04	-0.10	-0.10

Partial autocorrelation	N	1	2	3	4	5	6
Water reservoir level diff. FIN (%)	121	0.91	-0.34	-0.12	-0.09	0.13	0.06
Water reservoir level diff. SWE (%)	121	0.89	-0.21	-0.10	-0.01	-0.03	-0.01
Water reservoir level diff. NOR (%)	121	0.89	-0.27	0.00	-0.02	-0.07	0.05
Temperature diff. Helsinki (°C)	121	0.27	0.04	0.12	-0.12	-0.09	-0.07

TABLE A5 Pearson correlation coefficients of the monthly water reservoir levels from January 2006 to January 2016 in Finland, Sweden and Norway.

	FI	SE	NO
FI	1.00		
SE	0.78	1.00	
NO	0.79	0.96	1.00

TABLE A6 VAR lag selection results.

Lags	AICC
0	1214.43
1	1090.06
2	1083.38*
3	1088.01
4	1092.01
5	1097.34
6	1101.78
7	1111.12
8	1120.46
9	1128.13
10	1136.23
11	1133.87
12	1142.82

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