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The Nordic-Baltic Electricity Market: An Empirical Analysis of Market Efficiency

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Abstract

Increased competition faced by producers may have important consequences for electricity markets. Using 13 years of spot and futures prices, this study analyses whether introducing the Baltic states to the Nordic electricity market has translated into increased market efficiency. The theory of storage and convenience yield is considered in a regression model to allow comparison with previous findings on Nord Pool's efficiency. The results are significant and show an increased net convenience yield, equally distributed over the year, indicating a change in risk preferences of supply and demand. I argue that low spot prices incentivise hydropower producers to hedge a larger share of their production to ensure future operations. Spot price variance, water reservoir level and wind power are also found to have increased influence on this behaviour.

Keywords: Electricity, Nord Pool Spot, Convenience yield, Hydropower

JEL: C20, C52, Q4, Q41

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Preface

This Master's thesis, titled *The Nordic-Baltic Electricity Market: An Empirical Analysis of Market Efficiency* was undertaken as my final work at Stockholm School of Economics (SSE) within the field of Economics. This is the result of one intense semester spent in the complex world of electricity markets. Understanding the market dynamics was tough, and entailed me to use every bit of knowledge, experience and patience I have gained throughout my years as student.

I wish to thank my supervisor Chloé Le Coq of the SSE and the SITE for helpful guidance and advise throughout this thesis. Special thanks goes to my girlfriend and soulmate Minna Lennermo. If I ever lost interest, you kept me motivated. It was always helpful to brainstorm ideas about my research with you. My deepest gratitude for your invaluable support and love.

Stockholm, May 15, 2017

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1 Introduction

In response to growing concern of energy security, The European Commission set out an action plan, the Second Strategic Energy Review, to strengthen the North-South interconnections in Central and Eastern Europe (Figure A) (The European Commision 2008). Effective interconnection of the Baltic Sea region was identified as one of the six priority energy infrastructure projects, and the Energy Baltic Interconnection Plan (BEMIP) was launched in 2008, aimed to integrate the Baltic states into EU's Internal Energy Market (Elforsk 2012).

EU's energy goals are to diversify energy supplies, decrease energy prices and improve interconnection to ensure supply security. Another long-lived goal is to promote competition in energy markets. This can be accomplished by e.g. increasing the size of the market. In the last few years, the Baltic states joined (Estonia in 2010, Lithuania in 2012, and Latvia in 2013) the Nordic electricity market known as Nord Pool, thus creating a joint Nordic-Baltic electricity market. The traditional monopolistic and government-controlled market is now rapidly developing into a fully competitive market. Currently, the Nordic-Baltic electricity market is one of the world's largest, multinational and advanced electricity markets. Regardless of its commercial success, it is unclear whether introducing the Baltic states has lead to a more efficient market.

Extending the market size increases the amount of competition that a profit-maximising producer[1] faces and forces it to submit bids closer to its marginal cost curve (Wolak 2015). As a result, consumers can directly benefit from lower electricity prices[2]. Electricity's homogeneous characteristic as well as capacity constraints from electricity producers make a Nash-Cournot framework adequate to theoretically evaluate the impact of increased competition from Baltic producers. To complement, a supply-demand framework is suitable to interpret a hypothetical shift in supply in the Nordic electricity market. Following the Nash-Cournot and supply-demand framework, a hypothesis can be derived: *Introducing the Baltic states to the Nordic market leads to higher market efficiency.*

In order to assess the effect on market efficiency, the theory of storage and the convenience yield is considered. One definition of convenience yield is *"the flow of services which accrues to the owner of a physical inventory but not to the owner of a contract for future delivery"* (Brennan 1991). In the context of the Nordic-Baltic electricity market, hydropower producers may effectively store electricity by hoarding water in their water reservoirs and combine it with financial contacts to generate risk-free profits. Increased competition from Baltic producers should reduce the possibility of implementing such a strategy. A better understanding of how market participants act in financial

[1] Sanda et al. (2013) findings indicate that Norwegian hydropower producers' objective is to maximise revenue subject to water reservoir levels and inflow.

[2] Competitiveness benefits are primarily a transfer from producers to consumers only if lower prices are passed on to lower retail prices. In fact, Mirza and Bergland (2012) find substantial asymmetry when Norwegian retailers pass on the impact of price changes in the system price to retail prices. So, there may be potential consumer surplus and producer surplus from increased competition.

markets is vital for designing electricity market in the long run (Deng and Oren 2006), and prices in financial markets provide signals for investments in energy infrastructure, contributing to an adequate development of supply and demand (Botterud et al. 2010).

This thesis analyses 13 years of spot and futures prices in the Nordic-Baltic electricity market in a regression model, allowing comparison with previous finding on efficiency in the Nordic electricity market (Botterud et al. 2010; Weron and Zator 2014). Data have been collected, assembled and consolidated from various sources, see Table 2. Introducing the Baltic states can be viewed as a natural experiment[3]. Thus, two sub-periods, 2003-2013W22 and 2013W23-2017[4], are created. A regression model is constructed to analyse whether the market extension has increased the market efficiency where explanatory variables, e.g. water reservoir level, electricity demand and wind power, are chosen based on previous literature and a preliminary data analysis.

This thesis makes a number of contribution to the existing literature in Energy Economics. It is among the handful of research that consider the theory of storage cost and convenience yield when analysing electricity markets. In addition, the analysis is undertaken in the Nordic-Baltic electricity market, which has received little attention outside the geopolitical field and, to the best of my knowledge, no empirical study has examined efficiency effects of integrating the Baltic and Nordic electricity markets. Finally, some lights are shed on asymmetry between hedging-demand by producers and retailers, and thereby seasonality in market efficiency.

The remainder of this thesis is organised as follows: First, Section 2 gives a theoretical prediction from both a Nash-Cournot and a supply-demand framework. In addition, Section 2 also briefly presents the two main theories of the relationship between spot and futures prices. Section 3 gives a review of previous studies on commodity markets, with special emphasis on energy and electricity markets. Section 4 gives an introduction to the Nordic-Baltic electricity market. Section 5 presents my hypothesis. Section 6 provides a preliminary data analysis on spot and futures prices from the Nord Pool. Section 7 presents the regression model and its components. Section 8 gives an empirical analysis and discussion of the regression results. Finally, Section 9 concludes.

[3]Introducing the Baltic states was anticipated by market participants, creating some noise in the data as it does not fully resemble a random assignment.

[4]2013W23 denotes the week when Latvia joined the Nord Pool market.

2 Theory

2.1 Nash-Cournot and supply-demand framework

Electricity is a homogenous good, which is difficult to differentiate. Producers face capacity constraints as their supply is limited to the amount of electricity they can generate (Weron 2014). A Nash-Cournot framework is therefore adequate to evaluate the impact of an extension of the Nordic electricity market to the Baltic states, as producers will compete with their corresponding international equivalent. In the Nash-Cournot framework, firms compete by simultaneously choosing quantity supplied, and the market equilibrium is determined through the quantity decisions of producers (Weron 2014).

Let the demand function of the industry be $P(q) = a - bQ$, cost function be $C_i(q_i) = cq_i$ and profit function be $\Pi_i = P(q) \cdot q_i - C_i(q_i)$, for all i. The best decision by the firm is to find the value of q_i that maximises Π_i given q_{-i}, i.e. firm i takes the other firms outputs into account and thereby chooses the profit maximising output. Hence, the maximum of Π_i with respect to q_{-i} is to be found. The derivations used to find Cournot equilibrium are well known and are left for the reader. The equilibrium values are as follows:

Each individual firm's output:

$$q_i = Q/N = \frac{a-c}{b(N+1)}, \tag{1}$$

Total industry output:

$$\sum q_i = Nq = \frac{N(a-c)}{b(N+1)}, \tag{2}$$

Each individual firm's profit.

$$\Pi_i = \left(\frac{a-c}{N+1}\right)^2 \left(\frac{1}{b}\right) \tag{3}$$

Market clearing price:

$$p = a - b(Nq) = \frac{a+Nc}{N+1}, \tag{4}$$

As 4 shows, the market clearing price is determined by the number firms, N, and their cost functions, $c_i(q_i) = cq_i$. An increased number of firms would lower the market clearing price and vice versa. The Cournot Theorem then states that, in absence of fixed costs of production, as the number of firms in the market, N, goes to infinity, market output, Nq, goes to the competitive level and the bidding price from firms converge to their marginal cost of production, $\lim_{N\to\infty} p = c$. Assuming constant demand, the total amount of electricity would still be the same as the industry supply is

split equally between firms, $Q = q_1 + q_2 + ... + q_3 = \sum q_i = Nq$, a Nash-Cournot framework predicts a decreased market clearing price if the number of firms increases in a competitive market.

Electricity is produced from a wide range of energy sources such as hydropower, wind power, nuclear power, gas and oil; each energy source differing from the others in terms of marginal cost of production. The assumption of identical cost structures in the Nash-Cournot framework therefore only applies for similar energy sources and needs to be extended into a supply-demand framework to more precisely predict the outcome from increased competition.

In the Nordic-Baltic electricity market, the market clearing price is the equilibrium price found where the supply (the merit order[5]) and demand curves are equal[6]. Figure 1 shows a visual representation of the Nordic electricity market. The width of the bars approximately corresponds to the share of each energy source in the total supply of the Nordic electricity market. In reality, the bars are not completely flat since the marginal production cost also varies within each energy source. But for the sake of the argument, lets assume all firms in the same energy source have the same cost function. The height of the bars represents producers short-run marginal costs plus a little margin for profits.

For simplicity, assume that the Baltic market only consists of nuclear power producers[7] and full integration is possible, i.e. no transmission constraints when transferring electricity. Analogous reasoning can be used for each energy source in the supply curve. An extension of the Nordic market to the Nordic-Baltic market increases the number of firms, N, in the nuclear power industry, thus increasing competition amongst firms. As a result, the total supply of nuclear power increases and, following the Nash-Cournot framework's result, forcing bidding curves from nuclear power firms to submit bids closer to their marginal cost of production.

As illustrated in Figure 2, the nuclear power bar become wider from a increased number of firms in the nuclear power industry and lower from increased competition in the nuclear power industry. The additional supply and lower bidding prices of nuclear power producers crowd out the more expensive marginal electricity producers, thereby lowering the market clearing price.

[5]The supply curve is derived by ordering the suppliers according to ascending short-run marginal cost. This is called the merit order.

[6]As electricity demand is volatile, market equilibrium may frequently move along the entire supply curve (Söder 2014). As a result, the height of the bars may also vary, although in small magnitude, as producers bidding strategies alters according to price levels.

[7]Nuclear production in the Nordic countries is highly concentrated to areas in connection to the Baltic states, see Figure B. Nuclear is therefore the most adequate energy source to illustrate.

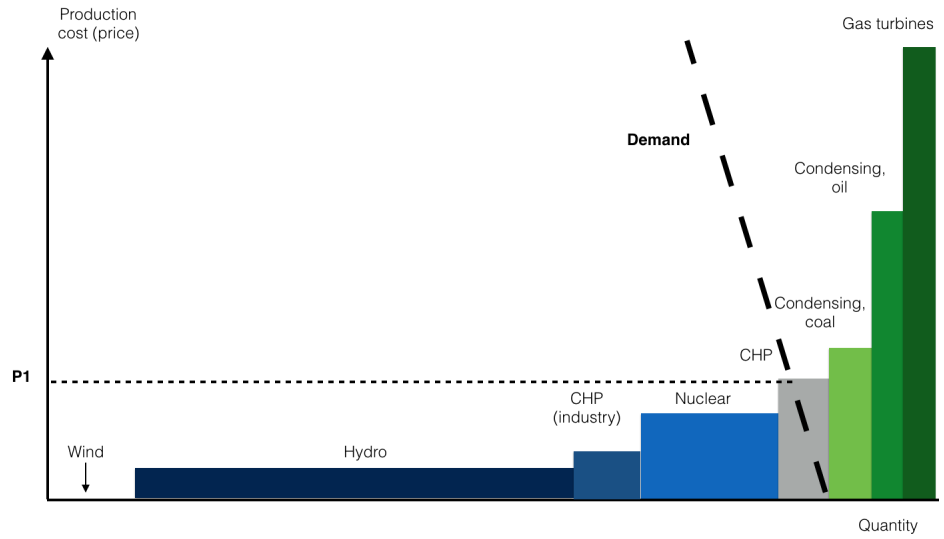


Figure 1: *An illustration of the Nordic electricity market.*
Notes: Combined heat and power (CHP) recover wasted heat from conventional thermal energy sources such as gas and oil. Source: Author's own illustration.

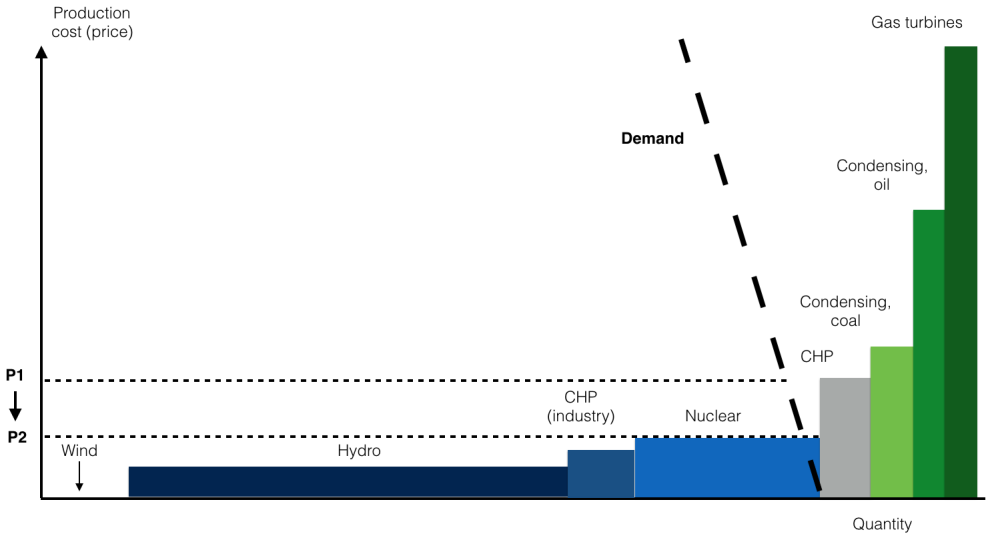


Figure 2: *An illustration of introducing Baltic nuclear power producers into the Nordic electricity market.*
Notes: Combined heat and power (CHP) recover wasted heat from conventional thermal energy sources such as gas and oil. Source: Author's own illustration.

2.2 Measure of market efficiency

Efficient markets hypothesis (EMH) has been a cornerstone in research for decades since it was brought to the spotlight, and has served as a faithful servant for measuring market efficiency. The theory states that it is impossible to systematically beat the market in the form of a above-average risk adjusted return. There exist various ways of measuring market efficiency. A specific measure of market efficiency can be good in one particular market and bad in another. Deciding which one is suitable depends on market and data availability among other factors. In general, the perception of increased efficiency is a lower price. Focusing on the price may omit other factors that play an important role in an electricity market such as flexibility, security and stability. A well functioning environment for producers and retailers is also a key for a long term healthy electricity market.

Fama and French (1987) elaborates on two different, yet closely related, theories for explaining the relationship between a commodity's spot and futures price[8]. The relationship between these two prices has long been investigated in various definitions and used as an measure of market efficiency. This section provides a brief introduction of the theory of storage.

2.2.1 The Theory of Storage

The theory of storage (Kaldor 1939; Working 1948; Brennan 1958; Telser 1967) explains the difference between spot and futures prices in terms of interest gone in storing a commodity, storing costs, and a convenience yield on inventory. In this theory, the return from purchasing a commodity and selling it for future delivery should, under the assumption of no arbitrage, equal the interest foregone plus the storage cost minus the convenience yield. This can be stated mathematically as:

$$F_{t,T} = S_t e^{(r_{t,T} + sc_{t,T} - cy_{t,T})} \tag{5}$$

Where $F_{t,T}$ is the futures price observed at time t with delivery at T periods ahead, S_t is the spot price at time t, $r_{t,T}$ is the risk-free interest rate, sc_t is the price of storage, and cy_t is the convenience yield. One definition of convenience yield is *"the flow of services which accrues to the owner of a physical inventory but not to the owner of a contract for future delivery"* (Brennan 1991). One can view this as a liquidity premium of holding the commodity in inventory e.g. to be able to meet fluctuations (predictable or unpredictable) in demand and take advantage of accompanied high electricity prices, i.e. the convenience yield is an implied return on inventories. A convenience yield obtain and financially realised from holding a commodity in inventory can be comparable to the dividend obtained from holding a company's stock in your portfolio (Pindych 2001).

Electricity's lack of direct storage possibilities and physical requirement of constant match of supply and demand make it impossible to buy electricity today and store it for future sales. The

[8] A futures (correct spelling) is an agreement to buy or sell a commodity at a predetermined price at a specified time in the future.

no-arbitrage argument underlying the storage theory is therefore not directly applicable to the Nord Pool market. However, since hydropower producers have the availability to store water in reservoirs, obtaining a risk-free position is feasible (Botterud et al. 2010). This possibility is easiest shown by an example.

Assume the spot price currently trades at \$30/MWh, while the 4 week futures trades at \$34/MWh. In addition, storing water for 4 weeks cost \$1. A hydropower producer would sell, i.e. take a short position, the 4 week futures at \$34, save his money, and delay electricity production until the futures expires 4 weeks later. In the meantime, he store the amount of water needed to produce one MWh in his reservoir, thereby ensuring a "risk-free"[9] of \$3.

The Kaldor-Working-Brennan-Telser hypothesis states that the convenience yield is dependent on the commodity's inventory levels and arises in times of insufficient inventory levels. When demand is inelastic, as the case of electricity, low inventory levels drive the spot price to a higher level than the futures price, creating a benefit to hold the commodity in storage, i.e. a positive convenience yield. The opposite is also true; when a commodity's inventory levels are high, the spot price tends to be lower than the futures price, resulting in a negative convenience yield. So, there exist an negative relationship between a commodity's price and inventory levels, and consequently a negative relationship between the commodity's convenience yield and inventory levels according to the theory of storage.

In markets for storable commodities, inventories play a crucial role in price formation. Producers must determine their production paths with their expected future inventory. This decision is made in light of two prices; the spot price and the price of storage (Pindych 2001). As the price of storage, sc_t, cannot be directly observed for electricity, one need a simple derivation to determine the convenience yield. By assuming a interest rate of zero[10], $r_{t,T} = 0$, following formula for the *net convenience yield* can be derived from Eq 5:

$$NCY_{t,T} = cy_{t,T} - sc_{t,T} = \ln\left(\frac{S_t}{F_{t,T}}\right) \tag{6}$$

where $NCY_{t,T}$ is the net convenience yield at week t for a futures with delivery at time T. The NCY is defined as the convenience yield minus the price of storage, $cy_{t,T} - sc_{t,T}$, and will be term used in the remainder of this thesis. The perception of storage costs in a hydro-dominated electricity market would be different from other commodity markets. Constructing water reservoirs typically require large investments, but ones built, the marginal cost of storing water is zero as long as the water reservoir is not in danger of overflowing. The price of storage, sc_t, can therefore represent the financial risk of overflow, which increases as the water reservoir gets filled (Botterud et al. 2010).

A basic knowledge of the risk premium theory is necessary to understand and interpret previous research findings. This theory explains the price of futures in terms of a expected future spot price

[9] In reality, the spot price may vary and increase to a level above \$30/MWh.

[10] A reasonable assumption for the short holding period of one to six weeks.

and risk premium for the underlying commodity. In other words, the ex-ante risk premium, $(RP_{t,T})$, is the difference between expected spot price, $\mathbb{E}_t\left(S_{t+T}\right)$, at time t and futures price, $F_{t,T}$ with time to maturity T i.e. the premium a trader is prepared to pay today for delivery of the commodity in the future (Weron and Zator 2014). Another approach is to simply use the ex-post risk premium where the expected spot price, $\mathbb{E}_t\left(S_{t+T}\right)$, is replaced by its realised value, S_{t+T}.

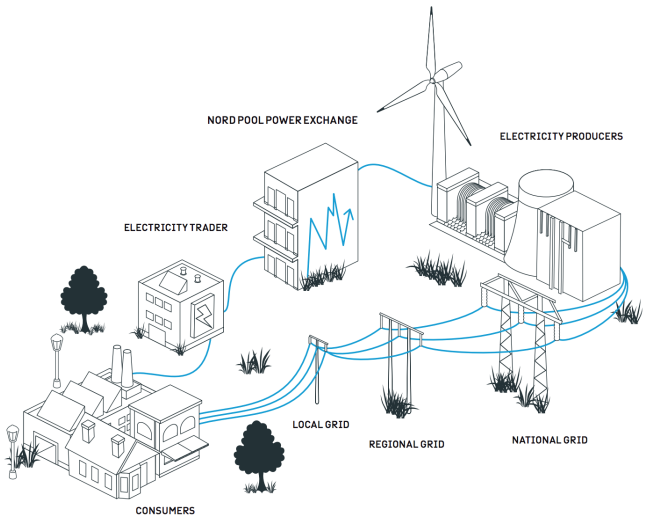


Figure 3: *A stylised visualisation of the Nordic-Baltic Electricity Market.*
Source: Svenska Kraftnät (2011)

3 The Nordic-Baltic Electricity Market

3.1 Background

Norway redesigned and liberalised its monopolistic and government controlled electricity market in 1990 with the objective to increase market efficiency, lower consumers prices and allow consumers to freely choose their electricity supplier. In the years to follow, other Nordic countries went through similar deregulations. Sweden became part of the market in 1996, enabling trade across national borders. Finland (1998) and Denmark (2000) followed in what became the first international power exchange (Nord Pool Spot 2013). The Baltic states subsequently joined years later (Estonia in 2010, Lithuania in 2012, and Latvia in 2013) thus creating a joint Nordic-Baltic market for electricity.

Today, Nord Pool operates markets in the Nordic-Baltic region, Germany and the UK while also servicing power markets in Poland, Croatia and Bulgaria (Nord Pool Spot 2017*a*). Nord Pool coordinate two different markets for electricity: one physical and one financial. Figure 3 provides an simple overview of the Nordic-Baltic electricity market. The left hand side represents the financial market while the right hand side represents the physical market (author's own interpretation of the figure). Nord Pool consists of several independent members; public and private producers, large consumers, distributors, energy intensive industries, funds, investment companies, banks, brokers, utility companies and financial institutions[11], whereas its ownership is more concentrated, see Figure C.

[11]For a full list of members, see `http://www.nordpoolspot.com/TAS/membership/`

3.2 The Physical Market

Nord Pool spot consists of a day-ahead market, Elspot, and an intraday market, Elbas. 380 participants from 20 countries trade directly in the physical market through Nord Pool Spot. In 2016, a total of 505 TWh was traded where 391 TWh was traded in the Nordic-Baltic day-ahead market (Nord Pool Spot 2017*a*). This makes Nord Pool Spot the world's largest exchange for electricity measured in both volume and participants.

In Elspot, market participants submit bids to buy or offers to sell physical electricity for each hour of the next day. Gate closes at noon to allow transmission system operators (TSOs) to plan the electricity flow in order to avoid transmission congestion problems[12]. The market clearing price, also known as the system price or spot price, is set through a double auction, and is the equilibrium price found where aggregated supply and demand are equal. Sellers who asked less and buyers who bid more than the system price trade at the system price regardless. As market participants cannot predict their supply and demand, intraday physical trade is possible through Elbas. Elbas enables electricity trading until one hour prior to delivery. Sellers and Buyers can therefore adjust their electricity sold or bought and balance will be maintained.

Electricity production in the Nordic-Baltic electricity market is based on various energy sources. In total, more than half (55,8%) of the electricity produced stem from hydropower, followed by nuclear power (18,4%), fossil fuels (10,5%) and wind power (8,9%) (ENTSO-E 2016). Table 1 presents each country's electricity production mix. Solid fuels and gas are the main energy sources of the Baltic states, followed by hydropower, wind power and biomass. The former are mainly imported from Russia whereas the latter are locally produced. Including the Baltic states into the Nordic market would give an extra energy supply of mainly hydropower, wind power and biomass. Figure B shows a more detailed distribution of electricity production the Nordic countries. It is clear that nuclear power plants are located geographically close to the Baltic states, whereas hydropower mainly prevail in the northern areas.

Different marginal cost of production and total capacity of energy sources create a convex supply curve, and demand curve for electricity is inelastic in the Nordic-Baltic electricity market. Its unique composition of the supply curve implies that including the Baltic states may still have major consequences on the electricity system. Small variation in supply may lead to large volatility in the spot price.

In addition, electricity price spikes may occur due to the supply curve's convexity and the demand curve's inelasticity. For the Nordic-Baltic electricity market, this has been the case in several occasion (Figure 5). A high share of hydropower in the market makes it easy to regulate electricity generation on short notice, and the spot price fluctuates, in general, less than in a pure thermal power market

[12]A system operator has to be a non-commercial organisation, neutral and independent with regard to the market members (Nord Pool ASA 2017). The Nordic-Baltic transmission system operators are the owners of Nord Pool, see Figure C.

(Botterud et al. 2002). Amundsen and Bergman (2006) argue that the dominating position of hydropower in the Nordic-Baltic electricity market makes the spot price highly dependent on weather conditions. Large seasonality in the spot price is indeed apparent in the system due to variation in weather over the year, which both effect water inflow to the reservoirs (Figure D) and demand for electricity[13] (Figure F).

Table 1: *Electricity generation in the Nordic-Baltic electricity market in 2015.*

Energy Source	**Sweden**	**Norway**	**Denmark**	**Finland**	**Baltic**
Total generation (TWh)	162,1	144,0	28,9	68,6	20,9
Solid Fuels	0,4%	0,0%	24,5%	12,0%	38,5%
Petroleum and Products	0,2%	0,0%	1,1%	0,3%	1,9%
Gases	0,7%	2,4%	6,3%	8,4%	25,6%
Nuclear	34,8%	0,0%	0,0%	33,9%	0,0%
Hydro	46,6%	95,8%	0,1%	24,4%	13,9%
Wind	10,0%	1,7%	48,8%	3,4%	8,0%
Biomass	6,6%	0,0%	14,5%	16,6%	9,5%
Solar	0,1%	0,0%	2,1%	0,0%	0,3%
Other	0,7%	0,0%	2,8%	0,9%	2,4%

Notes: Percentage is share of each country's total generation. Source: The European Commision (2017); Statistik sentralbyrå (2017)

3.2.1 The Baltic Electricity Market

Due to geographical and historical reasons, the Baltic electricity market is strongly connected and integrated with the Russian electricity market in terms of physical connection, transmission interconnection and system stability (JRC Science for Policy Report 2016). Current EU energy security and energy independence goals encourage the Baltic states to seek for alternative electricity sources. Estonia, Latvia and Lithuania are all going through extensive restructuring of their power industries, e.g. privatisation of state owned companies and large investments in renewable energy (Elforsk 2012).

The electricity generation landscape in the Baltic states changed dramatically in 2010 when the Ignalina Nuclear Power Plant (1500 MW) in Lithuania was shut down. It produced almost 40% of the overall consumption in the Baltic states (JRC Science for Policy Report 2016). As a result, the Baltic states, especially Lithuania, became dependent on electricity imports from Russian oil and gas.

The extent to which increased competition from Baltic producers can affect the market depends on the transmission capacities. Interconnection with the Nordic countries occurs through Estlink

[13]It is common for small houses in the Nordic region to use electricity for heating purposes.

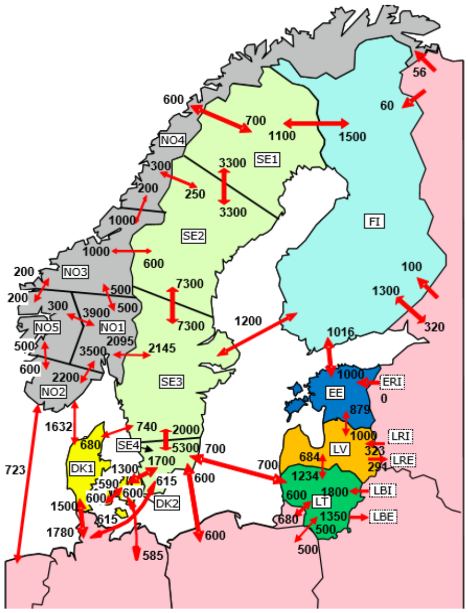


Figure 4: *Bidding areas and maximum net transmission capacities (MW) in the Nordic-Baltic electricity market.*
Source: ENTSO-E (2016)

1&2 (Estonia-Finland) and NordBalt (Lithuania-Sweden), see Figure 4. NordBalt was taken in operation in Feb 2016, whereas Estlink 1&2 have operated since Jan 2007 and Feb 2014. These connections' purpose is to secure supply and facilitate trading of electricity between the Baltic and Nordic electricity markets. The maximum transmission capacities are 350MW, 650 MW and 700 MW for Estlink 1&2 and NordBalt respectively.

The system price would be the whole Nordic-Baltic market's price if it were not for these transmission grid constraints. Transmission grid constraints split the market into sub-markets, and the Nord Pool Spot exchange area is divided into a number of bidding areas, see Figure 4. Due to bottlenecks in the transmission system, different prices exist in each bidding area (Nord Pool Spot 2017*b*).

3.3 The Financial Market

The market for financial contracts in Nord Pool is known as NASDAQ OMX Commodies Europe, and has been offered since the beginning of 1995. It changed name from Eltermin, which is still common in everyday speech, after an acquisition by NASDAQ OMX in 2010. Trading with financial contracts imply no physical delivery of electricity. Instead, financial contracts are cash-settled, i.e. the buyer of a contract pay the difference between the spot price and the contract's predetermined price when the contract has expired. Financial contracts serve as financial risk management tools for

market participants, mainly retailers and producers. The contracts offered by NASDAQ include, but is not limited to, futures, forwards, EPAD's[14] and options with forward contracts as underlying assets. All of these financial contracts use the system price as reference price.

The supply and design of financial contracts have varied and changed over the years. One example is futures, which in the beginning had a time horizon up to 3 years, but have been restructured several times. Today, futures contracts are available in the Nordic-Baltic region for the next 3-9 days and the next 6 weeks in consecutive periods. The different contracts have a time horizon of up to six years, covering daily, weekly, monthly, quarterly and annual contracts, and now also include German, Dutch and UK market contracts[15].

In 11 July 2002, Nord Pool introduced euro as its trading currency, transitioning from Norwegian kroner. All new contracts with delivery period starting on or after 1 January 2006 were to be listed in euro. The goal of the transition was to make cross-border trade easier as Nord Pool grew in the European market for trade in and clearing of energy products, especially as most EU members already had Euro as national currency. In addition, contracts would become more standardised and easier to compare with other products on the market (Nord Pool ASA 2002).

3.3.1 Hedging Behaviour in the Nordic Market

There exist three types of market players in the futures market; producers, retailers and financial companies, each with its own behaviour in financial markets. Fleten et al. (2015) elaborates on possible hedging scenarios resulting from differing hedging demands. Due to the unique non-storable nature of electricity and highly volatile electricity prices, producers of electricity want to hedge their physical production up to a few years (Sanda et al. 2013). However, retailers tend to enter the derivative market once their sales obligations to consumers are known. If there exist no natural buyers, such as retailers, of the futures, financial companies are typically the producers' counterpart. When retailers know their sales obligations and enter the derivative market, the financial companies are usually counterparts since producers already have sold their futures[16]. The financial companies provide liquidity for market particiants, but to take on the price risk, they may require a risk premium in both cases. If the demand and supply for futures are equal amongst producers and retailers at a specific time, there is no need for a financial counterpart and the risk premium should equal zero. As the possibility to store water in reservoirs is only possible for producers, my focus will mainly lie on their hedging behaviour.

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

[15]For all full review of the contracts available, I refer the reader to NASDAQ OMX.

[16]Financial contracts are cash settled, which require no physical delivery of electricity. So financial companies can therefore hold futures until maturity without worrying to produce any physical electricity.

4 Literature Review

This section provides a review of relevant literature on the theory of storage and the theory on risk premium in commodity markets, with focus on electricity markets. Considering the theory of storage and convenience yield in electricity markets is relatively new and few studies exist. Hence, the majority of literature reviewed in this section have used the theory of risk premium. Note that the difference between the NCY and risk premium is that the former use the current spot price while the latter use expected or realised spot price. Results can therefore be interpreted as similar, but with caution. Data sets in studies below vary in both size, spanning from 1993-2016, and market e.g. the Pennsylvania-New Jersey-Maryland Interconnection (PJM), the European Energy Exchange (EEX) and Nord Pool Spot.

4.1 Evidence from Commodity Markets

Fama and French (1987) finds marginal evidence of a positive NCY when 21 commodities (wood, animal, agriculture and metal products) are combined into portfolios. However, their result is not statistical strong enough to resolve controversy about the existence of nonzero expected premiums. Chang (1985) also find evidence of positive NCY for agricultural products (wheat, corn and soybeans) and show that the theory of storage's validity vary over market and time periods. Lee and Zhang (2009) examines the characteristics of price movements in 29 markets (agriculture, metal products and currencies) from 1987-2007 and finds that the theory of storage does exist in some markets (mineral, currency and agriculture) but stress the uniqueness of each market.

In energy markets, Wei and Zhu (2006) study the U.S natural gas market by comparing spot and futures prices for the time period 1991-2003. In their model, they use spot price shock and volatility as explanatory variables. They find evidence of a positive convenience yield and risk premium, both are measurable and economically significant while the results for the former is consistent and the latter mixed. The convenience yields are highly variable and depends on the commodity's spot price and variance. Pindych (2001) analyses the futures market for petroleum products (gasoline, crude oil and heating oil) and concludes two main findings regarding the theory of storage. First, the NCY fluctuates considerably over time, and there are frequent and extended periods of high NCY. Secondly, the convenience yield is significant and correlate with the spot price, i.e. the convenience yield tends to be high during periods when the spot price is unusually high. He argues that the underlying mechanism behind this correlation is temporary shifts in demand or supply that make short-run marginal costs higher than long-run marginal costs. When this happens, the commodity's inventory will be highly demanded because it can be used to reallocate production across time and thereby reduce production costs. Considine and Larson (2001) also find strong support for the presence of a positive convenience yield in petroleum markets, which positively correlates with the

price volatility. Milonas and Henker (2001) examines the determinants of convenience yields in two similar crude oils (Brent and WTI), and reveals significant convenience yields that exhibit yearly and monthly seasonalities.

4.2 Evidence from Electricity Markets

Botterud et al. (2002) were among the first to analyse the Nord Pool market's risk premium. Their study show results of negative risk premiums for futures with 1, 4, 26 and 52 weeks to delivery in a data set consisting of observations between 1996-2001, contradicting to most other findings in other commodities markets, where the risk premium tend to be positive or zero. Moreover, the magnitude and variance of the risk premium increase with the length of the holding period of the futures. They argue this is due to difference in flexibility on the supply (producers) and demand (retailers) side of the electricity market, leaving the demand side with a higher incentive for hedging in futures. The producers can control a share of their electricity generation on a very short notice as a majority are hydro producers, allowing them to take advantage of price fluctuation, especially price spikes, in the market. The demand side, on the other hand, has very limited ability to adjust the demand according to the spot price. Hence, they have incentive to hedge their sale obligations regardless. The excess demand for futures would translate into a negative risk premium. Botterud et al. (2002) also plots the average reservoir level against the spot and futures price, and make some weak conclusion of causation, but stress the importance to treat the results with caution due to a small data period used in the study.

Botterud et al. (2010) further investigate the relationship between water reservoir levels and risk premium by an OLS regression model, and find water reservoir levels (negative), deviation in hydro inflow (negative) and electricity demand (positive) to be significant explanatory variables for the existence of a risk premium. As Botterud et al. (2002), the magnitude and variance increase with the length of the holding period of the futures. Weron and Zator (2014) points out a couple econometric flaws in the OLS regression used by Botterud et al. (2002), e.g. seasonality and simultaneity bias. They find a positive relationship between the water reservoir level on the risk premium, which contradicts the results of Botterud et al. (2002). The opposite results makes it interesting to repeat their study with a newer data set as Nord Pool is continuously changing.

Since the Nord Pool electricity market exhibit seasonality in several aspects, producers' hedging behaviour is seasonal as well. Sanda et al. (2013) find seasonal variation in the share of production hedged when analysing Norwegian electricity producers. The results contradict the neoclassical theory of hedging for income smoothing and indicate that companies utilise hedging strategies to maximise profits rather than to increase predictability in cashflow. Indeed, the majorities of companies earn a substantial share of their total profit from hedging activity. One can therefore assume that hydro producers in the Nord Pool market operate as financial companies trying to optimise their profits. For a hydropower producer, precipitation and inflow of water in the reservoirs are two central factors

for planning production and hedging, and thus also for explaining the relationship between spot and futures prices (Weron 2014). Since there is great uncertainty associated with water inflows and predcipitation, most hydropower producers utilise complex stochastic dynamic optimisation tools to calculate water values, optimise electricity generation and manage reservoirs (Botterud et al. 2010). As Sanda et al. (2013) findings indicate; the objective for producers is to maximise the revenue subject to reservoir level, water inflow etc.

Cartea and Villaplana (2008) develop an electricity price model under the assumption that wholesale electricity prices can be explained by two state variables: demand and capacity. They use data from three different markets: Nord Pool (data for 2003-2006), PJM (USA) and E & W (England and Wales), and find seasonality in the forward premium in all markets due mainly to demand volatility's seasonality[17]. In month of low demand volatility, forwards trade at a small negative risk premium or slightly above zero. This situation was present during the months of February-July, with the exception of March that had a high positive risk premium, in the Nord Pool market. Contrary, during the months of high volatility of demand August-January, forward contracts were trading at a large negative risk premium. The authors intuitively explain the risk premium's seasonality by seasonal hedging behaviour from buyers and sellers in the markets. Since the probability of observing price spikes is relatively low in month of low demand volatility, buyers have low incentive to hedge their risk positions by purchasing forward contract, but sellers still prefer to sell their forward contracts to secure profits.

Lucia and Schwartz (2012) analyse Nordic spot, futures and forward prices in the period 1993-1999. They find evidence of a seasonal, systematic pattern throughout the year which play a central role in explaining the shape of the futures/forward curve. Weron and Misiorek (2008) also find evidence of seasonal fluctuation in Nord Pool, their analysis consist of two different periods; one with high water reservoir levels (1998-1999) and one with low levels (2003-2004). In their study, they use air temperature[18] as an exogenous variable to explain the spot price. Seasonal fluctuations in water reservoir levels have an impact on the temperature's influence on the spot price. In particular, low reservoir levels make the air temperature less significant. Furthermore, their results reveals that even though air temperature is the most influential of all weather variables it is not such a strong driver of electricity prices as the demand.

Gjolberg and Johnsen (2001), Gjolberg and Brattested (2011) and Redl and Bunn (2013) argue that the risk premium's existence may be due to market power as deregulated electricity market are still relatively immature. In addition, entering the market require high entry costs for producers. Gjolberg and Johnsen (2001) analyse monthly futures and spot prices in the period 1995-2001, and argue that the Nordic electricity market exhibit high producer concentration and is therefore

[17]Note that the authors use the forward premium, which has a opposite sign of the risk premium. Results below are presented in risk premium

[18]Air temperature was calculated as an arithmetic average of the hourly air temperatures of six Scandinavian cities/locations (Bergen, Helsinki, Malmö, Stockholm, Oslo and Trondheim).

not informationally efficient. The concentration of producers may generate a 'reservoir rent', since arbitrages opportunities may exist for producers when combining futures positions and storage levels planning. Fridolfsson and Tangeras (2009) compare electricity's output price with its marginal cost of production as a short-term competitive benchmark. Their findings reveal producers may take advantage of the constraints in transmission capacity. The phenomenon seems to be problematic in some price areas of the Nord Pool market. They argue that government intervention in the Nord Pool market, such as price regulation or market design, is not necessary. However, they highlight that transmission grids should be at least 50% government-owned to reduce incentives for private transmission investments. Amundsen and Bergman (2006) reasons that market power is difficult to find in market dominated by hydropower. An outside observer cannot easily judge whether a given reduction of hydropower production reflects market power exercise or just conservative expectations about climatic conditions during the coming months.

The overall methodology used in academic literature is to model spot prices and financial derivatives related to the electricity markets. Many studies use the same type or extension of models with some variation where Bessembinder and Lemmon (2002) equilibrium model (B-L model) serve as a cornerstone. Electricity market's specific nature and the inability to store electricity gave rise to their model in which risk-averse electricity producers and retailers maximise expected profits in the spot and forwards markets. In equilibrium, the observed risk premium is positively correlated with the expected variance in the spot price, but negatively related to its skewness (probability of price spike). When market participants believe a price spike's probability to be high, they are willing to buy forwards/futures contracts and thus drive the spot price up and the risk premium down. They conduct some initial empirical analysis in the PJM market using a short period of data set of the period 1997-2000. The evidence supports the model and find a positive risk premium for summer and winter period while none in the spring or fall period. They argue that electricity markets are not well integrated with the financial market, i.e. financial speculators does not exist to a large extent. Longstaff and Wang (2004) results on the PJM electricity market in the period 2000-2002 are consistent with the Bessembinder and Lemmon model's prediction. They use an extensive high-frequency set of hourly spot and day-ahead forward prices and confirm the existence of a positive risk premium. The risk premium's size varies throughout the day, ranging from -3 percent to 16 percent, with the overall average premium across the whole day being 6.4 percent, and relates to economic risk factors such as prices spikes and unexpected changes in prices and demand. Karaktsani and Bunn (2005) argues that the positive premium, dominant in peak periods, can be perceived as a compensation to flexible producers for bearing spot price risk. On the other hand, in times of low demand, a plausible interpretation is that the inflexible producers (e.g. nuclear plants) need to sell their output forward at a discounted price in order to ensure continued operation and avoid shut down costs. Douglas and Popova (2008) also come to a conclusion in line with the Bessembinder and Lemmon model in the period 2001-2004. In addition, their model shows that gas

inventories has a measurable negative effect on the electricity forward risk premium under some market circumstances and time of the day. Moreover, the gas storage inventories adds information to electricity price forecasting beyond the information available from the electricity price data itself.

5 Hypothesis

Given the above theoretical and literature review, a hypothesis regarding the relationship between the NCY and the market extension to the Nordic-Baltic market can be formulated. Both the Nash-Cournot and supply/demand framework suggest a lower spot price from increased competition in the market, which would have implications on the market participants behaviour. As hydropower is a dominant energy source and its marginal cost is close to the equilibrium price, the influence on their behaviour would affect the net convenience yield the most.

An increased supply and competition from Baltic producers leads to higher flexibility in the system, lower price volatility and, consequently, lower hedging demand from hydropower producers. In addition, hydropower producers' share of total electricity generated is smaller and their hedging demand decrease even more. On the other hand, a lower price imply lower profit margin, which may increase their hedging demand. As the spot price varies over time and season, the above-effects may vary significantly. In general though, the futures prices, $F_{t,T}$, in relation to the spot price, S_t, is expected to decrease, leading to an increased NCY.

How to define the level of NCY that correspond to full market efficiency is unclear and vague. Generally, a futures' price is higher than the spot price due to price uncertainty, and a premium is included in the futures. A positive NCY can therefore be assumed to be a sign of efficiency. In addition, a stable NCY would be an indication of a mature and well-functioning market. Thus, my hypothesis is as follows and should be interpreted as a stable and slightly positive NCY:

Hypothesis: Introducing the Baltic states to the Nordic market leads to higher market efficiency.

It is also relevant to examine if previous explanatory variables have changed between the PreBaltic and PostBaltic periods. A change of the production mix and supply curve composition in the system is likely to affect producers in numerous ways, in particular hydropower producers. The literature on Nord Pool presents evidence of seasonality on both spot price and risk premium. Hence, specific attention will be paid on whether including a less seasonality-sensitive area as the Baltic has an impact on seasonality in the NCY.

6 Preliminary Analysis

This section presents the data used in this study and an preliminary analysis of spot price, futures price and NCY. Data have been collected, assembled and consolidated from a number of four sources, see Table 2. The analysis is based on daily spot and weekly futures prices in the period June 2003 to March 2017, a period of almost 14 years.

Spot and futures price data have been obtained from Nord Pool's FTP server and Thomson Reuters, respectively. The hourly spot price data from the day-ahead market have been consolidated accordingly into weekly average spot prices for the 14 year's period to make them comparable to the futures. More precisely, for each week t, the weekly spot price, S_t, is the arithmetic average of hourly prices in week t. The futures price, $F_{t,T}$, is the closing price of a futures, with maturity T and delivery in week $t+T$, last day of trading in week t . The analysis consists of the maturities 1W, 2W, 3W, 4W, 5W and 6W (W=weeks). All spot and futures prices are quoted in Euro per megawatt hour (EUR/MWh). Overall, the data set consists of 683 weekly data points. To analyse the impact of the Baltic states, data have been divided into two sub-periods, 2003W26-2013W22 (PreBaltic) and 2013W23-2017W9 (PostBaltic)[19].

In addition, spot and futures prices have also been divided into seasons[20] in the preliminary analysis, allowing us to observe seasonal dynamics. Seasonal dynamics are captured by water reservoir and inflow, electricity consumption and wind power production, collected from Nord Pool FTP serve, Montel, and Energinet.dk, respectively. A more detailed description of each of these variables are provided seperately in Section 7.

Table 2: *Data sources.*

Data	**Source**	**Frequency**	**Time period**
Spot	Nord Pool FTP server	Hourly	1999-2017
Futures	Thomson Reuters	Daily	2003-2017
Consumption	Montel	Hourly	2000-2017
Water inflow	Nord Pool FTP server	Weekly	1995-2017
Water reservoir level	Nord Pool FTP server	Weekly	1995-2017
Wind production	Energinet.dk	Hourly	1999-2017

[19] I was unable to detect a structural break in the time series data.

[20] Seasons have been defined according to the Northern Meteorological Seasons, commonly used in weather forecasting, where winter is defined as 47 and 7. Spring, summer and autumn are defined as the following consecutive thirteen-week periods.

6.1 Spot Price

Table A presents descriptive statistics for the weekly average spot price in period 2003-2017. The spot price is plotted in Figure 5[21]. The average spot price is 35.35 EUR/MWh for the entire data set where the highest/lowest average price are observed in winter/summer, 38.18EUR/MWh and 31.51 EUR/MWh respectively. The spot price standard deviation for the entire data set is 12.21 EUR/MWh, indicating a highly volatile market. The standard deviation is similar throughout the year with a slightly lower value in the summer period. The kurtosis for the whole data set (4.49) indicates a higher probability of extreme values than a normal distribution. The kurtosis is indeed higher in winter (5.69) than in summer (3.02). A positive skewness (0.96) suggests a more frequent occurrence of positive than negative price spikes. The summer period (0.12) have skewness close to zero, which indicates that price spikes are equally likely to be negative and positive. Again, the winter period (1.33) exhibit a higher skewness than the summer period. Above observations of data seasonality are in line with previous findings, e.g. (Lucia and Schwartz 2012; Cartea and Villaplana 2008).

A closer look on the two sub-periods yield some interesting differences. The PostBaltic period has experience a lower and less volatile spot price than the PreBaltic period, 38.22/27.80 and 12.76/7.15 respectively. Indeed, this is also reflected in the kurtosis and skewness, where the PostBaltic period have -0.42/0.20 and the PreBaltic period have 0.85/3.96.

The observed price spikes in spot price each have their own explanation. Sijm et al. (2006) find that the introduction of the European Trading Scheme (ETS), launched in 2005, explains much the observed price increase in 2006 as it changed carbon-emission producers' cost structure. The two price spikes observed in the winter 2009/2010 and 2010/2011 can be explained by unscheduled stops in several Swedish nuclear power plants, unusually cold winters and low reservoir levels (see Figure D). High temperatures, substantial precipitations and high production of wind power caused the spot price to plummet the following year 2011.

6.2 Futures Prices

This thesis includes weekly futures with time to maturity, T, between one and six weeks, covering the corresponding period to the spot price, i.e. 2003-2017[22]. Table B shows descriptive statistics for the weekly futures prices. The futures prices exhibit, not surprisingly, many of the same characteristics as the spot price. First, the futures' average prices are higher than the spot price in general, indicating existence of a premium for electricity. The average futures price increase with time to maturity for

[21] Note that large variations and spikes seen in hourly spot price may have disappeared due to consolidation into arithmetic average.

[22] However, there exist some missing data, e.g. 3W covers data only from 2010-2017 and 6W is missing data from the year 2014. In addition, weekly futures with a longer holding periods typically have low liquidity and volume in trading. Still, the financial market is considered to be sufficiently efficient and all weekly futures prices are processed equally.

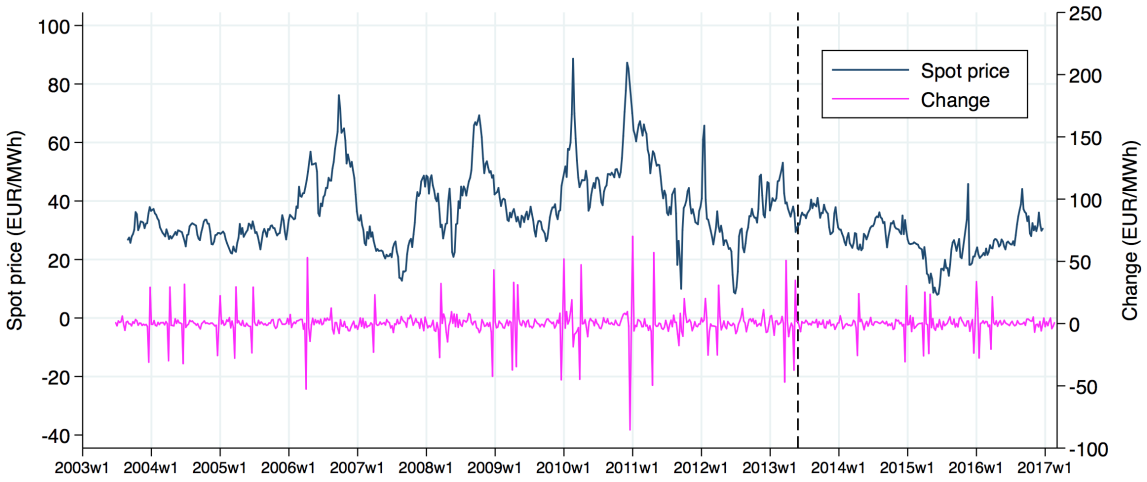


Figure 5: *Figure 5 shows the weekly spot price in Nord Pool for the period 2003-2017. The vertical, dashed black line is week 2013W22. The spot price is given in EUR/MWh*

the PreBaltic period but not for the PostBaltic period.

Figure 6 plots the spot price, 1W and 6W futures. All three are correlated and follow each other closely during the entire period. The 6W futures seems to react slower than the 1W futures; longer futures do not fully capture unexpected spot price spikes or drops, and as the spot price returns to its initial state, futures prices still include pervious price levels. Hence, the futures with a long holding period give the impression of being smooth and delayed relative to the spot price. The min values of the futures are higher than the spot price and increase with the holding period. Respectively, the max values are lower than the spot price and decrease and increase with the holding period. The Skewness and Kurtosis also suggest a smooth and delayed futures prices as they decrease with the holding period.

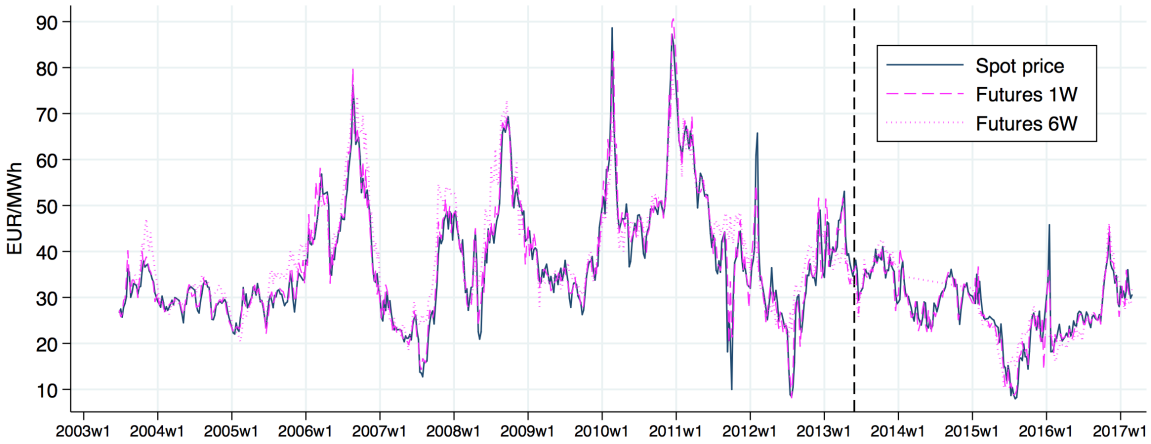


Figure 6: *Figure 6 plots weekly spot price, 1W and 6W futures for the period 2003-2017. Remaining futures showed similar trends and were excluded for better visual effect. All prices are given in EUR/MWh.*

6.3 Net Convenience Yield

This thesis aim is to investigate the Nord Pool market's efficiency in terms of the theory of storage and convenience yield. As discussed in Section 2.2.1, the storage theory can be applied in a electricity market with a substantial share of hydropower and the net convenience yield can consequently be derived: $NCY_{t,T} = cy_{t,T} - sc_{t,T} = \ln\left(S_t/F_{t,T}\right)$, where $NCY_{t,T}$ is the net convenience yield at week t for a futures with time to delivery T.

Table C presents summary statistics for the NCY. A closer look on the full period observes a negative average NCY for all maturities, which increase with time to delivery T, i.e. the spot price is lower than the futures price for delivery. Market participants are willing to pay more for electricity delivered in the future than today by an extra -0.8% for 1W and 5.4% for 6W. One can conclude on a $> 95\%$ statistical confidence level that the NCY's are negative for all futures. Moreover, the standard deviation as well as min and max values indicate higher uncertainty in futures with longer holding period.

A negative NCY for all futures is also found in the PreBaltic period, whereas the PostBaltic period has no significant difference from zero. It has a higher NCY in all futures while volatilities are similar. Since the NCY is fraction of spot price and futures price, the lower spot price in the PostBaltic has no explanatory power for the higher NCY observed in the PostBaltic period. To analyse this in more detail and look for potential seasonality, an average NCY for all futures in each individual week t is calculated. Figure 7 shows the average NCYs for futures relative to average water reservoir levels in Nordic countries. A clear, distinct seasonal pattern is distinguished in both PreBaltic and PostBaltic periods. In the first half of the year, the market exhibit positive average NCYs. In contrast, the average NCYs are negative in the second half of the year.

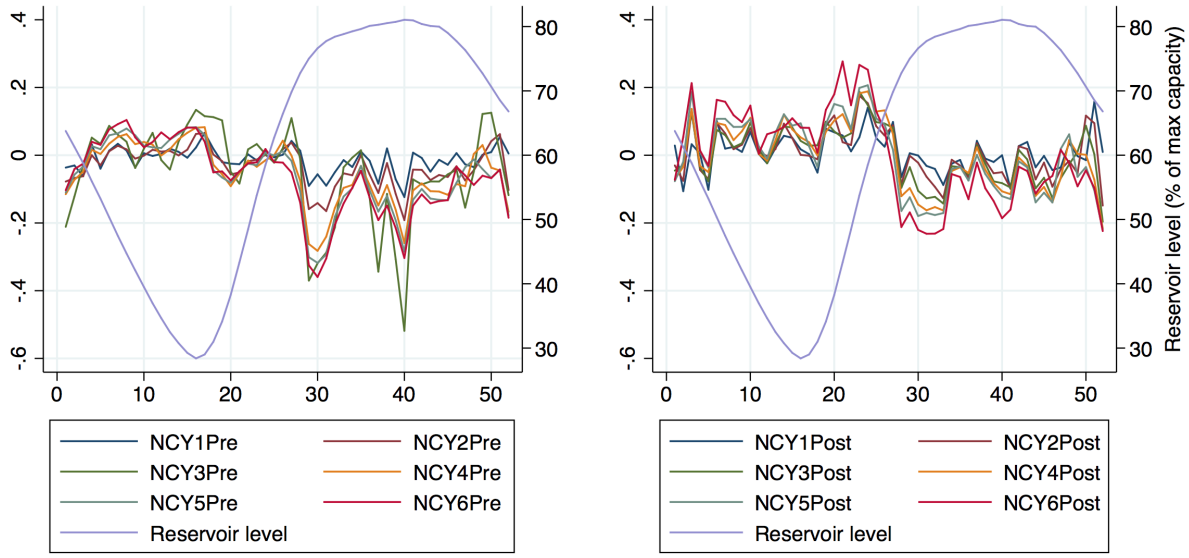


Figure 7: *Figure 7 shows average net convenience yield on weekly futures with 1W to 6W holding periods relative to average water reservoir levels in Nordic countries in the period 2003-2017. Nordic countries are defined as Norway, Sweden, Finland and Denmark.*

As discussed in Section 2.2.1, the theory of storage and convenience yield states that there exists a negative relationship between a commodity's NCY and storage level, i.e. low storage level indicate high NCY and vice versa. By visual observation of Figure 7, one can conclude that such relationship do in fact exist in the Nord Pool market. The first period of the year has low water reservoir levels and high NCY, whereas the second period of the year have high water reservoir levels and low NCY for both sub-periods. A correlation analysis reveals that correlation between water reservoir level and NCY ranges from $-0,19$ for a 1W futures to $-0,53$ for a 6W futures, i.e. longer futures correlates with water reservoir levels to a larger extent. For all futures in the PreBaltic period, the negative deviation from zero in the second part of the year is more distinct than the positive deviation from zero in the first part of the year. This explains the negative average convenience yield for all futures in Table C.

7 Regression Model

A regression model is constructed, based on findings from previous literature and the preliminary analysis, in order to investigate the Baltic states effect on market efficiency and seasonality, and also scrutinise potential shifts in explanatory variables. This Section first elaborates on econometric considerations followed by the model itself and its components.

A variety of methods, variables and ideas have been developed over the last 20 years, with varying degree of success, for predicting electricity prices and its financial instruments [23]. The electricity spot price is dependent on a large set of fundamental factors, including system loads (demand), weather variables (temperature, wind speed and precipitation), fuel costs (oil, natural gas and coal) and market specific factors e.g. water reservoir levels in the Nord Pool market. Thus making it difficult to incorporate its complexity into a model.

Estimation of expected risk premium, $\mathbb{E}_t\left(S_{t+T}\right)$, includes an aspect of uncertainty and results becomes model-dependent. On the other hand, using the current spot price, S_t, allows for uncertainty in defining independent variables such as, water inflow and demand. Following OLS model is not intended to specifically distinguish explanatory variables, but rather emphasise potential significant, fundamental changes in market efficiency from introducing the Baltic states.

Data have been divided into two samples, PreBaltic and PostBaltic, as described in Section 6. The regression model below is performed for each of the two samples separately. For example, a 2W futures in the PreBaltic estimates the net convenience yield, where $T = 2$, using PreBaltic data only. Each futures maturity, 1W, 2W, 3W, 4W, 5W and 6W, is treated separately, i.e. a regression table consist of 12 individual regressions.

7.1 Econometric Considerations

Accurate consideration is crucial when specifying explanatory variables in a regression model on electricity markets to reduce the likelihood of biased estimators. Weron and Zator (2014) elaborates on the Ordinary Least Square (OLS) method's advantages when analysing econometric data. They label it as the "workhorse of econometrics" due to its simplicity and favourable properties (unbiasedness, consistency and efficiency) but stress the importance of fulfilling certain conditions. Similar variables and approach as Botterud et al. (2010) and Weron and Zator (2014) have been embraced to allow comparison of their findings to be able to evaluate whether the Baltic states have increased market efficiency in Nord Pool.

One crucial assumption in an OLS regression is stationarity, especially when analysing time series. A non-stationary variable creates biased estimators and the regression results become spurious. To put it simply, the results will turn out more or less meaningless. Coefficients may still be significant,

[23] For a full review and evaluation of electricity spot price modelling approaches, see Weron (2014); Aggarwal et al. (2009).

but the significance is artificial. In the context of electricity markets, the assumption of stationarity is often violated due to seasonality in independent variables, and need to be accounted for. Nord Pool clearly has seasonality in water reservoir level and inflow (Figure D and E). Furthermore, the Nordic climate makes electricity demand vary throughout the year (see Figure F). Hence, independent variables have been deseasonalised, if necessary, accordingly to yield stationary data.

7.2 Model

$$NCY_{t,T} = \alpha_0 + \beta_1 RESM_t + \beta_2 RESD_t + \beta_3 INFD_{t,T} + \beta_4 WINDP_t + \beta_5 DEMAND_{t,T} + \beta_6 VAR_t + \beta_7 SKEW_t + \beta_8 SPOT_t + \epsilon_t \tag{7}$$

$NCY_{t,T}$	Net convenience yield in week t for a futures with maturity T
$RESM_t$	Median water reservoir level in week t (%)
$RESD_t$	Deviation in water reservoir level from median in week t (%)
$INFD_{t,T}$	Total deviation in water inflow from weekly average deviation between week t and week $t+T$ (GWh)
$WINDP_t$	Wind production in week t in Denmark (GWh)
$DEMAND_{t,T}$	Total deviation in consumption in Sweden, Norway, Denmark and Finland from weekly average deviation, between week t and week $t+T$, (MWh)
VAR_t	Variance in spot price in week t
$SKEW_t$	Skewness in spot price in week t
$SPOT_t$	Spot price in week t
ϵ_t	Regression error

7.2.1 Water reservoir level and inflow

Water reservoirs level is the main variable influencing the NCY, $cy_t - sc_t$, as it directly represents the marginal cost of storage, and commonly used in studies of the Nord Pool market. Cartea and Villaplana (2008) use water reservoir level as an approximation of total capacity in Nord Pool while Gjolberg and Johnsen (2001) use it as an independent variable in their study of market power. Weron and Zator (2014) argue that water reservoir level is seasonal and captures seasonal influence from omitted variables. A similar deseasonalisation approach as Weron and Zator (2014) is therefore utilised, dividing water reservoir level into two independent variables: a stochastic component, $RESD_t$, to capture variation, and a seasonal component, $RESM_t$, to capture seasonality. $RESD_t$ is the deviation in water reservoir level from the median in week t while $RESM_t$ is the median reservoir level in week t. Both variables are expected to have an impact on NCY as $RESD_t$ reflects unexpected change in water reservoir levels and $RESM_t$ represent inventory levels to which hydropower producers adjust both production and hedging.

As outlined in 2.2.1, NCY would have a negative relationship with the water reservoir level. High level of water indicate low NCY and vice versa. A high positive deviation, $RESD_t$, exceeds hydropower producers' expectations, influencing their production schedule. They will be inclined to produce more in order to revert to their intended production path, which will give expectation of a lower spot price as supply curve shifts to the right. Thus, decreasing the NCY.

Both (Botterud et al. 2010) and Weron and Zator (2014) also include water inflow in their analysis and find significant coefficients. Water inflow would increase the supply of electricity available in the system and lower the spot price. Consequently, demand for futures decreases, resulting in a positive relationship between water inflow and NCY as ($F_{t,T}$) decreases(Botterud et al. 2010). Gjolberg and Johnsen (2001) argue that water inflow is stochastic and may lead to overflows if the reservoir utilisation is already close to maximum capacity, implying a higher market sensitivity at higher water reservoir levels. It is very surprising that none of the above studies mention the multicollinearity problem of water inflow and reservoir deviation. Indeed, the variables have a correlation ranging from $-0,14 - 0,30$ over the different futures maturities. However, multicollinearity only affects coefficients of individual predictors and not the reliability of the OLS model itself. Hence, both variables are included in the model to avoid possible omitted variable bias. $INFD_{t,T}$ is defined in the same way as demand for electricity, see below.

7.2.2 Wind power production

Wind energy production as a percentage of total electricity consumption has increased from 17% to 42% and capacity by 62% from the years 2006-2015 in Denmark alone [24]. A simple regression does confirm a significant trend (0,25% per week[25]) in wind power production, and the variable $WINDP_t$ has been detrended accordingly to provide stationary data. Due to data limitations, Sweden and other countries wind production in the system have not been included.

An increased wind power production will shift the supply curve to the right and reduce the spot price[26] and may influence the NCY. Jónsson et al. (2010) analyse how day-ahead spot prices are affected by day-ahead wind power forecasts in the Western Danish price area of the Nord Pool market. Their study finds a dramatic impact of predicted wind power on not only the spot price but also its distributional characteristics. On average, the spot price is shown to decrease with increased predicted wind power. Li (2015) results show that wind power production reduces electricity prices in Nord Pool spot market and increases short-term price volatility. However, when referring to a longer time period, the wind power production reduces price volatility.

[24]Source: Energinet.dk and Danish Energy Agency.
[25]The trend seems small but adds up quickly over a few years since the data is weekly.
[26]Wind power producers bid zero in the double auction. The supply shift is known as the merit order effect.

7.2.3 Demand

Cartea and Villaplana (2008) find evidence of seasonal effects of demand on the risk premium. High demand volatility implies a large negative premium and low demand volatility implies a risk premium around zero. Their seasonal variation in risk premium for the Nord Pool market were similar to my findings, see Figure 7. In addition, demand itself is seasonal due the Nordic Climate and higher demand during the cold part of the year, see Figure F.

To adjust for this seasonality, the demand variable, $DEMAND_{t,T}$, is defined as the total deviation in electricity consumption from weekly average deviation between week t and $t+T$. For example, $DEMAND_{t,T}$ for a 4W futures in 2010W1 is the deviation in total consumption in 2010W1 and 2010W4 and average deviation of W1 and W4. Note that $DEMAND_{t,T}$ represents deviations between realised and average values. This definition allow use to capture market participants expectation of future demand[27]. A high deviation in $DEMAND_{t,T}$ imply that market participants expect electricity consumption to be high, which would increase the aggregated size hedged by retailers.

7.2.4 Spot price, Variance and Skewness

Spot price is one variable included in almost every study related to electricity markets, e.g. Pindych (2001) found strong correlation between spot price and convenience yield. So, one could think including spot price in the regression model goes without saying and is most likely to influence the NCY. Weron and Zator (2014) elaborates on the endogeneity problem with the spot price. Including it may cause simultaneity bias while excluding it may lead to omitted variable bias. They propose to use two version of the regression model, and if the estimates are consistent between the two models, conclusions form the analysis are reliable; the second model is obtained by simply letting $\beta_8 = 0$.

The spot price has experienced high volatility over both sample periods. In addition, Considine and Larson (2001) and Wei and Zhu (2006) both find of evidence of correlation between the NCY and price volatility of the commodity in question. Several studies also include spot price skewness in their analysis (Weron and Zator 2014; Douglas and Popova 2008; Wei and Zhu 2006)[28]

[27] This relies on the assumption that market participants do have reliable forecast of future electricity consumption

[28] This is partly due to the fact that Bessembinder and Lemmon (2002) include skewness in their model, and many of studies on electricity markets are variations or extensions of the Bessembinder and Lemmon model.

8 Empirical Analysis and Discussion

Regression results are reported in Table 3 and Table 4, with spot price included and excluded, respectively. Standardised coefficients[29] are presented in Table 5 and Table 6 to facilitate comparison of the PreBaltic and PostBaltic periods. In general, both regression models have modest explanatory power, as measured by the goodness-of-fit, R^2. It increases with the futures maturity and decreases slightly when discarding the spot price for both periods. A low goodness-of-fit may be an indication of noise in the price data or multicollinearity.

Table D presents a correlation matrix of dependent and independent variables used the model for 1W and 6W futures[30]. As discussed in 7.1, the spot price is particularly exposed to multicollinearity problems. Indeed, the spot price has correlation exceeding ± 0.20 for the following dependent variables: RESM, RESD, INFLOW and VAR. Excluding the spot price, by letting $\beta_8 = 0$, allows us to analyse a possible existence of simultaneity bias and/or multicollinearity, caused by the spot price, by looking at the difference of Table 3 and Table 4.

The positive significant relationship of the spot price and the NCY is captured to some extent by the dependent variables with high correlation. Especially, RESD changes in magnitude and significance when excluding the spot price. Not surprisingly, the correlation between RESD and the spot price is $\approx -0,50$ across all futures. This indicate multicollinearity bias and strengthens the suspicion of multicollinearity in the regression model. However, the intercept increases in magnitude and significance, indicating that spot price may influence the NCY on its own. A higher goodness-of-fit and possible omitted variable bias concludes that a regression model including the spot price is justified. Below discussion and interpretation of coefficients will therefore be based on Table 3 and 5.

The intercept has increased in the PostBaltic period for all futures, with varying degree of significance. Visual observation of Figure 7 demonstrates that the PostBaltic's increased NCY is equally distributed throughout the year. It seems as if hydropower producers are inclined to hedge a larger proportion of their production throughout the whole year than in the PreBaltic period[31]. A loose pattern interpretation of the PostBaltic period is that the second half of the year is mirrored by the first half. This seasonal behaviour is in line with Cartea and Villaplana (2008)[32] and Botterud et al. (2010) observations of premium seasonality. They both argue that the premium's seasonality is due to seasonal hedging by market participants.

A closer inspection of the NCY in each individual year (see Figure H) reveals a turbulent period between spring 2015 and spring 2016, with a large, negative NCY spike in summer 2015. Negative NCY spikes also occurred in the PreBaltic period, namely in summer of 2007, 2011 and 2012, see

[29] In a multivariate regression model, the standardised coefficients measures the relative importance of one dependent variable against the others.

[30] Similar results are present in all other futures as well.

[31] Retailers would have same incentive to hedge as before since electricity demand has been the same over both periods. Moreover, hydropower's aggregate electricity generation have decreased.

[32] They use the forward premium in their study, the NCY can be calculated by taking the inverse of their results.

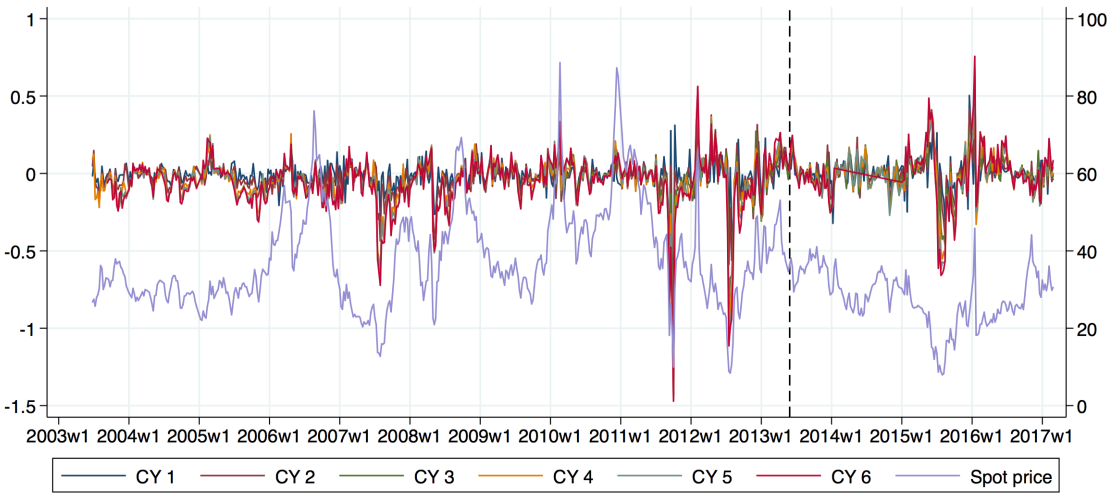


Figure 8: *Net convenience yield on weekly futures with 1week to 6week holding periods compared with the weekly spot price under the period 2003-2017.*
Source: Nord Pool and Montel

Figure G. Remaining summers do not show similar behaviour.

Plotting the NCY relative to the spot price reveals some interesting findings, see Figure 8. Not entirely unexpected is the correlation between the spot price and NCY. However, unusually low spot price levels occur at the same time as negative NCY, whereas unusually high spot price levels are not accompanied by positive NCY. In addition, periods of low prices have generally occurred when water reservoir levels are at extraordinary high levels, see Figure D.

As outlined in 2.2.1, the price of storage, sc_t, represents the financial risk of overflow in Eq (6), and the convenience yield, cy_t, is viewed as a liquidity premium for having sufficient water in reservoir to take advantage of fluctuations the in spot price. Sanda et al. (2013) found that Norwegian hydropower producers maximise profits rather than to increase predictability in cashflow. So, hydropower producers want to have the opportunity to take advantage of the high winter prices, and therefore do not want to risk having insufficient water available[33]. In addition, water reservoir levels typically peak in Autumn (weeks 35-47). So, hydropower producers do not know their total production capacity for the winter in the summer.

As predicted by theory and literature, the NCY has a negative relationship with the water reservoir level, RESM, for all futures in both periods. Higher levels of water indicate a low NCY and vice versa. Interestingly, the coefficient increases with futures time to maturity. The financial risk of overflow during a 6W period is higher than a 1W period. Hence, the theory of storage and convenience yield may be more suitable for longer time periods.

VAR's coefficient is significant and positive for all futures in the PostBaltic period but non-

[33]Since the production capacity during winter is dependent on water used for summer production.

significant in the PreBaltic period. The positive influence of variance is consistent with Botterud et al. (2010) and Weron and Zator (2014). The results are rather surprising since both spot and futures price variances have been lower in the PostBaltic period, and one could expect a lower coefficient.

One possible interpretation of this is that generally lower spot price levels is closer to hydropower producers' marginal cost. Lower margins imply higher sensitivity towards price fluctuation and futures are bought to manage the risk. Negative price spikes that occurs in times of high spot price levels still leaves room for large margins and hydropower producers is less prone to buy futures. Sanda et al. (2013) findings of profit maximising hydropower producers might may only be valid in times of high spot prices. If spot prices are at low levels, cashflow predictability to ensure future operations seems to be of higher priority.

INFD is positive in both periods, which is in accordance with both my prediction in 7.2.1 and the results of Botterud et al. (2010) and Weron and Zator (2014). However, the coefficients should be treated with caution due to multicollinearity problems with RESD. INFD has increased in the PostBaltic period, and also increases with time to maturity, i.e. an unpredicted inflow of water into the water reservoirs has a higher impact in the PostBaltic period than the PreBaltic period. Hydropower producers' production schedule seems sensitive to unexpected changes in inflow. RESD, DEMAND and SKEW show inconsistency and are nonsignificant for the majority of futures, making it difficult to interpret the real effect of these variables on the NCY.

VAR, RESM, and INFD are all variables whose coefficient increased in magnitude, indicating that these factors' influence of the NCY has increased in the PostBaltic period. But perhaps the most significant change between the PreBaltic and PostBaltic periods is the WINDP variable. It has become significant and negative in the PostBaltic period, despite controlling for the substantial increase of wind power. Literature suggest that an increased wind power production would decrease the spot price and increase variance of the spot price (Li 2015) (Jónsson et al. 2010). This may explain the lower spot price and variance in the PostBaltic period. Indeed, an increase amount of wind power would theoretically shift the merit order to the right, see Figure 1, pushing hydropower producers closer to bidding for residual demand. It is important to highlight that WINDP does not include Sweden and other countries wind production. Still, the effect is captured in spot price and variance of the market. However, coefficients should be interpreted with caution. Understanding how wind power affects spot and futures prices, and whether it translates into market efficiency seems highly relevant for future research.

Whether the increased NCY in the PostBaltic period is due to increased competition from Baltic producers or higher share of wind power in the Nord Pool market cannot be determined. A more detailed study on price areas in and connected to Baltic states as well as transmission capacities in a more precise data setting could be fruitful to closer estimate effects on efficiency. In addition, this study focused on the wholesale market. To what extent potential efficiency gains are pass on to end consumer is not considered.

Table 3: *Regression statistics for the net convenience yield.*

	Const	RESM($\times 10^3$)	RESD($\times 10^3$)	INFD($\times 10^5$)	DEMAND($\times 10^7$)	WINDP($\times 10^3$)	VAR($\times 10^4$)	SKEW($\times 10^2$)	SPOT($\times 10^3$)	R^2
PreBaltic										
1W	-0.006	-0.786***	-0.006	0.705***	-0.944***	0.132	0.453	-0.027	0.747**	0.18
	(0.019)	(0.219)	(0.054)	(0.260)	(0.144)	(0.017)	(0.401)	(0.263)	(0.379)	
2W	-0.005	-1.685***	-0.638	0.813***	-0.455***	0.166	0.846*	0.283	1.646***	0.22
	(0.024)	(0.271)	(0.672)	(0.252)	(0.142)	(0.211)	(0.504)	(0.327)	(0.471)	
3W	-0.296***	-2.854***	-9.969***	1.130**	-0.063	-0.733	-0.563	-0.066	10.804***	0.42
	(0.083)	(0.689)	(2.282)	(0.563)	(0.300)	(0.624)	(0.900)	(1.013)	(1.657)	
4W	-0.010	-3.016***	-1.218	0.886***	0.000	0.071	0.911	1.182***	3.601***	0.32
	(0.030)	(0.333)	(0.825)	(0.306)	(0.155)	(0.259)	(0.621)	(0.399)	(0.583)	
5W	-0.002	-3.565***	-1.347	1.040***	0.164	0.137	1.272**	1.411***	4.035***	0.38
	(0.031)	(0.344)	(0.886)	(0.302)	0.152	(0.273)	(0.639)	(0.412)	(0.618)	
6W	0.017	-4.135***	-1.746*	1.300***	0.222	0.250	1.456**	1.627***	4.306***	0.42
	(0.032)	(0.355)	(0.913)	(0.318)	(0.153)	(0.281)	(0.657)	(0.427)	(0.637)	
PostBaltic										
1W	0.081**	-1.437***	-3.445**	1.480***	-0.417*	-1.099***	2.432***	0.530	0.231	0.31
	(0.037)	(0.397)	(1.511)	(0.461)	(0.243)	(0.347)	(0.814)	(0.632)	(1.078)	
2W	0.102**	-2.361***	-4.268**	1.520***	0.233	-1.290***	5.707***	1.017	1.199	0.41
	(0.054)	(0.452)	(1.723)	(0.423)	(0.205)	(0.394)	(0.890)	(0.716)	(1.233)	
3W	0.080*	-3.194***	-2.963	1.640***	0.168	-1.459***	5.499***	0.850	3.663***	0.46
	(0.057)	(0.483)	(1.852)	(0.451)	(0.204)	(0.420)	(0.953)	(0.764)	(1.297)	
4W	0.067	-3.918***	-1.674	2.058***	0.335	-1.629***	5.537***	0.837	5.623***	0.49
	(0.050)	(0.539)	(1.062)	(0.479)	(0.231)	(0.465)	(1.039)	(0.866)	(1.446)	
5W	0.055	-4.759***	0.229	2.543***	0.594**	-1.542***	5.593***	0.886	8.012***	0.55
	(0.051)	(0.544)	(2.081)	(0.477)	(0.233)	(0.473)	(1.056)	(0.862)	(1.464)	
6W	0.135**	-6.284***	1.457	4.060***	0.897***	-1.184**	6.266***	0.435	8.935***	0.66
	(0.060)	(0.689)	(2.374)	(0.624)	(0.264)	(0.586)	(1.148)	(1.021)	(1.668)	

Notes: Dependent Variable is the NCY. PreBaltic is the period 2003W26-2013W22 and PostBaltic is the period 2013W23-2017W9.
Standard errors in parenthesis. Significance levels: * p<0.1, ** p<0.05, *** p<0.01. Two-tailed test.

Table 4: *Regression statistics for the net convenience yield, excluding spot price.*

	Const	RESM($\times 10^3$)	RESD($\times 10^3$)	INFD($\times 10^5$)	DEMAND($\times 10^7$)	WINDP($\times 10^3$)	VAR($\times 10^4$)	SKEW($\times 10^2$)	R^2
PreBaltic									
1W	0.032**	-0.778***	-0.638	0.724***	-0.953***	0.138	0.701*	0.058	0.17
	(0.015)	(0.219)	(0.460)	(0.261)	(0.145)	(0.171)	(0.381)	(2.602)	
2W	0.061***	-1.667***	-1.891***	0.863***	-0.484***	0.181	1.383***	0.456	0.20
	(0.025)	(0.274)	(0.575)	(0.254)	(0.143)	(0.213)	(0.485)	(0.327)	
3W	0.165***	-3.697***	-2.276	1.200*	-0.336	-0.262	1.943**	1.213	0.27
	(0.049)	(0.758)	(1.463)	(0.631)	(0.333)	(0.695)	(0.913)	(1.112)	
4W	0.114***	-2.973***	-3.932***	0.991***	-0.125	0.115	1.995***	1.523***	0.27
	(0.023)	(0.345)	(0.726)	(0.317)	(0.159)	(0.269)	(0.618)	(0.410)	
5W	0.135***	-3.465***	-4.587***	1.170***	0.028	0.145	2.485***	1.768***	0.32
	(0.024)	(0.359)	(0.767)	(0.314)	(0.157)	(0.284)	(0.638)	(0.425)	
6W	0.164***	-4.040***	-5.177***	1.410***	0.061	0.253	2.712***	1.983***	0.36
	(0.024)	(0.371)	(0.794)	(0.332)	(0.158)	(0.294)	(0.660)	(0.443)	
PostBaltic									
1W	0.087***	-1.429***	-3.601***	1.480***	-0.419*	-1.092***	2.478***	0.551	0.31
	(0.026)	(0.393)	(1.305)	(0.460)	(0.242)	(0.345)	(0.785)	(0.622)	
2W	0.131***	-2.318***	-5.034***	1.520***	0.222	-1.260***	5.937***	1.122	0.41
	(0.030)	(0.450)	(1.503)	(0.432)	(0.204)	(0.393)	(0.859)	(0.708)	
3W	0.168***	-3.059***	-5.479***	1.660***	0.141	-1.367***	6.161***	1.170	0.43
	(0.033)	(0.490)	(1.656)	(0.460)	(0.208)	(0.426)	(0.939)	(0.771)	
4W	0.202***	-3.700***	-5.422***	2.200***	0.279	-1.479***	6.614***	1.273	0.44
	(0.037)	(0.557)	(1.891)	(0.496)	(0.240)	(0.481)	(1.040)	(0.893)	
5W	0.247***	-4.448***	-5.055**	2.710***	0.544**	-1.334***	7.156***	1.547*	0.47
	(0.039)	(0.584)	(1.992)	(0.514)	(0.251)	(0.506)	(1.097)	(0.922)	
6W	0.335***	-5.848***	-4.520*	4.350***	0.890***	-0.893	8.128***	1.364	0.58
	(0.052)	(0.755)	(2.311)	(0.684)	(0.291)	(0.647)	(1.207)	(1.110)	

Notes: Dependent Variable is the NCY. PreBaltic is the period 2003W26-2013W22 and PostBaltic is the period 2013W23-2017W9.
Standard errors in parenthesis. Significance levels: * p<0.1, ** p<0.05, *** p<0.01. Two-tailed test.

Table 5: *Regression statistics for the net convenience yield, standardised beta coefficients.*

	Const	RESM	RESD	INFD	DEMAND	WINDP	VAR	SKEW	SPOT	R^2
PreBaltic										
1W	N/A	-0.153***	-0.057	0.118***	-0.290***	0.032	0.050	-0.004	0.102*	0.18
2W	N/A	-0.259***	-0.046	0.140***	-0.143***	0.032	0.074*	0.037	0.177***	0.22
3W	N/A	-0.263***	-0.476***	0.129**	-0.015	-0.073	-0.048	-0.004	0.782***	0.42
4W	N/A	-0.351***	-0.066	0.118***	-0.000	0.010	0.060	0.119***	0.293***	0.32
5W	N/A	-0.389***	-0.068	0.136***	-0.045	0.018	0.079**	0.133***	0.309***	0.38
6W	N/A	-0.423***	-0.082*	0.156***	0.059***	0.031	0.085**	0.143***	0.309***	0.42
PostBaltic										
1W	N/A	-0.247***	-0.182**	0.221***	-0.126*	-0.201***	0.214***	0.057	0.017	0.31
2W	N/A	-0.331***	-0.181**	0.232***	0.075	-0.191***	0.410***	0.090	0.070	0.41
3W	N/A	-0.406***	-0.115	0.225***	0.052	-0.196***	0.356***	0.067	0.194***	0.46
4W	N/A	-0.437***	-0.057	0.269***	0.090	-0.192***	0.317***	0.058	0.261***	0.49
5W	N/A	-0.492***	0.007	0.307***	0.147**	-0.169***	0.299***	0.057	0.346***	0.55
6W	N/A	-0.516***	0.041	0.392***	0.199***	-0.108**	0.316***	0.024	0.350***	0.66

Notes: Dependent Variable is the NCY. PreBaltic is the period 2003W26-2013W22 and PostBaltic is the period 2013W23-2017W9.
Standard errors in parenthesis. Significance levels: * p<0.1, ** p<0.05, *** p<0.01. Two-tailed test.

Table 6: *Regression statistics for the net convenience yield, standardised beta coefficients, excluding spot price*

	Const	RESM	RESD	INFD	DEMAND	WINDP	VAR	SKEW	R^2
PreBaltic									
1W	N/A	-0.151***	-0.058	0.121***	-0.293***	0.034	0.078*	0.010	0.17
2W	N/A	-0.256***	-0.136***	0.149***	-0.152***	0.035	0.121***	0.061	0.20
3W	N/A	-0.342***	-0.109	0.134*	-0.081	-0.026	0.165**	0.080	0.27
4W	N/A	-0.346***	-0.213***	0.133***	-0.034	0.016	0.132***	0.154***	0.27
5W	N/A	-0.378***	-0.231***	0.153***	0.007	0.020	0.155***	0.167***	0.32
6W	N/A	-0.413***	-0.244***	0.170***	0.016	0.032	0.159***	0.175***	0.36
PostBaltic									
1W	N/A	-0.246***	-0.190***	0.221***	-0.126*	-0.200***	0.218***	0.060	0.31
2W	N/A	-0.325***	-0.217***	0.233***	0.071	-0.187***	0.427***	0.100	0.41
3W	N/A	-0.388***	-0.213***	0.228***	0.044	-0.184***	0.402***	0.093	0.43
4W	N/A	-0.413***	-0.185***	0.279***	0.075	-0.175***	0.380***	0.088	0.44
5W	N/A	-0.460***	-0.160**	0.329***	0.135**	-0.147***	0.382***	0.099*	0.47
6W	N/A	-0.480***	-0.128*	0.419***	0.197***	-0.082	0.410***	0.076	0.58

Notes: Dependent Variable is the NCY. PreBaltic is the period 2003W26-2013W22 and PostBaltic is the period 2013W23-2017W9. Standard errors in parenthesis. Significance levels: * p<0.1, ** p<0.05, *** p<0.01. Two-tailed test.

9 Conclusion

The Energy Baltic Interconnection Plan (BEMIP) aimed to integrate the Baltic states to the Internal Energy Market of the EU in order to improve interconnection, ensure supply security and increase competition. As a result, Estonia (2010), Lithuania (2012) and Latvia in (2013) joined the Nordic electricity market, thus creating the Nordic-Baltic electricity market. Using the theory of storage and convenience yield, this study examines whether this extension has translated into a more efficient market. 13 years data of spot and futures prices, water reservoir level, electricity consumption and wind power production in the Nordic-Baltic electricity market were at disposal.

A higher net convenience yield is found in the PostBaltic period, equally distributed over the year, indicating a shift in risk preferences of the supply and demand. VAR, RESM, and INFD have all had a higher influence in the PostBaltic period. In addition, negative spikes in net convenience yield occurs in times of low spot prices. Hydropower producers seem more sensitive to price fluctuations. and hedge their profits in futures accordingly. Increased wind power seems to be the root cause of this behaviour. WINDP has indeed become significant in the PostBaltic period, but with negative coefficients. Still, a merit order effect of wind power is an intuitively appealing explanation as it pushes hydropower producers to compete for the residual remand, and leaves them with higher incentive to secure profits in the financial market. Continued low spot price levels and further increased net convenience yield may have critical consequences for the hydropower industry's profitability, and thereby threatening investments in hydropower plants. Preserving hydropower is essential to maintain flexibility and stability in a electricity market with an increased production of renewable energy, in particular, wind power.

A more detailed study of area price regions in the Baltic and interconnected regions would be fruitful, and paint a clearer, distinct picture of the overall effect on efficiency from introducing the Baltic states. In addition, this may also distinguish the effect between increased wind power and increased competition from Baltic producers, given the ambiguous results in this study. Future research could focus on ways of sustaining adequate development and preservation of hydropower to ensure long term stability. Finally, evaluating the impact of further integrating the Nordic-Baltic electricity market with the rest of Europe is highly relevant.

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A Appendix

Table A: *Spot price - Descriptive Statistics.*

Holding period, T	All	Winter	Spring	Summer	Autumn	PreBaltic	PostBaltic
Observations (N)	683	171	155	175	182	495	188
Average	35.35	38.18	35.15	31.51	36.56	38.22	27.80
Std.deviation	12.41	12.32	12.75	11.15	12.52	12.76	7.15
Minimum	7.95	18.18	20.28	7.95	9.99	8.40	7.95
Maximum	88.64	87.26	88.64	63.70	76.15	88.64	45.80
Skewness	0.96	1.45	1.30	0.12	0.88	0.85	-0.42
Kurtosis	4.49	5.69	4.54	3.02	3.60	3.96	0.20
CFI lower	34.13	35.75	32.52	29.34	34.17	37.09	26.88
CFI upper	36.57	40.61	37.79	33.68	38.95	39.35	28.83

Source: Nord Pool, 1999-2017. Winter is defined as the weeks between 47 and 7. Spring, summer and autumn are defined as the following consecutive thirteen-week periods. All spot prices are given in EUR/MWh. CFI upper and lower are 99% confidence levels.

Table B: *Futures - Descriptive Statistics.*

	Observations	Average	Std.deviation	Minimum	Maximum	Skewness	Kurtosis	CFI lower	CFI upper
Full Period									
1W	683	35.63	12.61	8.10	90.68	1.00	4.54	34.68	36.57
2W	683	36.10	12.56	9.75	86.75	0.92	4.09	35.16	37.04
3W	358	35.46	13.01	10.10	79.40	0.79	3.70	34.11	36.82
4W	683	36.62	12.24	10.00	78.18	0.83	3.63	35.70	37.54
5W	670	36.86	12.32	10.50	80.90	0.79	3.47	35.93	37.80
6W	622	37.48	12.57	10.25	80.90	0.70	3.30	36.49	38.47
PreBaltic									
1W	495	38.67	12.88	8.10	90.68	0.91	4.04	37.53	39.81
2W	495	39.31	12.67	10.50	86.75	0.85	3.64	38.19	40.43
3W	170	43.88	12.77	16.00	79.40	0.41	3.26	41.95	45.82
4W	495	39.91	12.12	18.00	78.18	0.78	3.26	38.84	40.98
5W	483	40.30	12.14	19.50	80.90	0.73	3.11	39.22	41.39
6W	481	40.45	12.10	18.50	80.90	0.74	3.14	39.37	41.53
PostBaltic									
1W	188	27.62	7.22	8.73	45.60	-0,34	3.00	26.57	28.65
2W	188	27.66	7.27	9.75	42.90	-0.26	2.87	26.61	28.70
3W	188	27.86	7.31	10.10	42.38	-0.11	2.72	26.80	28.91
4W	188	27.96	7.36	10.00	45.00	-0.02	2.58	26.90	29.02
5W	187	27.97	7.33	10.50	45.30	0.08	2.49	26.91	29.03
6W	141	27.36	8.08	10.25	46.05	0.29	2.29	26.01	28.70

Source: Montel, 2003-2017. All futures prices are given in EUR/MWh. CFI upper and lower are 95% confidence levels.

Table C: *Net convenience yield - Descriptive Statistics.*

	Observations	Average	Std.deviation	Minimum	Maximum	Skewness	Kurtosis	CFI lower	CFI upper
Full Period									
1W	683	-0.008	0.096	-0.756	0.503	-1.26	14.82	-0.015	-0.001
2W	683	-0.023	0.121	-1.172	0.616	-1.74	20.25	-0.032	-0.014
3W	358	-0.021	0.170	-1.336	0.616	-2.30	17.43	-0.039	-0.004
4W	683	-0.042	0.158	-1.433	0.650	-2.16	17.55	-0.054	-0.030
5W	670	-0.047	0.169	-1.448	0.678	-2.08	15.65	-0.060	-0.034
6W	622	-0.054	0.186	-1.471	0.756	-1.83	13.62	-0.068	-0.039
PreBaltic									
1W	495	-0.014	0.094	-0.756	0.311	-2.08	17.96	-0.022	-0.005
2W	495	-0.034	0.119	-1.172	0.385	-2.86	25.41	-0.044	-0.023
3W	170	-0.040	0.200	-1.336	0.436	-2.84	16.44	-0.071	-0.010
4W	495	-0.055	0.157	-1.433	0.436	-2.88	21.26	-0.069	-0.041
5W	483	-0.061	0.168	-1.448	0.553	-2.70	18.85	-0.076	-0.041
6W	481	-0.066	0.176	-1.471	0.562	-2.52	16.88	-0.083	-0.050
PostBaltic									
1W	188	0.007	0.100	-0.321	0.503	0.42	7.68	-0.007	0.021
2W	188	0.005	0.122	-0.414	0.616	0.72	7.43	-0.012	0.023
3W	188	-0.004	0.135	-0.463	0.616	0.08	6.51	-0.023	0.016
4W	188	-0.008	0.154	-0.551	0.650	-0.36	6.61	-0.030	0.014
5W	187	-0.010	0.167	-0.619	0.678	-0.62	6.76	-0.034	0.014
6W	141	-0.011	0.202	-0.659	0.756	-0.41	6.00	-0.044	0.023

Source: Nord Pool and Montel, 2003-2017. All futures prices are given in EUR/MWh. CFI upper and lower are 95% confidence levels.

Table D: *Correlation matrix of regression variables in 1W and 6W futures.*

	CY1	RESM	RESD	INFD	DEMAND	WINDP	VAR	SKEW	SPOT
CY1	1.00								
RESM	-0.18	1.00							
RESD	-0.13	-0.34	1.00						
INFLOW	0.35	0.03	-0.21	1.00					
CONSD	-0.32	-0.02	0.03	-0.35	1.00				
WINDP	-0.24	-0.03	0.07	-0.12	0.10	1.00			
VAR	0.28	-0.02	0.14	0.07	-0.39	-0.02	1.00		
SKEW	0.18	-0.23	0.13	0.14	-0.23	0.09	0.21	1.00	
SPOT	0.15	0.22	-0.49	0.15	-0.17	0.01	0.20	0.11	1.00
CY6	1.00								
RESM	-0.47	1.00							
RESD	-0.02	-0.31	1.00						
INFLOW	0.40	0.03	-0.33	1.00					
CONSD	-0.05	-0.06	0.15	-0.37	1.00				
WINDP	-0.15	0.01	0.09	-0.18	0.08	1.00			
VAR	0.40	-0.03	0.14	0.03	-0.21	-0.01	1.00		
SKEW	0.23	-0.20	0.14	0.04	-0.17	0.08	0.23	1.00	
SPOT	0.35	0.22	-0.48	0.24	-0.19	0.00	0.23	0.13	1.00

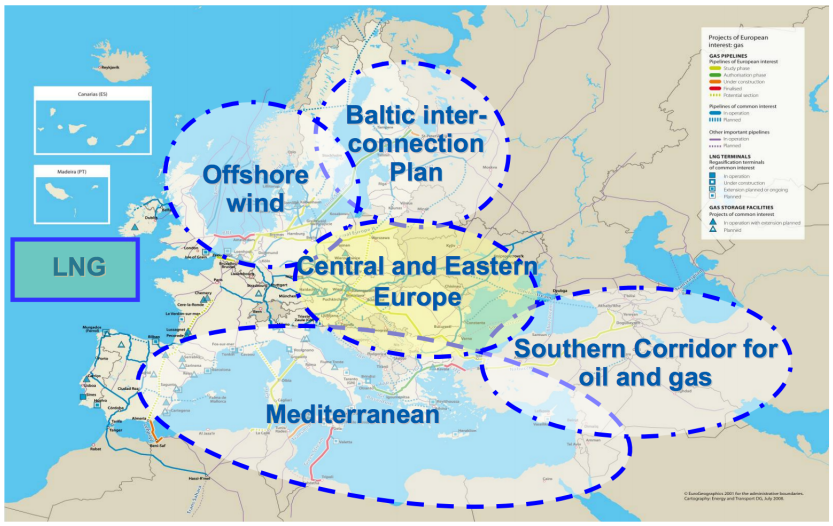


Figure A: *Six infrastructure priorities in the Second Strategy Energy Review.*
Source: Elforsk (2012)

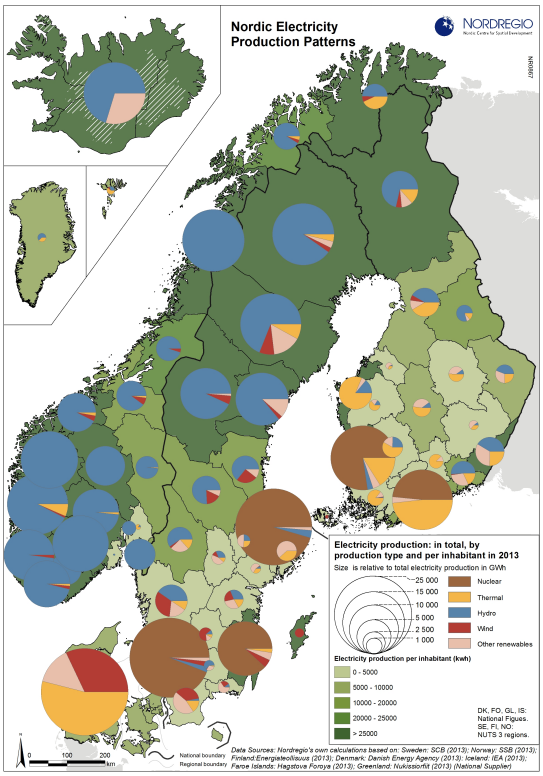


Figure B: *Total Electricity production by production type and per inhabitant in 2013.*
Source: Nordregio. Accessed at 2017-04-16 `www.nordregio.se`

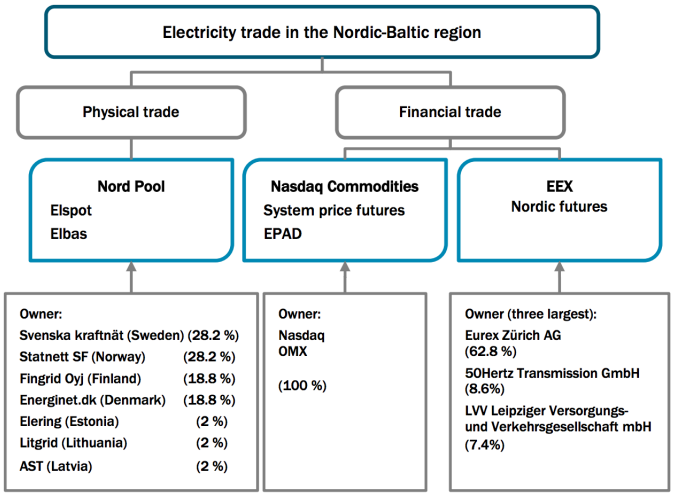


Figure C: *Ownership structure of the Nordic-Baltic electricity market.*
Source: Ei (2016)

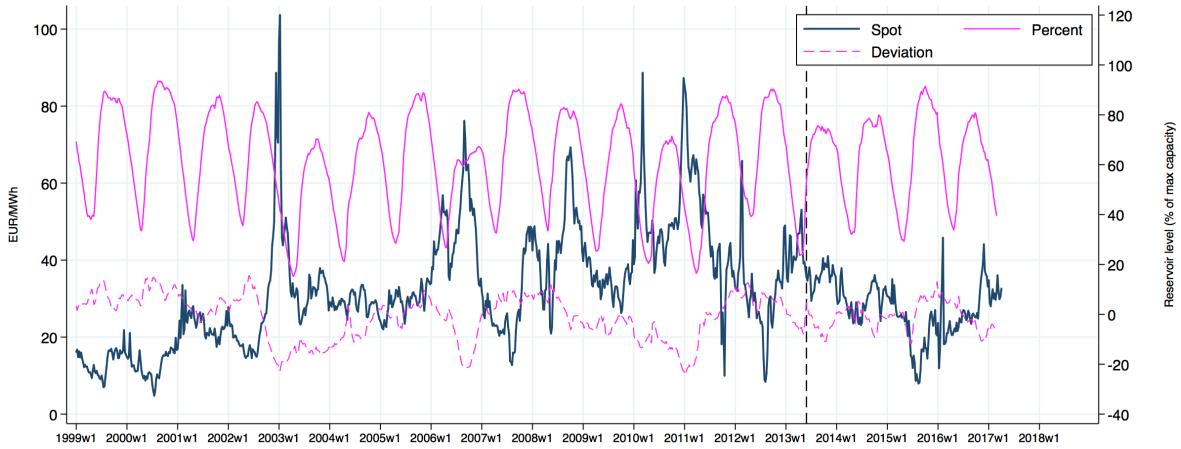


Figure D: *Figure D plots the water reservoir level, the deviation in water reservoir level from its median and the spot price in the period 1999-2017. The water reservoir level is the current amount of water in Sweden, Norway and Finland divided by the total water reservoir capacity. The spot price is measured on the left hand axis and is given in EUR/MWh, while the reservoir level and deviation from median is measured in the right axis and are given by percent of maximum capacity. Horizontal dashed line is the week 2013W22.*

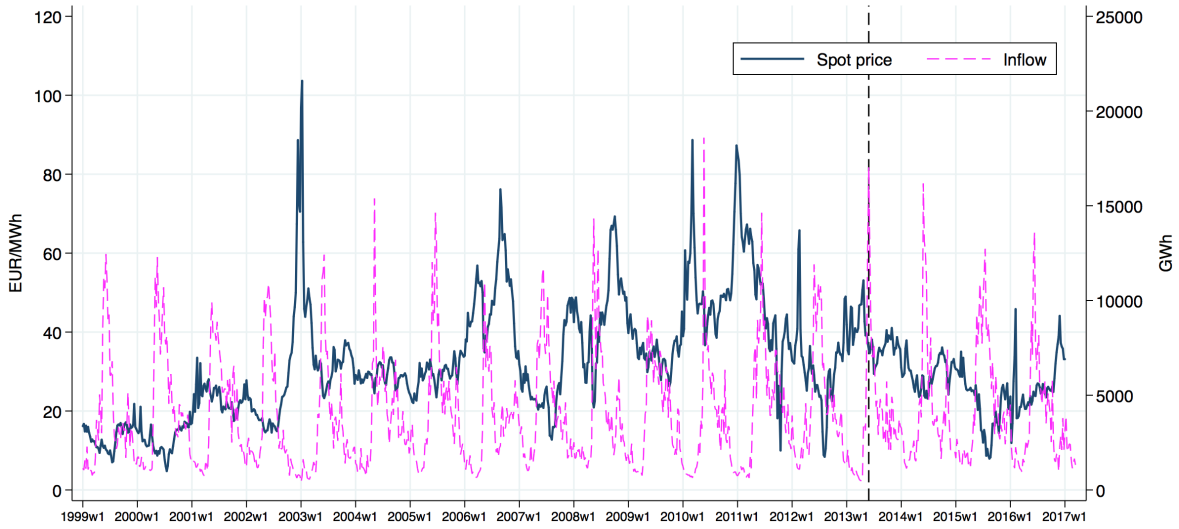


Figure E: *Figure E plots the water inflow and the spot price in the period 1999-2017. The water inflow is the total water inflow in Sweden, Norway and Finland, and is given by the amount of electricity it can produce. The spot price is measured on the left hand axis and is given in EUR/MWh, while the water inflow is measured in the right axis and is given by GWh. Horizontal dashed line is the week 2013W22.*

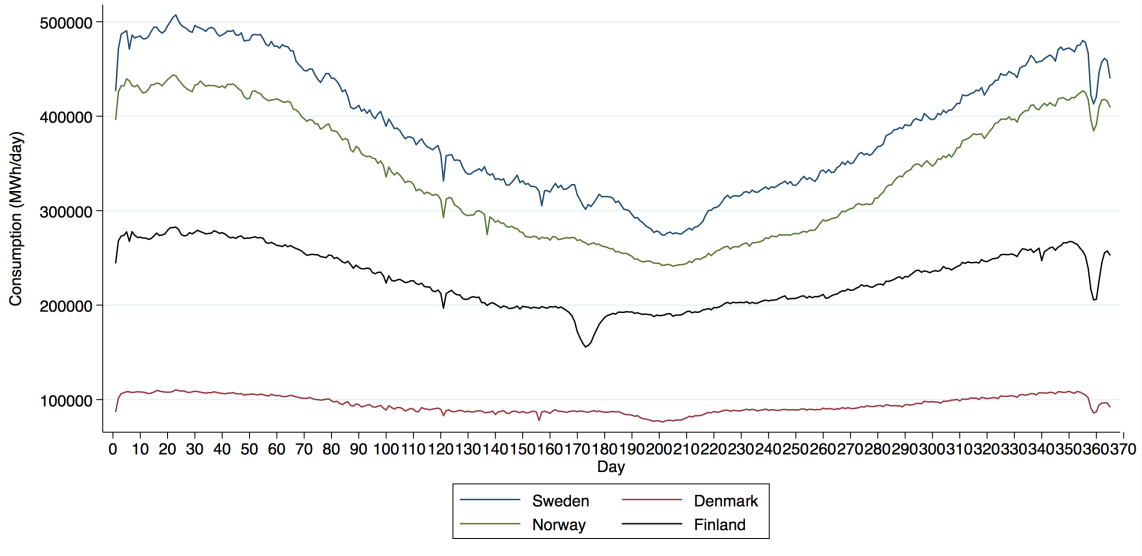


Figure F: *Average daily electricity consumption in Nordic countries in the period 2003-2017.*

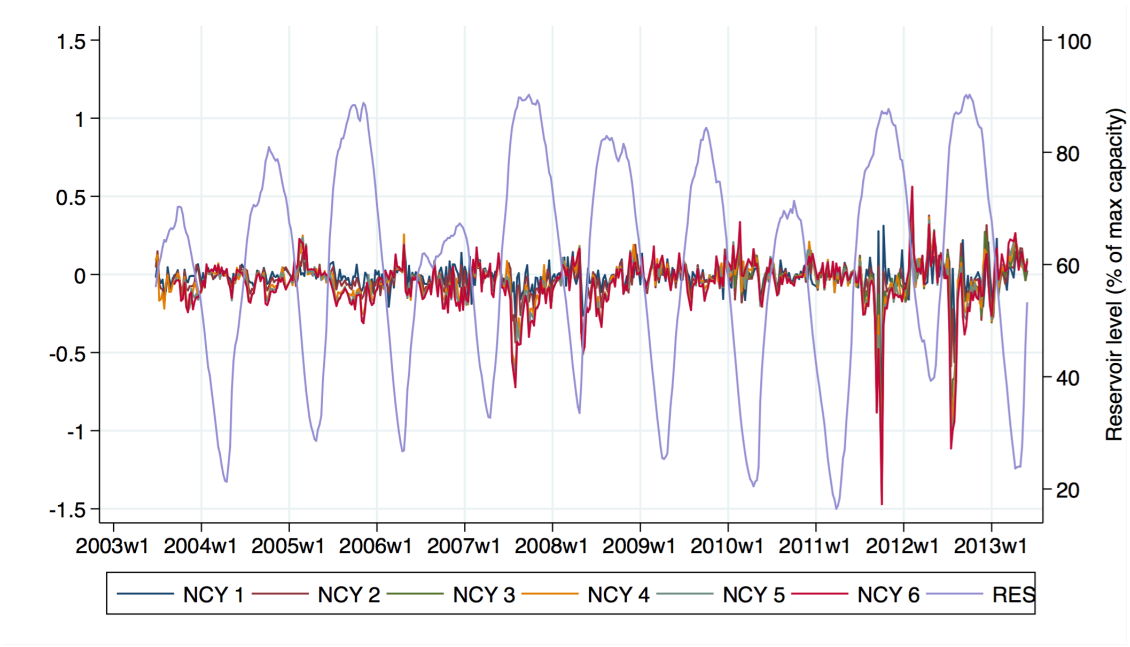


Figure G: *Net convenience yield on weekly futures contracts with 1week to 6week holding periods relative to water reservoir levels in the market under the period 2003-2013W22.*

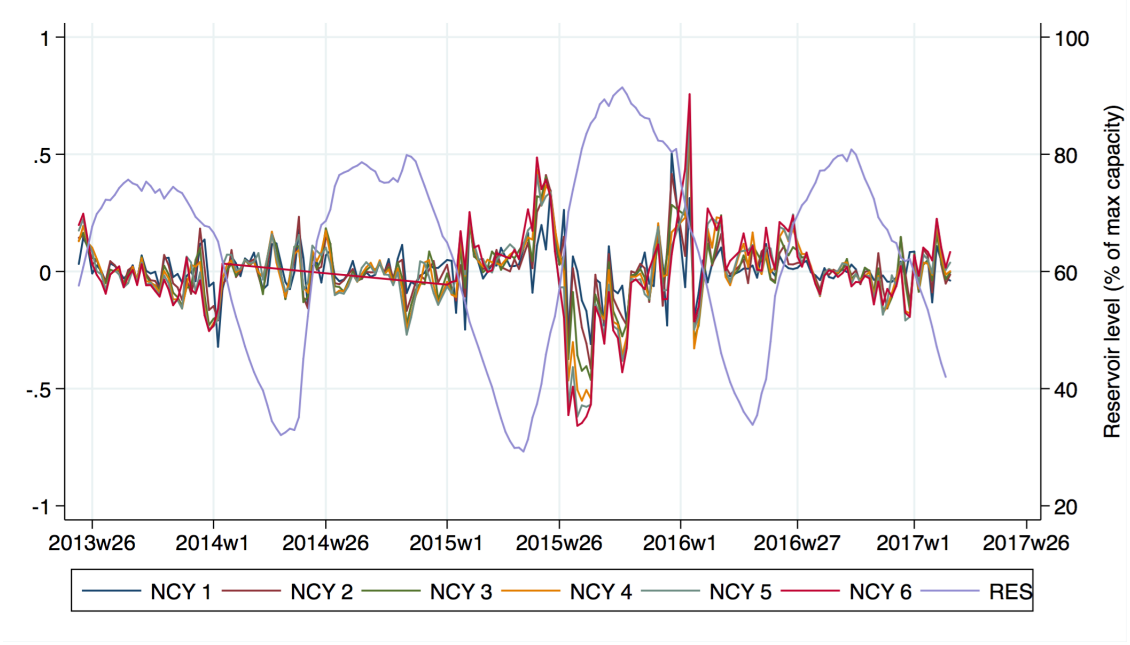


Figure H: *Net convenience yield on weekly futures with 1week to 6week holding periods relative to water reservoir levels in the market under the period 2013W23-2017.*