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QUANTILE REGRESSION ESTIMATES FOR HYDRO BALANCE AND TEMPERATURE AFFECTING ELECTRICITY SPOT PRICE

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ABSTRACT

Electricity has become an exchange-traded commodity in many parts of the world as local electricity networks have been connected into larger, international power pools for price stability and security in power delivery at all times. The Nordic power market Nord Pool is considered a forerunner in creation of the continental European power market.

In practice the process has been challenging as Nord Pool still has several price areas caused by physical transmission restrictions. Also the prices have not been stable as the physical nature of the non-storable electricity sets strict requirements for supply to meet the circumstance-driven demand. The current market structure has created new financial risks for operators in the field of electricity, and understanding the factors behind electricity prices has become increasingly important.

It is known that the demand i.e. electricity consumption is highly dependent on the seasonal temperature circumstances, creating changes in the need for heating and cooling. The production as supply leans on the availability of generation and therefore on costs of utilized fuels. The environmental circumstances in the Nordic region are rather challenging with cold winters and hydropower representing half of the power generation. Especially when cold seasons occur simultaneously with the low hydro fuel balance, the market balance is endangered and the risk for extreme price reactions has increased.

The thesis estimates the explanatory effect of Oulu temperature and Scandinavian hydro balance on Nord Pool Finnish area price, within the variable value range using quantile regression. The effect was expected to reach its highest at the negative extremes of variables and decrease towards the normal and up. In the Nordic region, hydro balance reflects the long-run price levels, while mean reversion and extreme price jumps are affected by short-term fluctuation in temperature.

KEYWORDS: Nord Pool, electricity spot price, temperature, hydro balance, quantile regression.

1. INTRODUCTION

The role of electricity in the modern society is essential, in running our everyday routines, industry and workplaces. Especially in challenging Northern circumstances and climate, electricity manages to keep us alive both physically and mentally through the cold and dark winter season with heating and lighting. Electricity delivery procedure from the local generation facility to the end-user has changed rapidly during the recent decades into a complicated market system, and the local energy utility is now facing all the risks from dynamic financial markets and international legislation. The basic idea remains the same: there is a certain amount of circumstance-driven and time-varying consumption, and the power generation has to satisfy the demand to keep the network in balance. Since everyone has to pay for the electricity consumed and distributors are obliged to deliver the demand, the cost and price of electricity in the deliberated wholesale electricity market has become an extremely important and interesting topic both in public discussion as well as in research as it seems to have problems a perfectly functioning free market should not have.

The whole chain from generating to distributing and selling electricity to the end-users used to be completely in hands of the local city or town owned electricity utility that had the pricing power of the commodity based on its cost structure added with a contribution margin. That system was considered to have too much power in setting the premium on the commodity and most importantly insufficient level of transparency. The delivery risk in local power grid areas within problem circumstances i.e. power outages was also seen too high and possibly out of control. The power network connects all electricity producers to all consumers within and across national borders.

The continental Nordic countries created the first international deliberated power market connecting the national grids into a common market place Nord Pool, physically located in Oslo, Norway. The Nord Pool exchange performs as the market place for supply and demand to meet. The electricity producers sell their production to the power exchange and the electricity retailers and large consumers buy their estimated consumption. The balance between demand and supply must stay stable during all times and that is the key task for national grid companies. Demand i.e. consumption is the driving force that the generation as supply is supposed to cover, mostly because price elasticity of the demand is rather non-existent. Consumption follows our daily routines and varies by the time of the day, day of the week and also through seasons. The most energy intensive times are the working hours (07 - 19) on business days during the coldest winter months, meaning from Mondays to Fridays holidays excluded. The base consumption is met by keeping the passive electricity consuming devices powered. Lights, computers, companies and other offices etc. are activated during the day and switched off after work and when going to sleep. The seasonally changing consumption consists of the need for heating houses and other buildings. Common knowledge says heating turns into cooling around +18 ˚C, which is also used in weather derivatives (Hull 2008 and Geman 1999) between cooling degree days (*CDD*) and heating degree days (*HDD*), counted as the difference to 18 ˚C. In Nordic region this means most of the year for heating. The consumption for heating increases as the temperature decreases, and the demand peaks can be rationalized to occur during the coldest winter months when temperature might settle at -40˚C or even colder as winter 2010-2011 has shown. On the other side demand reaches lowest during the summer months during holiday season, though can also peak on hottest summer days.

The Nordic power market is considered (Amundsen and Bergman 2006) to be a forerunner and a good example for others in the process of building the EU pursuit of continental European power exchange. Amundsen and Bergman (2006) suggest that some of the Nord Pool's success has to do with Nordic cultures, the way of pursuing and doing things. The largest differences between different power markets consist of weather circumstances, and generation structure with different utilized fuels: How much the demand fluctuates, and how well the supply meets the demand. In highly seasonal markets the peak capacity rises into focus.

Electricity differs from other traded commodities mostly in storability. Electricity itself is not storable, but fuel often is. Characteristically in Nordic countries approximately half of the consumption is met by hydropower, most of it produced in Norway and Sweden. Water fuel reservoirs for hydropower consist of water above power plant's turbines, mostly in rivers and lakes but also melting water from snow is concluded. Precipitation is in the core as the rainfall fills the fuel tanks. In addition to natural lakes, water is also stored in artificial lakes to store as much water as possible for future use. Fuel reservoir for hydropower is followed by market counterparts, as the difference to the seasonal normal, *hydro balance*. The actual water level draws a similar seasonal cycle as temperature, but the hydro balance is considered (and proved also in this paper) a better underlying variable for the market price.

The production palette and the fuel circumstances are the force behind the price formulation. The availability of fuels is a key issue in analyzing the market functions and price dynamics. In Nordic region, nuclear power covers a certain level of consumption, as it is a good way of generating a stable feed to the grid. Other, more flexible production ways are used for balancing with the demand, and during extreme demand times the excess capacity is bought from Russia and Germany.

The challenges in the Nord Pool area occur during the most energy intensive times combined with problems in power generation in large production utilities. The liberated market structure sets its own challenges to generation capacity when the excess capacity has high marginal costs and is expensive to hold in reserve with use only at the highest demand peaks, usually lasting just hours. In circumstances of a deregulated market, there is no willingness to hold that kind of expensive reserve as power market is run by profit maximizing and cost minimizing companies, as in other businesses.

The market price of electricity in a wholesale market builds up on the balance in demand and supply. The varying cost structure of the different production types (see Figure 1.1.) set the challenges into price development of electricity. The price formation in electricity is based on the marginal costs of supply stack meeting the demand. During the warm summer season in the Nordic countries, the consumption is low and met by cheap production methods, hydro and nuclear to mention. When circumstances increase the consumption, the more expensive production is activated to meet the increased demand. Old production utilities in hydro and nuclear power run rather cost effectively as power plant investments have been paid off long ago, while gas turbines, oil and coal condensing cost more. The production plants activated for peak demand are rather expensive not so much for the fuel cost, but the procedure of production start, and shut-down for just few hours.

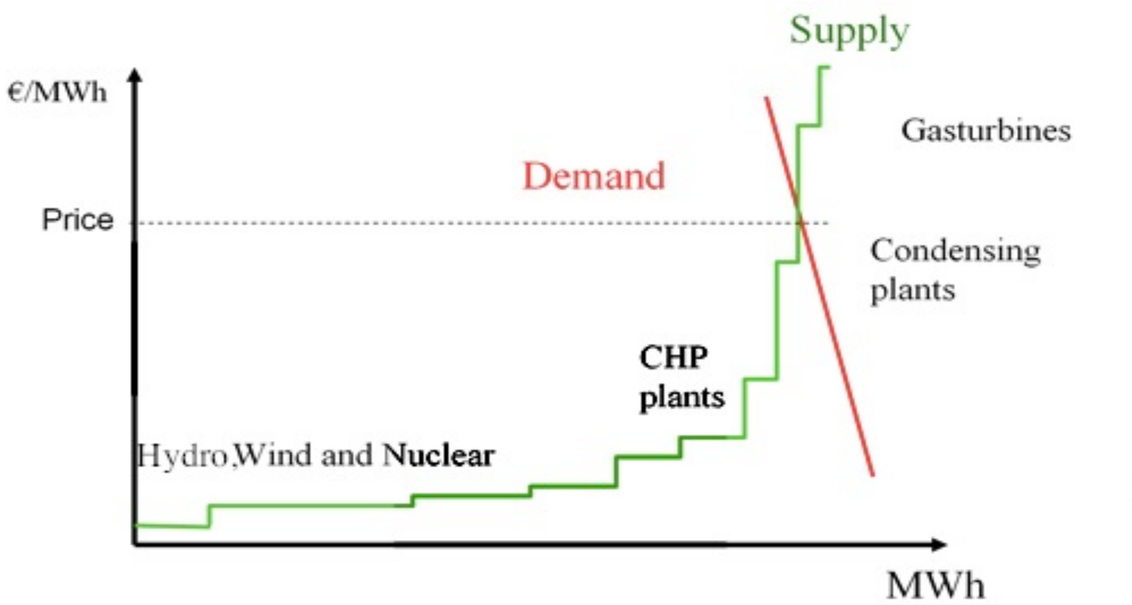

Figure 1.1. Marginal cost structure of different generation types.

The total cost of electricity production depends not only on used fuels, but the running costs of the power plant with different production activity. The cheapest methods often present the least flexibility and longest reaction times, and are used for covering the 'base load'. Gas turbines, oil condensing plants and those at the high marginl costs, have short response times to adjusting production and are often used as 'peakers', during demand peaks when needed. The cost for the start-up, running and shutting-down costs are rather high as these are often run only short periods of time, maybe just hours, making the fuel cost a minority in some cases. This is also the main reason for leaving the fuel costs (oil, coal etc.) out of the research. In situations lacking the cheap-end fuels, the electricity has to be produced with more expensive methods, bringing the prices up.

The capacity of each production method lives with time, as power plants have their annual service and other outages, most severe in large nuclear power plants. The most essential variable in the Nordic region is hydro fuel balance as hydropower represents approximately half of the total production capacity. In cases when the hydro production is extremely low due to low hydro reservoir, the cheap end of the production palette is short and the more expensive methods are utilized earlier on the demand curve, raising the overall prices.

The price changes in demand and supply imbalance situations understandably bring out the risk of market power abuse for price manipulation. Some operators might wait a while and let the price climb until starting to sell its production to the market to maximize the profit. The three largest electricity producers in Nord Pool area, Vattenfall, Fortum and Eon are seen (Isacsson 2011) to be in the position with too much market power as hydro power, especially in storable forms, offers opportunities for price manipulation. Water as the fuel for hydropower, is provided free of costs by Mother Nature but the opportunity cost of saving it for later is a trickier question. Also the nuclear power plants are such complicated facilities, that the reasons behind sudden outages are difficult to prove speculative.

Risk management is a crucial part of operating in electricity market. Modeling the demand is the starting point, ending with supply meeting it. Understanding the time-dependent, temperature driven structure of demand helps estimate the consumption at certain times. The price risk for operators in supply and demand sides have differing problems, trickier for the consumption and retail. The generation as supply has its capacity restrictions, selling the produced electricity to the market benefiting from high prices, opposite from retail and other consumers. Production utilities understandably execute maintenance outages during the lowest price times. The demand side, electricity retailers and consumers have the highest risks during the expensive times. For the most expensive times, some consumers might even restrict their activities to save costs. In paper industry with their own power generation for example, they might stop paper machines and sell the generated electricity to the market, as it might be more profitable that way.

Both sides, demand and supply, benefit from stable and predictable electricity prices and see extreme price deviation as poison for the financial performance. To secure and stabilize prices in financial operation, both sides use financial derivatives. The prices for production and consumption are usually locked with Nord Pool's standard derivatives, or other contracts well in advance. The actual electricity amounts seldom match the predicted, so adjustments have to be traded at market prices, in real time.

1.1. Research problem and contribution

The research problem in the study is to investigate the explanatory variables' effects on Nord Pool's Finnish area price within different levels of variable values, focusing at low values and high prices. The problem is examined from risk management's point of view, with variables temperature and hydro balance. Temperature is seen as a key element in electricity price risk management as it determines the consumption volume, i.e. the demand. Hydro balance represents the supply side explanatory variable as hydropower covers approximately half of the Nordic electricity generation. The cost of water as a fuel is also extremely low, yet combined with low running costs of relatively old hydropower utilities. Therefore the level of hydro fuel capacity is crucial for the overall production costs. As the hydro balance is a measure of difference to ‘seasonal normal’ (weekly average) in water reservoir as fuel balance for hydro power, the temperature data was also examined as comparable ‘temperature balance’, the seasonal pattern stretched to reveal the exceptions from the normal line, 0-level. The difference to the long-term daily mean also resulted in stronger effect results.

The electricity spot price tends to act nervous at extreme temperatures and especially during relatively low hydro balance, when the lacking capacity is hard to find, produce self or buy from neighbours. The spot price standard deviations rise for the winters, and combined with low hydro balance, it may result in extreme price reactions called ‘*spikes*’. These spikes are often linked to supply side shocks, where large production units may be, surprisingly or scheduled, out of use. The most extreme spikes usually only last for some hours and the prices may reach the exchange-limited high register at 1500 €/MWh, and even the smoothened daily average may be ten times the average, revealing the extreme observations.

The wholesale electricity market is a rather new market among financial market research and within its short history the market has developed rapidly and is still changing because of the market’s growth and progression in, for example legislation. Nevertheless, the basis of the market remains the same. The consumption performs its own cycle with effects from seasonal and economical changes with temperature being the largest factor behind consumption variations. The production as supply tries to keep up with demand maintaining the stability in the power grid stable for secure delivery. As approximately half of the Nordic electricity is produced by hydropower, the nature-provided water reserves and dammed reservoirs for hydropower then becomes the most important single factor in price development. The volume driven price risk in electricity business is complex, but it can be approached in a simplified manner:

Framework of the problem:

Temperature (°C)	represents the	Demand (Consumption)
Hydro balance (MWh)	represents the	Supply (Generation fuels)

Temperature is the largest single explanatory variable causing changes in volume. The volume risk is crucial for electricity market operators, for electricity retailers as well as producers as the total volume is directly linked to euros in trade. The volume risk is present at all times and manageable by selling or buying the difference between previously purchased (sold) MWh and the exact MWh in consumption (production). The price risk is also present at all times, as the electricity must be traded latest an hour before delivery. Price risk is the one leading into severe financial consequences for the market operators. Both risks, volume and price, are independently manageable, but simultaneously realized the risk may become seriously severe. The connection between temperature and price is therefore a fascinating tool in electricity traders financial risk management.

The electricity spot price is known to follow consumption volume; seasonally, within a week and intraday. Seasonal changes in consumption are caused by temperature changes while changes within a week and intraday are caused by people's working and living rhythms. The producers all together have major influence on the price formation based on their cost structure. The power generating companies aim to maximize their profits as all other companies and none of them are willing sell at loss. The necessicity commodity in oligopolistic market shouts for regulation and surveillance, which are executed by national and international regulators and several surveillance institutions.

The financial research in the field of electricity markets is rather recent due to markets' relatively short history. Commodities have been an active research topic within financial markets and mostly the financial theories are also applicable to electricity market. Then again, electricity does have features that other commodities do not. It is a real-time necessity commodity, physically non-storable, and affects absolutely everybody. Randomness of drift and seasonality and volatility changes are the most characteristical of those features. Major differences between different electricity markets (mostly in used fuels and their storability) also make comparison more complicated between the markets. The Nordic power market, Nord Pool, is a good example of a 'well-functioning' and versatile power market and often included therefore in international research. Approximately half of the Nordic electricity consumption is met by hydropower, which, as a fuel, is partly storable. In some markets, the production consists mostly of fossil fuels, with no such storage issues.

The price of the commodity is financially the most important factor in electricity market and the dynamics of the price is under active discussion also in public. Most of the market operators are publicly owned utilities and therefore the price risk affects financially the society's economy. Understanding the reasons behind price dynamics is therefore important for economical stability of the stakeholders.

The purpose of the thesis is to analyze the local temperature of Oulu and Nordic hydro balance as explanatory variables for Finnish area price traded in Nord Pool Spot power exchange. The simultaneous risk of colder than expected temperatures and low hydro reservoir causing excess consumption are major factors leading into extremely high electricity prices. These result in the largest single financial risk in the business, negative for the retailer, and positive for the producer.

The study investigates the effect linearity of hydro balance, temperature and temperature balance on the spot price throughout the range of variable values, and also by spot levels. The research uses *quantile regression* to investigate the effect of explanatory effect of these variables within variable quantiles. Quantile regression presents a new perspective for investigating electricity price drivers.

1.2. Research hypothesis

The research problem of hydro balance and temperature driving price dynamics on the Nordic electricity wholesale market is approached through five research hypothesis, which test the explanatory effect of the chosen variables to Nord Pool's electricity spot price for Finland.

1. The first hypothesis tests the explanatory effect through spot price scale and the assumption is that regression coefficients are much higher (negatively) in the highest price quantiles. The circumstances at normal and low price levels are assumed to be more stable with tolerable temperatures and sufficient hydro reservoir.

2. The second hypothesis tests the explanatory effect on spot price through temperature quantiles and the assumptions that the coefficients are clearest in the coldest parts of the observations. The effect was expected to change through the variable spectrum with the highest errors at the warmer half upwards from neutral temperatures.

3. The third hypothesis tests the effect on spot prices by quantiles of hydro balance observations. The hydro balance was expected to obtain the highest explanatory effect on spot prices below median at the lowest parts of the observation scale and not so significant at the normal levels of hydro reservoir.

4. The fourth hypothesis tests the temperature balance's changing effect through variable quantiles on spot price and the assumptions state that the most extreme quantiles obtain largest regression coefficients while at normal temperatures the price tension should be low.

5. The fifth hypothesis tests the combination effect of hydro balance and temperature (and temperature balance), and suggests that the effect is greatest at the negative end of combined values, and weakens towards the upper quantiles. The combined effect is also assumed to be greater than individual effect at the negative end.

6. The sixth hypothesis tests the assumptions that the correlation coefficients result highest during the coldest winter months, and even higher during the lowest hydro reservoirs.

1.3. About the thesis

The thesis examines the nature of electricity price dynamics in the Nordic power exchange with temperature and hydro balance as explanatory variables. To understand the idea behind the research, it is necessary to start from the physical structure of the Nordic power market and the reasons behind the price dynamics.

This thesis is structured as follows. After introduction chapter two provides background information about the structure and functions of the Nordic electricity market and Nord Pool exchange, and the market fundamentals that underlie the research problem, from deregulation to market surveillance and the structure of supply and demand. Chapter three discusses electricity price drivers, dynamics and market risks. Chapter four introduces the methodology used in the data processing and describes the data characteristics graphically. Chapter five provides research findings with analysis and conclusions chapter discusses the results of the study. In the end lies the list of references used throughout the thesis.

2. THE NORDIC POWER MARKET

The Nordic power market is located in seriously challenging circumstances, as strong seasonal changes in temperatures affect the consumption cycle in addition to economical activity. The seasonality also affects the supply, as approximately half of the nordic power generation consists of hydro power. Water reservoir changes dramatically throughout the years, in similar sense as temperature, with precipitation seasonality and melting water of snow in the spring. These characteristics differentiate Nordic power market from other. The Nordic power pool and market, Nord Pool, is often referred to as a forerunner within international deregulated markets. Within power market research, Nord Pool plays a large role, being often included in published research. As European Union is aiming for a continental power pool and market for all of Europe, Nord Pool is considered a good example in the process of market creation. (Amundsen & Bergman 2006).

Electricity market consists of four sectors: generation, transmission, distribution and retail. Generation means transforming energy stored in fuels or other forms into electrical energy. For example, hydro power is generated by the kinetic energy of water falling through a turbine. The generation is usually located far from where electricity is actually consumed and has to be transported to the distiribution centers (Transmission). Distributing electricity to the end-users takes place through local networks of wires and transformers. The actual business, retailing, is acquiring and selling power to the consumers and on the background, maybe the better side of business is to produce and sell to retailer and other demand side players. The authority operating the transmission system is responsible for keeping its area electrically stable and ensuring the supply meeting the demand, delivering the commodity to the end-user. The operator has connection to the producers in its area and tells them if they need to increase or reduce their production entering the grid. (Nord Pool 2012).

Local and national electricity transmission areas are connected to create national and international power markets throughout the world. The first international and one of the very first deregulated power markets was created by Norway, Sweden, Finland and Denmark. The Nordic national transmission system operators own and run the Nord Pool, a common power exchange. The Nordic power market is one of the best-known examples of electricity restructuring, and most actively studied in academic research.

The spot price is set at the demand and supply equilibrium in circumstances formed by economical activity and weather circumstances. The demand (consumption) is the driving force which the supply (generation) is meant to satisfy keeping the transmission and distribution networks stable, for the secured delivery. (Nord Pool Spot 2012).

The regulation in the Nordic electricity market is executed by the national authorities and the power exchange itself. Nord Pool Spot operates under Norwegian law as it is incorporated in Norway and is required to maintain a market surveillance function. Each Nordic country has a competition authority and an energy market authority. The national financial supervisory authorities are responsible over supervision of financial elecricity trade. The oligopolistic market structure exposes the large operators for temptation to abuse the dominant position in price manipulation. (Kauppi 2009: 36-37).

2.1. Deregulation

The whole chain from generation and transmission to distribution and selling electricity to the end-users used to be completely in hands of the local city or town owned electricity utility having all the pricing power of the commodity based on its cost structure added with a contribution margin. Electricity chain was seen as a natural monopoly, where one large publicly or private owned company would run the four supply functions more cost efficiently than several small companies. Retailing is not considered a natural monopoly as long as retailing companies have access to the distribution networks and are able to buy power from the exchange. Distribution networks and transmission are still seen as natural monopolies to a large extent, because duplication of the existing networks would be hard to execute due to laws of physics in electricity flows in interconnected powerlines and besides that, expensive to maintain.

Prior to deregulation process, the Nordic transmission grids were owned by the vertically integrated and large state-owned power companies (except for Denmark). The companies also possessed a large fraction of total generation in Finland and Sweden. Another large part of the generation capacity was owned by energy intensive firms from steel, aluminium and paper industries. Large industrial electricity customers and electricity producers also owned a parallel power grid in Finland. The basic idea behind electricity market restructuring has in most countries been to unbundle the vertically integrated incumbents and to open the retail and generation for competition. The consumers where given the freedom to freely choose their supplier, though the local network maintenant still has the distribution part of the consumers electricity cost which is required to be fixed regardless of the customers supplier. (Kauppi 2009: 16). The distribution fee for the local network company is also required to be reasonable. For example Turku Energia had charged too high distribution fees during 2005-2007 and was sentenced to refund that to its customers with lower distribution fees. (Turku Energia 2009: 24. yht. 71s)

The constructive idea behind deregulation of the national markets was to increase efficiency in generation through competition and to encourage investment in new generation capacity. The mixture of different production technologies was seen highly complementary for the market where participants are able to trade across the borders.

2.2. Nord Pool Spot

The organizer exchange of the Nordic wholesale electricity trade, Nord Pool Spot group, is owned and run by the national transmission system operators in member countries. Norwegian Statnett SF and Swedish Svenska Kraftnät both own 30 per cent and Finnish Fingrid Oyj and Danish Energinet.dk own 20 per cent each. Nord Pool Spot provides the market place for day-ahead and intraday trade to its participants (nearly 340 companies in 2010): producers, energy companies and large consumers. Nord Pool Spot is the central counter party in all trades, guaranteeing settlement for trade. Nord Pool Spot's system price is the reference price for futures, forwards and options traded in the financial market as well as for the OTC (over the counter) and bilateral wholesale market. (Nord Pool Spot 2012).

Market participants submit quantity-price schedules to the Elspot day-ahead hourly market, i.e. bids for each hour on the next day delivery. The spot price in Elspot is therefore set for each hour for each day. The Nordic market is divided into separate price/bidding areas as a part of a zonal pricing system because of the physical network limitations. Finland, Sweden, East and West Denmark and Estonia are the permanent price areas, when Norway uses its own zonal pricing system to manage transmission congestion within the country. In practice, Norway's five areas are divided in two pricing areas. From the beginning of November 2011, Sweden was also divided into four price zones due to physical restrictions in the transmission system. (Nord Pool Spot 2012).

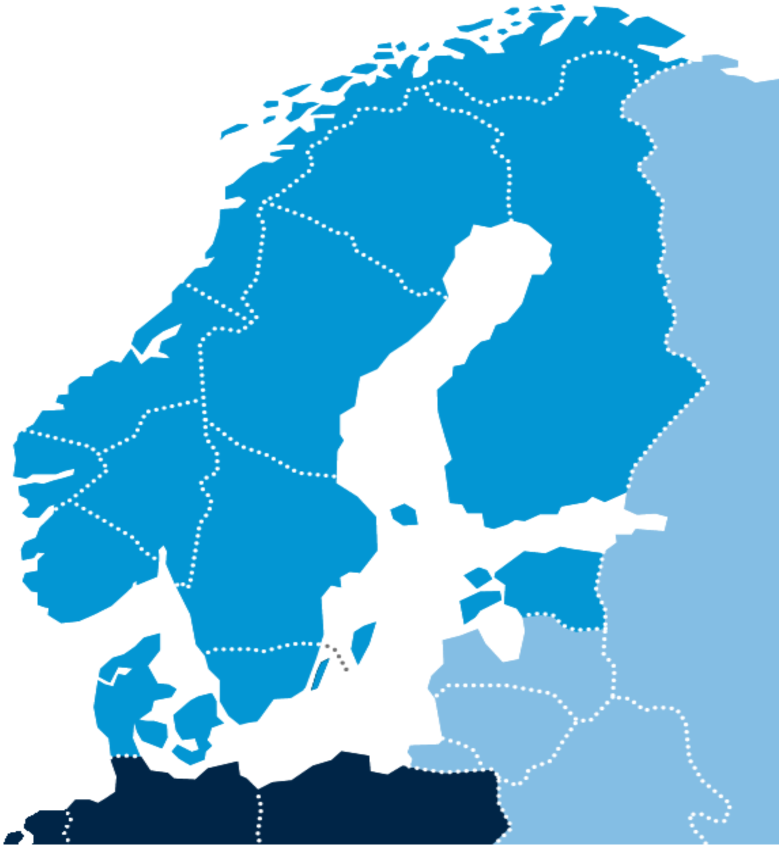

Figure 2.1. Nord Pool Spot price areas. (Nord Pool Spot 2012.)

In the other countries, system operator uses counter-purchases to deal with internal transmission congestion. A counter-purchase entails paying a producer to increase or reduce the scheduled production. (Kauppi 2009: 19.) In 2007 almost 70 per cent of total consumption in the Nordic countries was traded in Elspot and the rest was conducted by bilateral contracts. NASDAQ OMX Commodities operates the financial market where participants can hedge against price risk by trading standardized Nord Pool derivatives: futures, forwards, European options and contracts for difference (area price vs. system price). (NASDAQ OMX 2012)

2.2.1. Physical Market - The Elspot market

Nord Pool's core is the physical market called Elspot, where hourly power contracts are traded for physical delivery in the next day's 24-hour period. The spot price calculation is based on the balance between bids and offers from all market participants - finding the intersection point between the supply and demand curves. Participants in the trading in the spot market are producers selling and consumers buying. In this context consumers stand for electricity retailers and large industrial consumers, who buy their electricity staright from the exchange. The trading method used in the implicit capacity auction on the interconnectors between the bidding areas is referred to asequilibrium point trading, auction trading, or simultaneous price setting. The Nordic Elspot market concept's four key features are: (Nord Pool Spot 2012).

1. Implicit auction

The concept is based on bids for purchase and sale of hourly contracts using three different bidding types: hourly bids, block bids and flexible hourly bids that cover each or some of the next day's 24 hours. Market participants trade within their physical location (bidding area) in the market.

2. Grid congestion management

At the interconnections between the Nordic countries and within Norway, price mechanisms are used to relieve grid congestion (bottlenecks), by introducing different prices for each area. Within Denmark, Finland and Sweden, the grid congestion is managed by counter-trade purchases on bids from generators.

3. Area prices

The Nordic market is divided into bidding areas which may become two or more separate price areas if the contractual flow of power between bid areas exceeds the capacity allocated for Elspot contracts by the transmission system operators.

4. System price

Referred as the unconstrained market clearing price, the Elspot's system price balances sale and purchase in the exchange area while not considering any transmission constraints. All areas may also trade at the same system price in case there are no constraints between the bidding areas.

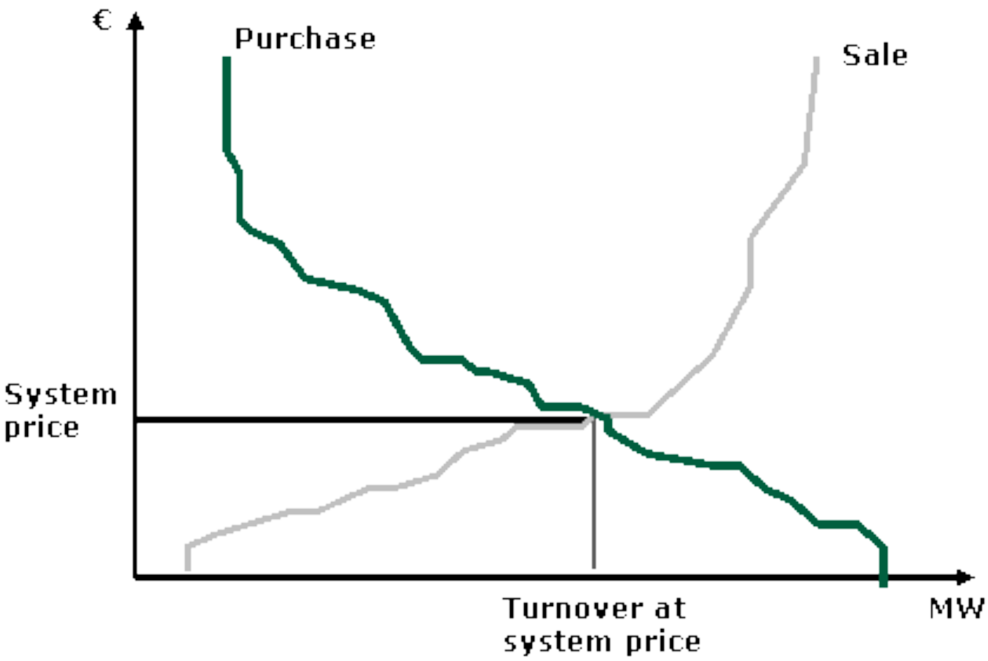

Figure 2.2. Nord Pool System price setting by buy and sell orders. (Nord Pool Spot 2012.)

Trading capacities for the next day delivery in each bidding area are publiced by Nord Pool Spot before 10:00. After bidding is closed at noon, all buy and sell orders are aggregated into supply and demand curves for each delivery hour. The intersection determines the system price for each hours. The system price is used as the clearing price for all trades and reference price for most traded financial contracts because of the assumtion of sufficient liquidity and efficient price settlement. Nord Pool Clearance acts as the counterpart for all trades keeping participants anonymous and executes the market surveillance to increase confidence in the market. Markets' transparency and equality of all members are also objectives of a well-functioning market.
(Nord Pool Spot 2011).

2.2.2. Intra-day balancing market - Elbas

Elbas market was created to balance the trades in day-ahead hourly market in a continuos cross border intra-day market covering Germany and Estonia in addition to the Nordic countries. Adjustments to trades in day-ahead spot market are made until one hour prior to delivery. Participants in the Elbas balancing market are power producers, power consumers, traders and national transmission system operators. Producers trade to increase control over their production balance. Access to counterparts with different market conditions and production type mixes improve possibilities to earn on intraday deals. Large industrial consumers trade to optimize their power costs as Elbas provides opportunity to sell power bought in the previous day's day-ahead auction with a profit. Traders try to make profitable deals in the intraday market with enough liquidity and substantial spread opportunities. Transmission system operators allocate their grid capacity to Elbas after day-ahead auction market is closed increasing grid capacity and operators revenue. (Nord Pool Spot 2012).

The electricity price in the balancing market is extremely volatile and known just before the delivery. Elbas works well as a balancing market for fine adjusting the amount of electricity needed. Most of the electricity demanded for consumers is bought beforehand in day'ahead spot market auction while costs and margins are locked with financial futures contracts. It would be an extremely risky strategy to leave too much just in the hands of day-ahead and intraday market. Uncertainty - you just don't know. Risk management is a key function for all market pariticipants.

2.2.2. Financial Market

Uncertainty in electricity spot prices in physical delivery market creates need for a financial market for market participants' risk management, to trade with price securing contracts. In the spot market participants sell and buy electricity for immediate use with physical delivery. The financial market provides contracts to secure future prices, where price movements come with financial compensation and without physical delivery. Producers and consumers both have need for insuring their sales and purchases. Investors may also have need to hedge their portfolio for power price movements. Speculators place bets on price movements and all of the above combined lead into sufficient liquidity and trading volume, for maintenance of the market efficiency.

2.3. Production capacities

Integrating the Nordic national power markets into Nord Pool resulted in diversity in different electricity generation technologies. Each country has its own characterstics in the generation structure, which combined fullfill each other in becoming a functional market. These structures are formed by the nature's circumstances and geographical location and form. Roughly the half of the Nordic consumption is met by hydro power, of which approximately 60 per cent is produced in Norway and 30 per cent in Sweden and the rest in Finland. (Kauppi 2009: 20). The mountains in Norway and Sweden combined with high precipitation (i.e. rainfall) and annual melting water create exceptional potential for hydro power. Denmark is quite flat and does not offer kinetic energy in water, but due to its constant wind circumstances has 'naturally' specialized in wind power. In Finland the shape of surface offers some potential for hydro power as a flat version of Sweden. Sweden and Finland have nuclear generation, and most of Nord Pool's thermoelectrical capacity and the direction of transmission and trade between the countries varies from year to year, mainly depending on the availability of hydroelectricity. During times when hydro reservoir and generation are significant the thermoelectrical capacity may run at lower capacity. During dry times the flow is reversed, from Finland and Denmark to Norway.

Precipitation is seen as the most important market fundamental to cause uncertainty and considerable price volatility, other factors just adding to it. The seasonality in hydro power availability follows a well-known pattern with snow melting from the highlands in the spring. Three months following week 18 arrives on average 50 per cent of annual inflow. Hundreds of hydro power stations in the area generate the average annual inflow of 200 TWh, of which 120 TWh is the aggregate reservoir capacity meaning that some stations are not able store the capacity and just produce the energy river offers. The total turbine capacity in the market area was 47 445 MW in 2005, standing for 72 per cent of the peak demand. (Kauppi 2009: 21-22). As forecasting future is hard, estimating the use of reservoir capacity is tricky. Rainfall is random and prolonged dry seasons affect the hydro reservoir, which might lead into losing its status as a fully storable fuel.

The Nordic nuclear plants are located in Finland (four reactors) and Sweden (10 reactors). Interestingly, the difference in capacity utilization differs quite a lot between the two countries: in Sweden 80,6 per cent and in Finland 93,8 per cent of full capacity in 1996-2006. (Olausson & Fagerholm 2008). Explanations for that vary but may result from a decision made by the Swedish government in 1980 after the Three Mile Island accident, to run down all nuclear plants by 2010 in Sweden causing decommission of two Barsebäck reactors, in 1999 and 2005. (Kauppi 2009: 23-26.) The plan was put on hold, and currently the plan is to reinvest into exixsting facilities to prolong their lifetime. Anyway it is known that maintenance outages in Sweden have been relatively time-consuming causing problems to supply and thereby market price. (NordReg 2011.) The Finnish nuclear generation has remained stable over the deregulated period, and currently a new reactor is being constructed by TVO with several years delayed schedule. Finnish parliament has given permission for two new reactors, one for each:

TVO and Fennovoima. Arguments for new nuclear plants are due to tightening emissions regulation and pending integration of the continental European market where electricity prices are on average higher than in Nord Pool. The structure of Finnish electricity supply differs from other Nordic countries being slightly more diverse and in balance:

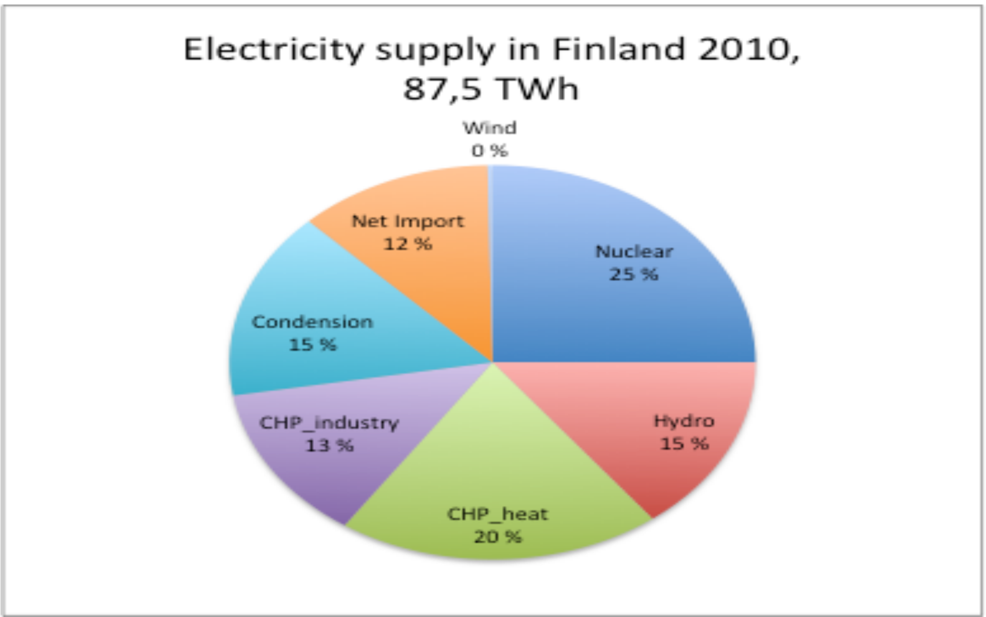

Figure 2.3. The structure of production and supply in Finland 2010. (Finnish Energy Industry 2011).

As the hydro power represents a large share of the Scandinavian power generation, its effect to the whole production palette and therefore to the market balance is remarkable. The fuel reserve for Nordic hydro power is in a key role for the price formulation on production costs. The production structure in Finland can be seen from figure 2.3 to be more diverse and evenly balanced, even though the net imports are quite high.

The political future for electricity generation has become uncertain after what happened march 2011 in Fukushima, Japan, as a tsunami caused by a strong earthquake hit and destroyd a poorly built nuclear power plant. After that Germany closed several nuclear power plants and decided to run down the nuclear generation in the future. The damaged reputation of nuclear generation combined with goals to decrease co2 emissions in power generation and the EU emissions trade, has lead the production palette into revolution with unknown future. Will the global reneissance for nuclear generation change direction, and what production type will cover the increasing consumption in the future?

2.4. Transmission and trade

The Nordic transmission power grid is operated by Nord Pool Spot, and owned by the four national transmission system operators. The Norwegian, Danish and Swedish operators are state-owned and Finnish operator Fingrid had been controlled by large power producers Fortum and PVO, which were forced to sell their shares to the state by EU legislation. (Kauppi 2009: 27). The trade was sealed on 19.4.2011 and currently the state of Finland holds 53 per cent of Fingrid and the rest is held by Finnish pension funds and insurance companies. (Fingrid 2011).

The zonal pricing system of Nord Pool is built to separate areas (shown in figure 2.1) by limitations in transmission links, so called *bottlenecks*. The area prices deviate, if transmission links between the regions become congested. (Nord Pool Spot 2012).

2.5. Demand

The consumption as demand is the driving force in the electricity market, which the production as supply is supposed to satisfy. The demand follows a well-known seasonal pattern, from intraday to weekly and annual cycles. Demand seasonality is closely related to temperature as the year-to-year variation in demand is often explained by variation in temperatures. Temperature moves rather quickly and might change up to 20 degrees celsius durig just one day, explaining the fine-adjustments to expected consumptions. Electricity consumption also follows economic and industrial activity which explains the weekly and intraday changes, with most electricity intensive times occurring during working hours of weekdays as offices etc. are closed at nights and weekends.

The short-term price-elasticity of electricity demand is very low, mostly because of the concumers' electricity consumption habits and contracts based on fixed prices and the lack of end-users facing the wholesale market price fluctuations. The absence of real-time pricing for consumers has important implications to the market while it increases the need for generation capacity, because insufficient capacity will lead to extremely costly forced outages during the coldest times in the winter, which prolonged would lead into a serious chaos. The demand inelasticity also renders the market more vulnerable to the exercise of market power and even small producers may have significant influence on market price. (Kauppi 2009: 30-31).

2.6. Market concentration

Each Nordic country used to have a vertically integrated and dominant electricity utility before the market restructuring when these utilities were separated into transmission and generation entities. The generating firms were left with most of their generating assets, and a large share of national production capacity and market share. They still hold a significant share of the total capacity even though the market has encountered activity within merger and acquisitions. The ownership in the Nordic market has historically been in public hands, with states and municipalities owning most of the production capacity. Recent trend has however been towards privatization. In most cases the municipal ownership has continued even though foreign ownership has increased at the same time. Limited liability companies have been seen as more a efficient way to run business in electricity market. (Kauppi 2009: 33-35). The monopolistic – or oligopolistic – situation in energy markets prior to deregulation, vertically integrated utilities providing electricity, has not changed after restructuring of the power industry. Europe for instance, is more concentrated than ever. (Geman 2005:45.)

For the price dynamics research it is important to highlight that the largest electricity generation companies (Fortum, Vattenfall and Statkraft) are all partly state-owned, and the management and the strategy of these companies are focused strongly on maximizing the profits. The market power in price manipulation is often been brought up in cases where (at least partly) state-owned firms make large profits and reward management in a similar manner as normal private sector by the profitability of the company. Price manipulation may be hard to be proved by the regulatory authorities, but it is known that the largest firms generate power and profits mainly by low-cost, old nuclear and hydro power plants which investments' have been paid off a long before the regulation. In short, these state-owned oligopoly companies are extremely profitable operating these plants and compensate their executives very lavishly. Another threat to the market is the joint ownership of power plants, nuclear and hydro, because of the information shared between the owners about the plant's production plans gives advance in planning other operations, hedging prices for example. Large fraction of Norwegian hydro capacity is owned jointly and nuclear capacity in Sweden is completely jointly owned by Sweden's largest producers. The Swedish Competition Authority investigated the behavior of the owners of the Swedish nuclear plants in 2006, and found out that firms had engaged in meetings about utilization of the plants. However, it did not lead into any legal actions. (Nordic Competition authorities 2007.), (Kauppi 2009: 35-36).

3. RISK DESCRIPTION AND ELECTRICITY PRICE DYNAMICS

Electricity is one of the most essential and vital commodities in our modern civilization and its costs and the price changes affect just about everyone. The prices for electricity are today settled in power exchanges all over the world, and exhibit some seriously troublesome characteristics for the vital commodity. The prices used to be stable in the old model with the complete production-distribution-retail chain in hands of the local electricity utility with the minimized amount of external factors in price modelling. Sure the price margins added to the chain's costs were remarkably higher, but for risk management in publicly owned power organizations, the previous model was simple and quite stable. The new system has introduced several new risks to the necessity functions that are still often run by town-owned utilities.

Uncertainty of future incomes, or "*randomness, and its consequences*", (Geman 1999: 207) describe the risk in financial operations. Electricity is no exception, and financial uncertainty is the key risk in the business for both: consumers and retailers, and producers: Cost for consumers, difference between sales and purchases for retailers and sales for producers. Financial risk builds upon underlying issues, most obviously volume and fuel circumstances. Transmission bottlenecks congest the power delivery between neighbouring areas creating price zones, which are principally against the initial idea behind the larger market. The big picture in electricity market structure is political, with favoured and supported generation types changing over time as well as the changing structure of the market itself.

The largest operators in the Nordic region, Fortum, Vattenfall and Eon as gigantic listed corporations, have almost infinite resources for risk management, and yet they have stumbled in the retailing business. The smaller local utilities face the same operating circumstances and basic requirements with fewer resources. The owner structure and risk tolerance basically form the core in the problem setting, as in the free market environment the weakest players often fall off and die. In the field of electricity and delivery obligations, there should not occur situations with too weak electricity systems (utility with its functions and network) to die because of some market-introduced risk. There are actually quite a few risks in the electricity chain itself, and because of the nature of electricity delivery, the deliberated markets have also been criticized, as it obtains characteristics a free market should not. Simply looking at the price charts, one can draw a conclusion that the market is not perfect.

As the price is settled in market trade, its characteristics are extremely interesting to investigate for better understanding. As storing electricity is very costly, the time-varying system demand determines the production palette used for satisfying the demand in real time. The storability and availability of region's utilized fuels play large role in price dynamics, especially in the extreme occasions. The production types and used fuels determine the price level by marginal pricing theory in trading as producers altogether represent the sellers and are hardly willing to produce and sell at negative margins. The risks for retailers and producers are quite the opposite, even though the price dynamics set challenges to both sides. (Harris 2006).

The old system with centralized regulation for supply was considered necessary for securing physical delivery and maximizing production efficiency through economics of scale. Introducing competition into the new system was believed to improve cost efficiency, increase diversity in production palette, and also provide benefits to the paying customer. In microeconomic theory the prices should decline after introducing competition to the market. However, the reaction has been different in many power markets. According to Haas (2000), Szalbierz and Weron (2000) the wholesale prices have risen back to pre-liberalization levels after an initial fall. According to Weron, Simonsen and Wilman (2003) this price reaction can be called a "road from state to private monopoly". This can be explained by new risks and increased uncertainty for utilities, which necessarily cannot easily pass costs to customers' bills. Strategic planning, trading, and required risk management by financial derivatives highlights understanding of the electricity spot price dynamics. (Weron, Simonsen & Wilman 2003).

Market research has a long history from financial markets and other commodity markets and has produced a long list of theories explaining price behaviour. From random walk to mean reversion, most theories are applicable to electricity markets as well, directly or somewhat adjusted to the special features in electricity market. The electricity market with its direct link to physical delivery and production palette bring out most of the differences in market dynamics. Demand and supply create the market for electricity as well, but the nigh non-existent price-elasticity of demand set the challenges to the competitive market.

The demand determines the market volume the supply side is required to produce. The cost structure of the production palette holds pricing power in control, making the wholesale electricity market with its price settlement process optimized for 'normal' circumstances. Largest problems are reported to realize during exceptional circumstances of market fundamentals when temperature on the demand side and fuel reservoirs and production problem on the supply side to reach their critical points jeopardizing the market balance. (NordReg 2011.) These occasions create the main differences between electricity market and other financial markets. The price process in electricity exhibits serious risks as these market imbalance circumstances have caused sky-high price spikes. (NordReg 2011).

During the early era of Nord Pool, from 1996 to 2002, the prices process drew a seasonal, clearly repetitive pattern. Especially the years 1997, 1998 and 1999 were nearly identical. Prices rose towards the turn of the year, peaking with a spike in January–February, and decreasing until October when the prices turned up again. The following years performed in a similar manner, though with higher price levels and higher price spikes. This price seasonality has weakened ever since, though the price tension has still been highest during the coldest winter months. The available capacity has not been able to keep up with the rising consumption.

The zonal pricing system built upon power networks' transfer limitations amplifies the extreme price shocks' effect on certain areas, meaning that the prices may stay at tolerable levels on other areas while the prices jump to the exchange limiter on other areas. The same bottlenecks – physical restrictions in power grids may also maintain price differences between price areas for longer times as well if the differences in supply-demand balance vary and the transmission links are congested. The main idea behind the liberalized market for electricity is that a large area, in this case Nordic region (and later the continental Europe), would have one market price for everyone. Then the market would be large enough to achieve the goals of benefiting everyone. A sufficient overall amount of producers would provide the desired price stability, with large enough region would smoothen the circumstance differences. The European electricity market is still far from one price zone, as for example the one price area in Sweden was divided into four in the beginning of November 2011. (Nord Pool Spot (2012).

Modelling the electricity prices is a complex dilemma with spiky prices and physical circumstances driving the market. The non-storability of electricity creates challenges as the electricity consumed has to produced right in time. Besides that, the fuels used in a market may be storable or not affecting the adjustability for circumstance changes. Some markets use just fossil fuels that can easily be stored nearby the plant, and some markets – Nord Pool Spot – have up to half of the total generation stack on just hydropower. Hydropower may be storable to some extent in reservoir lakes and such, but on the extreme end, not storable at all. These changing market structures set huge challenges to price modelling, which usually builds upon diffusion-type stochastic differential equations. Handling of the problematic jumps or spikes differentiates the models from one another.

3.1. Factors behind demand and supply

The electricity markets have become one part of the global financial markets, with an endless list of explanatory factors on the market price. The market price is naturally settled in market trade, in intersection point of demand and supply. The factors behind demand and supply play the key roles in price dynamics finding the balance point. The consumption is tightly bound to time and weather circumstances, and is nigh inelastic to price changes. Consumers just take the needed power out of the wall, and usually pay a fixed price for each kilowatthour consumed. Generation is the challenged counterpart, forged to satisfy the demand at each moment. Financial risk for consumers and producers are quite the opposite even though the reasons are the same. Consumers buy the electricity from the retailer, who has to purchase their sold electricity from the exchange, where producers sell their load. Supply benefits from high prices, and demand suffers. Following presents the factors behind demand and supply with overall effect on the price:

Factors behind demand:

1. Economical activity
    - 1.1. Daily and weekly consumption profiles
    - 1.2. Economical cycles in industrial production
2. Seasonal circumstances
    - 2.1. Temperature’s heating/cooling effect both in short-term and long-term
    - 2.2. Length of the day, need for lighting

Electricity consumption is the basis for the system, the demand exhibiting trends both in short and long time frame. The energy intensive activity draws the basic demand curve with reflections to price, as the market price is settled in demand and supply balance point. The economical activity rises for active hours during weekdays from the base load because of energy intensity in workplaces. In longer time frames the economical cycles with industrial activity changes through time, while the generation capacity remains somewhat the same. Changes in economical cycles are rather slow and irrelevant, as the spot price is settled for each hour. (Spees & Lave 2007).

In addition to the consumer activity changes, seasonal circumstances bring out other short-term challenges. Temperature is the most important external factor for consumption and might change dramatically even within a day and especially in few days intervals. In the Nordic region the daylight circumstances also vary during the year, with minimum lighting required during the least energy intensive holiday season in June, July and August. The seasonality draws a wavelet graph for warm and cold seasons. The need for heating or cooling is the factor behind the temperature driven short-term changes in volumes. On the supply side, the risks are mainly based on how well the production palette adjusts to changes in demand, both in short and in long term.

Factors behind supply

1. Availability and reactiveness of production capacity
2. Availability of utilized fuels

The generation capacity is adjusted to match the demand to keep the system stable. Different production types have their own characteristics in reaction times to start-ups and output adjustments, some faster and others really slow. In the Nordic region the base load is met by nuclear power and hydropower from freely flowing rivers. These production types are also the cheapest in marginal costs along with being slowest in reaction times, and not really adjustable at the limits with extremely high costs to shut-down and starting up again. In some cases during the ultimately low demand times and full water reservoirs, this system has even caused negative hourly prices. (Harris 2006).

Availability and costs of utilized fuels affect the prices together with running costs of different production types. In the Nordic region hydropower represents approximately half of the electricity generation, so the hydro fuel balance plays a strong role, as water is quite cheap even with opportunity costs. Other fuels play smaller roles in the region and are easier stored than water. Some other fuels' prices are settled in market trade as well, but the production costs or the price reflections of those are not as well comparable with hydropower's dominance. In other markets with other dominating fuels the situation is understandably different.

The risks in jeopardizing the operability of power plants in the system often concerns surprising shutdowns and planned service outages. Most of the generation utilities are so large, that they do have effect on the big picture in market balance, building need for exchange's *'Urgent Market Messages', UMM's* maintaining the informational market efficiency. Besides these outages usually cut the producers' revenues and may prolonged become seriously costly, these may attract some market participants to manipulate prices by 'planned' sudden outages, combined with planned financial operations.

When discussing generation capacity, investments cannot be left understated. What is the state of current capacity and is there enough capacity for consumption peaks; are just some questions for market regulators. Producers then must think about what is the need for maintenance and efficiency improvement investments into current capacity or even new capacity to ensure the sufficiency in secure delivery, and future incomes. Whether to invest into peat burning generation to also take coal, or into a completely new generation capacity for some other fuel: nuclear, wind, solar or gas for example. These investment decisions require certainty about the future profitability and 'public acceptance'. That is when politics come into play. Taxation of different fuels utilized has to be predictable as well as for other government supports for favourable generation types.

3.2. Political decisions and market risk

The physical circumstance risks are not the only risks the market participants are exposed to. The big picture in long-term market risks is mostly political, as political decision-making plays a huge role on the background and yet many of the market participants are still owned by the state or local municipalities. The whole market system is a product of political will, and locally the favoured (and banned) production methods and fuel tax rates change through time. Also investments to capacity, new or current, are often driven by political decisions. In liberalized and competitive market it is extremely costly to invest into peak capacity that is active only for short periods. Producers could easily just enjoy the high prices and forget pricey investments, but some of the producers are designated by the TSO's to be responsible for sufficient reserve capacity for the extreme circumstances as well. These fundamental supply side challenges state the importance of TSO's and market regulation in the liberated market environment. (Harris 2006).

The demand side – retailers and consumers – is more affected by the short-term price risks, and the supply side has larger stake on the long haul. Nevertheless, both sides benefit from stable prices and suffer from high price volatility, in sense of long-term financial profitability. And as most of towns have their own (at least a share) of local electricity utility, the price stability is maybe the most important, and sought after market feature in electricity.

Long-term risks consist of investments into new capacity and the changing costs for current generation capacity. There are some new nuclear projects starting for example, but no one knows whether those plants have the permission to be ignited in 2020. That happened to one brand new nuclear power plant in Austria in 1986, right after Chernobyl nuclear disaster.

Electricity generation is one of the most supported industries at least in Finland, and in the volume intense circumstances with not so high margins for all market participants, the future investments' profitability are slightly more mysterious than in a politically straightforward circumstances. For retailers and customers the picture is a lot simpler. Retailers buy from the exchange at market price (or from producer at some other price), and customers buy from retailers. For producers the big picture is much more challenging, especially for future investments. Current capacity is already built and utilized, but to which generation methods to invest in the future, has become more and more unstable. Nuclear power lost its reputation after the incident in Fukushima, Japan, in March 2011, and for example Germany decided to immediately shut down several of the oldest nuclear power plants and all of Germany's nuclear capacity before 2020. No one knows whether that decision holds or not, and how the atmosphere will develop from now on.

At the EU level, the development and schedule towards the continental EU power pool remains unknown. Also the carbon emissions trade with its future remain unknown. The EU Allowances' (EUA) values have been extremely volatile especially during the economically unstable times, and as some generation types' support systems are linked to EUA prices, the system becomes even more complex. The allowances lost temporarily their credibility during 2011 with a huge price drop with several simultaneous risks realized, as EU decided to bring some future allowances to present because of some ‘clean’ nuclear power was shut down and replaced with burning coal.

3.3. Electricity price dynamics

One of the most interesting parts of electricity market research is the statistical modelling of the electricity market prices for this unique commodity. The physical foundation of the commodity sets huge challenges to price dynamics modelling. First the price levels, then the frequency of mean reversion and finally the spikes. As mentioned earlier, the price path has not been repeating itself in an easily forecasted manner over longer periods. Nevertheless, it can be generalized that the price tension peaks when the demand and price levels are high. The sudden demand peaks with supply capacity at its limits create the largest price risks and therefore the fundamental circumstance variables must be taken into account, even though some have tried to examine just the prices to find some patterns. So before diving deep into statistical models, the underlying circumstances are briefly discussed, how they affect price dynamics in short run.

The price dynamics is best illustrated graphically, to show the consumption profile with explaining the underlying circumstances. Nord Pool Spot maintains and publishes ‘Urgent Market Messages’ (*UMM*) to inform the market about production and transmission capacities, power plant outages and such. Below is an hourly price graph for Finnish area price and Nord Pool system price presenting the intraday price dynamics on 20.2.2012. (Nord Pool Spot 2012).

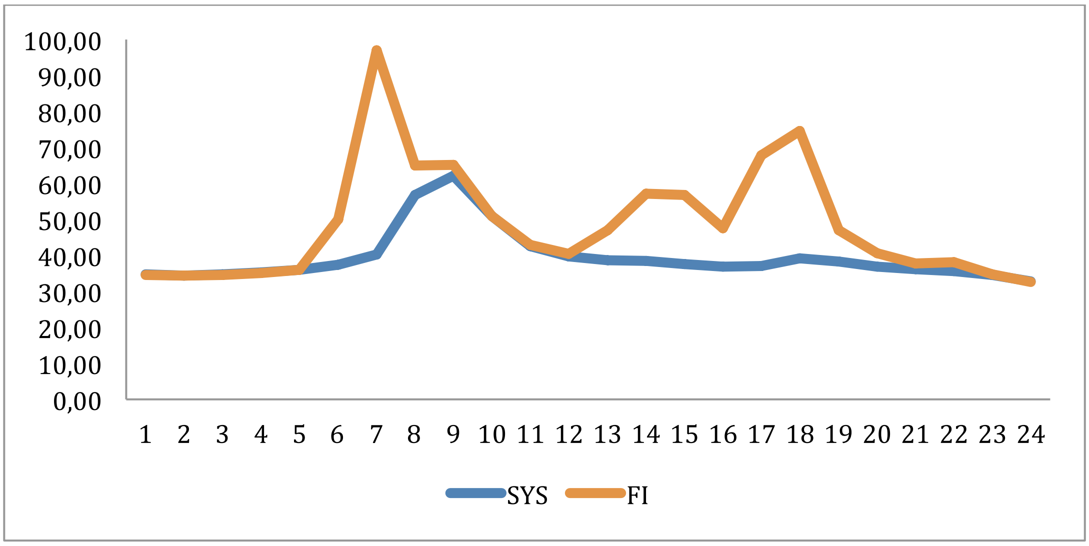

Figure 3.1. Intraday price dynamics: Nord Pool, system price and Finnish area price: 20.2.2012. (Nord Pool Spot 2012)

The intraday price variation can be quite high, with the cheapest hours of a day during the night, between hours 20 – 06. An initial price jump is observed at 06-10 as the daily routines start, and the peak load capacity is activated. After the initial jump, it cools down until a new price peak around 17 – 18 (five – six). The difference to lower and more stable system price could be explained by limited generation and transmission capacity in/to Finland while Germany's high wind energy feed satisfies other Scandinavian countries at south. (Nord Pool Spot 2012).

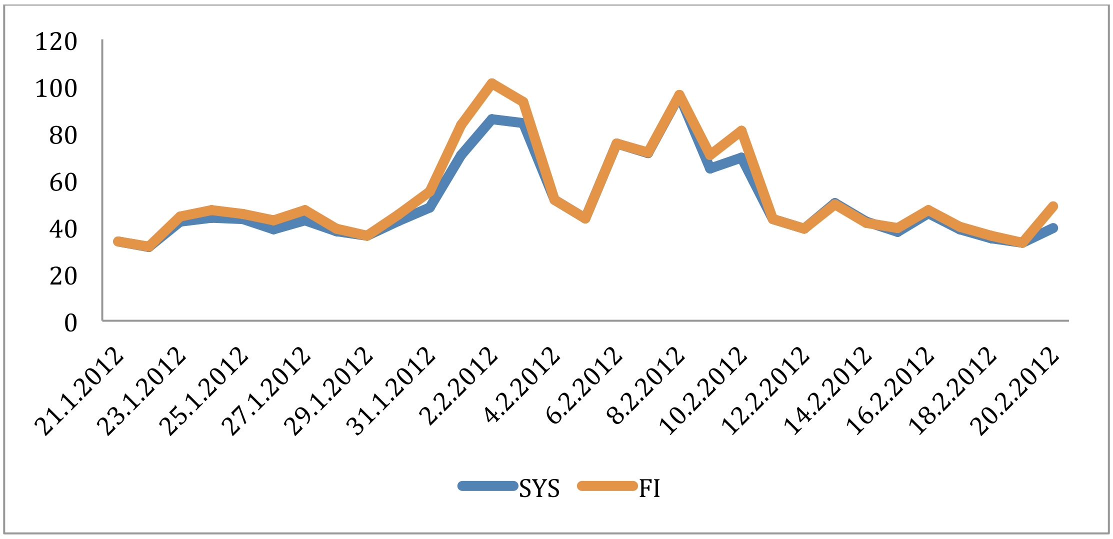

Figure 3.2. Daily price dynamics, Nord Pool system and Finnish area price: 21.1.2012–20.2.2012. (Nord Pool Spot 2012)

The price dynamics on monthly basis in figure 3.2 could again be explained by a cold two-week period starting from Monday 30th until Saturday 11th and Nord Pool Spot's *UMM*'s The weekend effect is clearly visualized especially for the cold weekend of 4th and 5th, as its demand decrease brought the prices down, until Monday 6th. The tension was strengthened by the cold-caused high demand in Russia as well, leaving less for transferring to Finland. Currently there are quite a lot of power plants on service outages bringing tension to the winter circumstances in the Nord Pool region. (Nord Pool Spot 2012).

Auctioned for the next day, the spot prices do not directly reflect future expectations in industrial activity and economic trends, but via the allowances' market values affecting the production costs, the future complexity comes to spot prices as well. Allowance prices can be considered as a measure of economical expectations for the future with prices rising with optimistic expectations and dropping when the economy brakes.

3.4. Statistical characteristics of electricity prices

Different assets' market price behaviour has been actively investigated since introduction of markets, and new traded assets have been introduced ever since electricity representing one of the most recent. The basic demand–supply characteristics in prices are fundamentally applicable to all traded assets, stocks and commodities to mention. Both demand and supply change through time, and these changes are often somewhat random, making prices revert to short-term mean levels in a zigzag figure. Volumes vary and affect the liquidity and therefore the initial price changes. Some prices and markets are more random and less predictable than others, more efficient so to speak. Electricity with its strict bound to time and place of delivery and, nigh non-existent price elasticity for demand, is one the commodities in the predictable end; at least in sense of short-term market undamentals (see previous figures 3.1 and 3.2). Electricity spot prices exhibit unique behaviour not observed in other commodity or financial markets creating need for specified models developed from numerous different aspects to explain and simplify the complicated price dynamics to market participants. (Weron et al. 2003).

Among stochastic (random) price dynamics there are different mathematical structures to fit the known features of the given commodity's distribution. Geometric Brownian motion, jump diffusion or any other structure found in the historical data, with possible adjustments for economical activity and temperature in this case, are used in choosing the appropriate structure. (Geman 2005: 49).

The choice of the stochastic process should:

- be consistent with the observed dynamics.
- lead to a probability for the random variable that agrees in particular with the empirical moments and other known features of this distribution.

After choosing the ”backbone model”, certain data estimated parameters are attached, to make the model as precise as possible. For the sake of randomness in price processes, the more parameters are used the better the outcome will be, also lowering the error term. (Geman 2005: 49).

Commodity markets do not generally exhibit trends over long periods, in contrast to stock prices, which grow on average for the investors’ time value expectations, at least in commodities other than oil and such clearly non-renewables. Naturally this suggestion works for commodities with constant or slightly increasing demand, for instance demand for gas and coffee, which the supply is able to grow with. For most commodities the production costs tend to rise with inflation. The resulting properties are therefore a consequence of the general behaviour of mean-reversion combined with spikes in prices caused by shocks in the balance of supply and demand. (Geman 2005: 52.)

3.4.1. Mean reversion, seasonality and jumps

Electricity price dynamics can be explained by simple features all linked together by demand and supply dynamics. Supply’s function is to meet demand at every single moment. Demand follows daily, weekly and longer economic activity patterns and temperature, which in short-term variation appear quite volatile, causing small zigzag (up-down) spikes in demand. When supply includes large generation units, that every now and then drop off and join the supply stack, the balance may be seriously congested creating own mean reversion to play with demand mean reversion.

Mean reversion is typically modelled by a drift term negative above the mean reversion level and positive below the level. The mean reversion level is settled by the historical averages and can even be made time dependent to reflect the varying price levels caused by fundamental factors behind demand and supply, temperature and production capacity (hydro balance in Nord Pool).

Electricity markets exhibits seasonality as the demand circumstances vary throughout the year in most market locations. In Northern hemisphere (Nord Pool for example) the winters are more energy intensive than summers and warmer climates the other way around with demand peaks during the hottest summer months. Depending on the total generation structure of the market, the supply side also shows seasonality in output in some locations. In Nordic region especially with hydropower representing a large fraction of the total supply stack, the seasonality in precipitation and snow melting play a huge role forming the supply capacity.

Besides mean reversion, a certain wavelet motion has been observed in historical price data, created by demand seasonality and marginal price structure of the supply stack. Proper sinusoidal functions (Pilipovic 1997) or certain estimate values for each month (Bhanot 2000, Lucia & Schwartz 2002) have been suggested for modelling seasonality in electricity spot prices. According to Weron et al. (2003: 6.) this flexible method lacks smoothness, which may have a negative impact on statistical inference of the deseasonalized price process. As markets have their individual characteristics, these must be carefully adjusted for each market to gain consistency with the real life observations. For example the supply side in the Nordic region is strongly affected by hydro reservoir levels, representing the cheapest and the most utilized fuel.

Mean reversion and seasonal wavelet are just basic features of the electricity market, while the most exclusive price dynamics in electricity culminates in infrequent and large price jumps that may tenfold the price for the next hour from the previous. Price jumps signal the non-storability of electricity; it has to be produced at the same time as it is consumed, and vice versa. Extreme load changes, sudden generation outages and transmission failures are the main causes behind the jumps. The prices also drop significantly causing downward spikes in controversial occasions, when the generation cannot decrease while demand drops. Even negative hours exist, though extremely seldom. The jumps are usually not permanent and tend to revert back to starting point rather quickly when the extreme situation is over. Even though jumps also come down, ‘spikes’ may explain better the trick because of the sharpness of the jumps, and because half of the spikes point down. The magnitude of the spiky jump varies and tends to be (Rambharat et al. 2005, Geman & Roncoroni 2006) stronger at higher price levels. The spikes naturally also exhibit stronger magnitudes when pointing upwards, as from average prices at 40€/MWh, zero is much closer than the sky-high exchange limiter at 1500 €/MWh. The response time of different generation utilities – both base load and peak load – stands behind the entire phenomena. Due to producer actions, these spikes are strongest upwards, and there is even an exchange set limiter at 1500 €/MWh per hour in Nord Pool Spot for the most extreme moments. The spikes are quite short-lived and prices tend to revert back to pre-jump levels quite as fast as they appeared, as the market is after all, able to adjust to circumstances also the circumstances tend to revert to normal.

3.4.2. Electricity spot price models

Traditionally stochastic (random) price processes have been approached by diffusion-type stochastic differential equations (SDE's) of the form

$$dX_t = \mu(X,t)dt + \sigma(X,t)dB_t, \qquad (1)$$

where $\mu(X,t)$ is the drift, $\sigma(X,t)$ is the volatility and dB_t are the increments of standard Brownian motion.

A popular base model for electricity spot price dynamics, including mean reversion and jumps, is called 'mean reverting jump diffusion' (*MRJD*). MRJD illustrates the problem quite well, spiced with major simplifying weaknesses. MRJD assumes mean reversion to be constant, which it is not. The complex circumstances on both sides, supply and demand, keep changing constantly. Another shortcoming of the MRJD model is that it assumes mistakenly the probability of jumps constant as well.

Several models rise upon mean reversion and jump diffusion with desired adjustments to create models that reflect the real life better. Rambharat, Brockwell and Seppi (2005) introduced a first-order threshold autoregressive model for wholesale electricity prices for more realistic mean reversion and jump dynamics while preserving the parametric parsimony of the MRJD model. Their model allows the mean reversion rate and the jump intensity to depend on the level of the price process relative to a threshold price level. They defined the threshold to be time varying by a time-varying mean. Rambharat et al. TAR model accommodates three sources of mean reversion: price process dynamics at high(1) and low(2) price levels, and seasonally mean reverting temperatures(3). Rambharat, Brockwell and Seppi used maximum daily prices and matching temperatures from Allegheny County, Pennsylvania, from December 1st, 1998, to November 30th, 2001. Their model for the daily logarithmic electricity spot price series $\{Y_t\}$ is of the form

$$Y_t = \mu_t + X_t \tag{2}$$

$$X_t = (1 - mX_{t-1})X_{t-1} + \rho(T_t - T^*)dT_t + G_t + \sigma Z_t, \tag{3}$$

where time t is measured in days. μ_t represents the time varying daily mean and T^* represents the price minimizing temperature (57°F ~ 13,9°C, in Allegheny County, PA). T_t is the temperature at the maximum price time. The mean reversion function m is of the form

$$m(x) \begin{cases} m_1, & \text{if } x \le k \\ m_2, & \text{if } x > k \end{cases}, \tag{4}$$

for some threshold k, estimated from the data. Z_t is a sequence of independent and identically distributed Gaussian random variables with zero mean and unit variance and σ is a non-negative scaling factor for volatility. Sequence of random variables G is the jump component, drawn from a gamma(α, β) distribution with probability

$$\lambda(x) \begin{cases} \lambda_1, & \text{if } x \le k \\ \lambda_2, & \text{if } x > k \end{cases}, \tag{5}$$

or otherwise set to 0. The threshold k is the same as with m above, or some other threshold. Conditionally on the sequence X_t, the G_ts are independent of each other.

Weron et al. (2003) proposed a model for electricity price dynamics as the electricity spot prices exhibit behaviour not observed in other financial and commodity markets. Weron et al. applied the *Average Wavelet Coefficient* (*AWC*) method of Simonsen, Hansen and Nes (1998) that was proven useful (Simonsen 2003) in particular for multi-scale time series such as electricity price. Even though electricity prices exhibit intra-day variations, Weron et al. analysed only daily average prices and dealt the intra-week variation by moving average technique into average week profile, and finally subtracted it from the spot prices. The rare but extreme price jumps usually lasting just one day (or some hours intra-day) were included into their model with a jump component $J_t dq_t$ which is estimated from the logarithm of the deseasonalized prices $d_t = \log(p_t - s_t -$

S_t) adjusted by both weekly and annual price cycles through a two-step procedure. As jumps are followed by negative jumps of about the same magnitude, the stochastic part X_t is let to be independent of the jump component. J_t represents a lognormal random variable and q_t a Poisson random variable. The Weron, Simonsen and Wilman (2003) model for electricity price dynamics has the following form

$$p_t = s_t + S_t + e^{J_t dq_t + X_t}, \qquad (6)$$

where $s_t + S_t$ present the annual and weekly seasonalities, and the exponent in the last term reflects the fact that the marginal distribution of X_t is Gaussian, whereas the deseasonalized cycles, and "spikeless" spot prices can be very well described by a lognormal distribution. Weron et al. verified the model's adequacy by fitting it to Nord Pool market daily average spot prices from the period January 1, 1997 – January 15, 2000. They also simulated price trajectories starting January 15, 2000 and saw that the simulated paths' statistical characteristics "closely resembled the original spot price" allowing them to use the model for pricing Asian options written on the Nord Pool electricity spot prices. (Weron et al. 2003).

The component that mostly differentiates the models for electricity spot prices is the jump component, and how these spikes are handled. Even though most models include a jump component, some of the authors (Lucia & Schwartz 2006) examining electricity spot prices have left the jump component out of the model for some reason. Nevertheless, these spikes do exist, and need to be included in models to reflect the real world price dynamics.

Besides price spikes that revert to pre-jump level, there also exists jumps in price trajectories. For example in Nordic region, where hydropower plays a huge role, the fuel reservoirs (hydro balance) consist of water in lakes and rivers above turbines combined with snow's melting water potential. The amount of potential energy from snow remains uncertain and may cause jumps in price levels in April when the actual hydro fuel potential is 'revealed'. The prices tend to jump up if the reservoir is lower than expected, and drop if the stack is higher than expected. The amount of cheap or even free fuel has understandably a huge role. Therefore the physical features of the market have to be included in the reliable statistical model, as closely as possible. (Geman & Roncoroni 2006).

Geman and Roncoroni (2006) tried to include as many real life components as possible to create the most accurate model. To ensure the strict positivity of prices and enhance the robustness of the calibration procedure, Geman and Roncoroni represented the spot price in natural logarithmic scale, consciously disregarding the occasional negative prices. Their solution of a stochastic differential equation is of the form

$$dE_t = D\mu_t dt + \theta_1(\mu_t - E_{t^-})dt + \sigma dW_t + h_{t^-}dJ_t, \tag{7}$$

where D denotes the standard first-order derivative and f_{t^-} stands for the left limit of f at time t. The predictable seasonal trend, around which the price fluctuates, is represented by the deterministic function μ_t. The second term ensures smooth reversion back to the average level μ_t with a positive parameter θ_1 representing the mean reversion scaled to the current electricity price level $\mu_t - E_{t^-}$. The process W is a standard Brownian motion for unpredictable price fluctuations with σ defining the volatility attached to the Brownian shocks. The instantaneous squared price volatility is represented by the conditional second-order moment of absolute price variations over an infinitesimal period of time: the sum of the squared Brownian volatility and a term generated by the jump component. The intensity of jumps is determined by historical evidence and the direction of the jump depends on where the current price lies on the price regime.

4. METHODOLOGY AND DATA

The empirical part of the thesis presents the research and aims to answer the research hypothesis. In line with the research strategy, a quantitative research method and some statistical tests were chosen to analyse the data. In this chapter the data collection process, statistical methods and descriptive analysis will be presented and the reliability and validity of the research will be discussed.

Data consists of daily averages for the last seven years, 2005 – 2011. Nord Pool's Finnish area spot price as the electricity price, the temperature from Oulu airport metering point and the weekly reported Norway-Sweden hydro balance as fuel reservoir. Temperature and hydro balance are the most actively monitored exogenous factors in electricity price risk management, as they play the largest roles for each market sides, supply and demand. The research problem is to clarify the effect of the chosen variables on electricity prices within different levels of variable values. Oulu is located approximately in the half way of Finland and on the coast of Gulf of Bothnia.

The weather forecast is the most important single categorized tool in electricity risk management and in estimating future price movements with temperature affecting the demand i.e. consumption, and the rainfall-based hydro balance affecting the supply as hydropower represents approximately half of the Nordic electricity generation. The hydro balance used in this research consists of the hydro reservoir in Norway and Sweden, as Finland's hydro balance represents only a small fraction of the total hydro generation capacity as well as a small fraction of Finnish generation capacity. As the hydro balance eliminates the effect of the actual hydro level, 'temperature balance' was created to measure the equivalent terms in temperature difference to long-term normal.

Other variables, such as market prices of oil and gas were also considered to the research but the practical effect of their market prices was considered marginal for the whole analysis. In marginal pricing theory these fuels do affect high-end prices, but the cost structure in electricity generation by oil and gas for only short periods during highest priced hours emphasizes mostly production costs including activating and shutting down costs of the generation facility. Therefore other fuels' market prices were left out.

The data is analysed excluding the holidays and weekends, after problem reasoning and arguments for the weekend effect. The weekend-effect of consumption reflects to electricity prices as they consistently drop by approximately 8 per cent for the weekends and rise back up for the new week. Weekdays were chosen as the market distractions and the risks are significant only during these hectic days.

The data is first analysed by basic statistical measures, such as means and distributional deviations. The effect on spot price of temperature and hydro balance are investigated separately by regression analysis based on variable quantiles. It is commonly known that these variables tend to have different effect to the prices depending on the level of the variable at a certain moment, especially strong in the extreme end of cold temperatures and low hydro reservoir, and not so strong in neutral circumstances. What this study tests, is the strength of the effect within different levels, by quantile regression.

As hydro balance neutralizes the seasonal wavelet cycle of actual hydro fuel level, the hydro level was also examined, as it presents a similar curve as the temperature. As the actual hydro level turned out to perform negligible effect on the price fluctuation, the temperature was also transformed into a 'difference to normal' variable, called *temperature balance*. In the matter of marginal pricing theory, the hydro balance exhibit a great effect on long-term price levels as hydro balance is relatively slow in movements. Temperature balance on the other hand exhibits great explanatory effect on the spot price in short-term inspection as temperature lives at a severely faster tempo, though performing a truly mean reversing.

The method used in this research is quantile regression, which means that the sample data is divided in 20 quantiles, meaning 5% (90 observations) intervals of variable observations. Quantile regression presents a new perspective for investigating electricity price drivers.

4.1. Quantitative research

Quantitative research expresses information in numbers and statistics while qualitative analysis tends to identify causal cause and effect and express information in meanings. Traditionally quantitative research fits better for surveys, when information is gathered in standardised form with a large sample, and the wanted outcome can be presented in numbers and categories. (Hirsjärvi, Remes and Sajavaara 2007). With quantitative analysis it is possible to look at the data from the chosen research viewpoint and conduct the empirical tests needed to support the hypothesis. It is typical for quantitative analysis to express causal cause an effect and base the analysis on logical reasoning (Hirsjärvi et al. 2007.)

Since the aim of this research is to map out the value of hydro balance, temperature and temperature balance as explanatory variables behind electricity spot prices, descriptive empirical calculations were chosen to explain the relationships between the variables. Due to the statistical characteristics of the sample data, investigation is executed through distribution and correlations analysis, focusing on deviations and exceptional observations.

4.2. Research design

As a process the quantitative research goes from collecting the data to organizing the observations, concentrating to the regularities or deviations in them, choosing the empirical tests to examine the hypothesis and finally analysing the test results. The execution of the research builds upon six steps from data collecting to analysing the results:

2. Collecting the data
3. Organizing the data
4. Data description
5. Choosing the methods
6. Empirical tests
7. Test results analysis

The data set used in the research consists of three sets of data on the same time series: daily average figures with two decimals accuracy from January 1st in 2005 until December 31st in 2011. Temperature data collected by the Finnish statistics authority, Statistics Finland, was received from Oulun Energia, a local electricity utility. The Nord Pool Finnish are price was also received from Oulun Energia, and confirmed from Nord Pool. Hydro balance figures are published by Norwegian energy market authority and also received from Oulun Energia.

The temperature figures are presented in Celsius centigrade grading ˚C and the electricity spot prices are in euros per MWh (megawatt hour), which is the official trading unit in the Nordic wholesale electricity exchange, Nord Pool Spot. To put on scale, for household end-users, electricity prices are in snt/kWh, i.e. 50 €/MWh equals 5 snt/kWh. Hydro balance is a figure presenting the current hydro reservoir compared to the average hydro energy storage for that time. Hydro reservoir level performs a strong seasonal cycles reaching its high during spring months when snow is melting into rivers and reservoir pools and lakes. Hydro balance is measured in TWh fuel capacity to scale against temperature with values between +20 and -40 in terawatt hours.

The data is analysed without weekends and other holidays, because of the market's weekend effect. Analysing the risks in electricity price, the weekends are considered irrelevant with consistently lower prices. Hydro balance is a weekly variable so in the analysis it is turned into daily variable by taking moving average of the surrounding five days, which presents the direction of change of the variable. Hydro balance can be estimated a few days ahead as precipitation forecasts are quite accurate two days ahead and movements draw quite large trends. The weekly average hydro balance figures represent Wednesdays and other days' values settle for average levels between two Wednesdays.

The temperature balance variable created for this research presents a comparable variable to hydro balance, as neutralizing the seasonal wavelet cycle. Compared to the slowly fluctuating hydro balance forming the long-term price levels, the rapid changes in temperature balance exhibit strong explanatory effect on short-term, daily price fluctuation.

In case of electricity, it is demonstrative to describe the sample characteristics, as financial market is strongly affected by the nature of the market trading physical electricity delivery each hour. The electricity price curve presents its own special characteristics unknown within mean reversion dynamics observed in other traded assets and commodities. The abnormal price peak phenomenon observed in electricity price index is called mean reverting jump diffusion, which adds occasional jumps to standard mean reversion. These jumps only last for a short period of time, usually just hours increasing only one day's average. These occasionally appearing jumps do not appear completely unexpected as these result from problems in physical circumstances when the demand may jump due to sudden temperature changes combined with problems in supply side. (NordReg 2011).

Data description with physical background was also seen necessary as the price dynamics and circumstances have changed dramatically during the seven-year period. The level of electricity spot prices has risen and above-mentioned price shocks have appeared with accelerating pace till the end of investigation period with the last year reverting to normal for all variables.

Mapping out the risk profile, uncertainty is the key. Preventing uncertainty and pursued accuracy in estimations of future scenarios, deviation of variable observations is often considered as the core risk. In this case the standard deviation of spot prices and other variables was seen more relevant than volatility, standard deviation of the changes, which is often referred to the risk measure. (Hull 2008)

It was generally known that hydro balance and temperature affect the spot prices, and that the effect is stronger at the extreme end of these variables, meaning cold temperatures and low hydro balance. Yet the strength of the effect has remained a mystery changing through time. Circumstances change each year, making a large and recent sample ideal for the big picture. Therefore this research tests quantile regression method. Temperature and hydro balance observations have been divided into quantiles to investigate how the effect develops through different levels of the variable.

The data processing was done in Microsoft Excel, the quantile regression and other statistics run in Eviews7. The results are discussed and analysed in written, and presented in graphs and tables for visual illustration.

4.3. Methodology

After deciding the subject of explanatory variables behind electricity spot prices, the methodology came into consideration. To investigate dependence between variables and spot price, correlation and regression analysis were chosen to provide numerical results.

As the sample is quite large and the interest was focused mostly in the extreme values: expensive, cold and dry, representing only small fractions of all observations, quantile regression was chosen. In quantile regression, variable observations are divided in quantiles and the regression coefficient is calculated for each quantile. Quantile regression thereby enables dependence analysis in cold and dry ends of variable observations and other quantiles can be left with less attention, as the market tension is remarkably lower at normal circumstances.

4.3.1. Correlation

Correlation provides a simple statistical tool for examining dependence between two random variables or two sets of data. Behind the electricity price dependence on explanatory variables is the fact that electricity demand depends on the temperature, as the need for heating or cooling increases in both ends of temperature scale. As the market price of electricity is known to build on marginal pricing costs, rising as the total demand rises as the utilization of power plants begin with the cheapest and stiffest methods and peaks with most expensive and flexible methods, the dependence between spot price and temperature, and spot price and hydro balance can be assumed to obtain correlation effect. (Greene 2008).

Most commonly in financial applications, correlations are estimated from historical data as the data is known and not modelled for the future. A statistically valid method of estimation based on historical data has a drawback – looking backwards.
(Galeeva, Hoogland and Eydeland 2008: 81-82).

The explanatory effect of these variables to spot price and each other can be measured by correlation coefficients, measuring the degree of correlation, which investigates the dependency of the chosen variables. Correlation of variables demonstrates the degree of moving hand-in-hand, or in this case, negatively hand-in-hand as high prices are suggested to reflect low temperatures and low hydro reservoir. Correlation coefficients between two series result in between values of -1 and 1. The desired correlations for explanatory variables in this case lie between zero and -1, meaning cold temperatures and low hydro balance leading into high prices and vice versa.

Motivation for using correlation for a commodity price study can be traced to the theory of storage developed by Keynes (1930) who stated negative correlation between price volatility and inventories. Kaldor (1939) and Brennan (1958) joined for theory of storage continuing that the spot prices exhibit more nervous behaviour within low inventory, by the lack of buffer stock for supply and demand shocks. In Nordic power market this is applied as the hydro fuel as supply side and temperature as demand.

Geman (2011) presents another aspect on the matter that during adequate inventory levels the changes in demand can easily be addressed by resorting to sufficient storage. Keynes (1930) also studied the relationship between inventory and forward curves, exhibiting positive correlation between backwardation (negative spread of the forward curve) and stockouts, which Fama and French (1987) took as given using the spread as an adequate proxy for inventory allowing commodities without inventory data. They showed that the price variances decreased with inventory.

The criticism for standard correlation is aimed at the characteristic that correlation measures the dependency of two variable by their arithmetic means, which often and especially in this case, deviates from the median, which is a better measure for distributional characteristics of sample sets. Even though there are several studies stating 'Median is not the Message', it is clear that in the case of electricity and its explanatory variables, it is a better message. As Koenker (2006) states, that it depends on the subject on matter, but usually the median describes the distribution better than arithmetic average, sample mean. And when it comes to analysing the properties at different levels of variables, quantile regression takes the distributional analysis to the next level.

4.3.2. Quantile regression

Regression analysis is a statistical method to examine dependence between one dependent variable and one or more independent variables. (Greene 2008). Electricity as an example: spot price as dependent variable and temperature, temperature balance and hydro balance as independent variables. Regression function explains how, for example, spot price reacts to different temperatures or hydro balance level if the other independent variable remains the same. The background for quantile regression can be described with these influental words from Mosteller and Tukey (1977: 266.):

> *What the regression curve does is give a grand summary of the averages of the distributions corresponding to the set of x's. We could go further and compute several different regression curves corresponding to the various percentage points of the distributions and thus get a more complete picture of the set. Ordinarily this is not done, and so regression often gives a rather incomplete picture. Just as the mean gives an incomplete picture of a single*

distribution, so the regression curve gives a corresponding incomplete picture for a set of distributions.

Regression analysis in most common sense estimates the linear dependence of the conditional mean (average) of the response variable within certain values of the explanatory variables. As the dependence in many cases differs from linear, quantile regression, introduced by Koenker and Bassett (1978), results in estimates in other locations of the sample distribution, median or other quantile location of the response variable. Quantile regression is thereby an advanced application of regression analysis, with focus on varying effect throughout the variable distribution. The desired advantage that quantile regression provides to examining electricity price predictors is that any quantile can be examined as it does not set strong requirements for the sample distribution. In quantile regression, the variable distribution can be divided into any amount of quantiles. (Koenker and Bassett 1978).

There are several approach methods for quantile regression estimation with slightly differing covariance computation. Bootstrap resampling method with XY-pairing was chosen, as it is the most natural form of bootstrap resampling. (Buchinsky 1995, Kocherginsky, He and Mu 2005.) The bootstrap covariance matrix is simply a scaled estimate of the sample variance of the bootstrap estimates.

Regression coefficients are comparable with correlation coefficients, scaling around zero depending on the direction and strength of the dependency. The expected coefficients lie on the negative side as the effect was assumed to be inverse: low temperatures and hydro balances causing high prices.

4.3.3. Standard deviation

The risk is usually referred to uncertainty of the future – and its consequences. Risk is often seen negative as its positive alternative is left with less attention. The same applies to electricity: High electricity price spikes are in usually thought of as negative as the electricity has to be purchased. On the other side, there is also the seller receiving the spike price regardless of the production cost.

The standard deviation of market price is the core problem in the electricity market. Volatility is often regarded as the measure for price risk as it measures the strength of price changes. The volatility σ is a measure of uncertainty in price change provided by a traded asset or commodity, in this case electricity. The volatility can be defined as the standard deviation of the return or percentage change of the value of traded asset in one year when the return is expressed using continuous compounding. The volatility can also be estimated from historical data or by future estimations. Uncertainty about a future asset price, as measured by its standard deviation, increases - at least approximately - with the square root of how far ahead we are looking. (Hull 2008: 282).

In this case, the change strength of spot price series is left with less attention as the actual prices met with certain critical levels of explanatory variables are in the core of the study. Therefore the risk measure used in the study is the standard deviation on the prices within the sample, not as a time series.

4.4. Data Description, 1.1.2005-31.12.2011

The data time series in the research covers daily averages of temperature and spot price figures, and weekly hydro balance figures from years 2005 to 2011 at a total 1785 weekday observations of each variable. The electricity market in current form is rather new so the chosen seven years of data presents a demonstrative view of the market's current state. The electricity price data used in the research is gathered from Nord Pool and the temperature figures from Oulu airport are from the Finnish statistics authority Tilastokeskus. The hydro balance is gathered by Norwegian market authority and received from Oulun Energia. This chapter discusses dynamics of the Finnish spot price, Oulu temperature and Norway-Sweden hydro balance individually within the time series starting with a combined chart of the observations and dependence of the three variables.

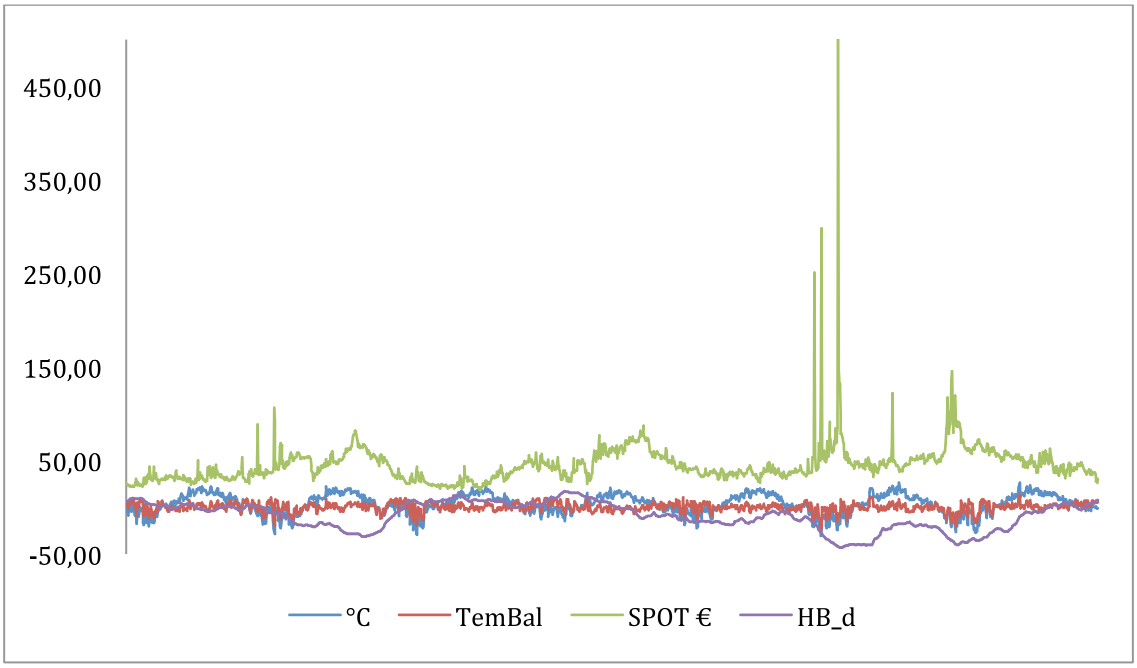

Figure 4.1. Nord Pool Finnish spot price, Oulu temperature, temperature balance and Scandinavian hydro balance averages, 1.1.2005-31.12.2011.

As seen on figure 4.1, seasonal changes in temperature are regularly cyclic and predictable, compared to more irregularly acting electricity spot price. Hydro balance was close to normal in the beginning of the period, and later reaching its bottom during the last sample year. Temperature low is during the winter months and highest during the summer months. Temperature drives demand volume, which is the core of the problem in production structure driving price development by its marginal costs. The temperature spot price was estimated to draw a mirror image of the temperature, i.e. cold temperatures leading into high prices and vice versa. This is seen especially during the last two years in the sample period. The problematic price spikes are a rather new phenomenon in the price time series, which complicates the analysis quite a lot. Price shocks deviate extremely from the index as shown and upwards on most extreme cases.

As the price jumps distract the overall interpretation of the figure above, monthly figure illustrates the big picture and problem layout more clearly:

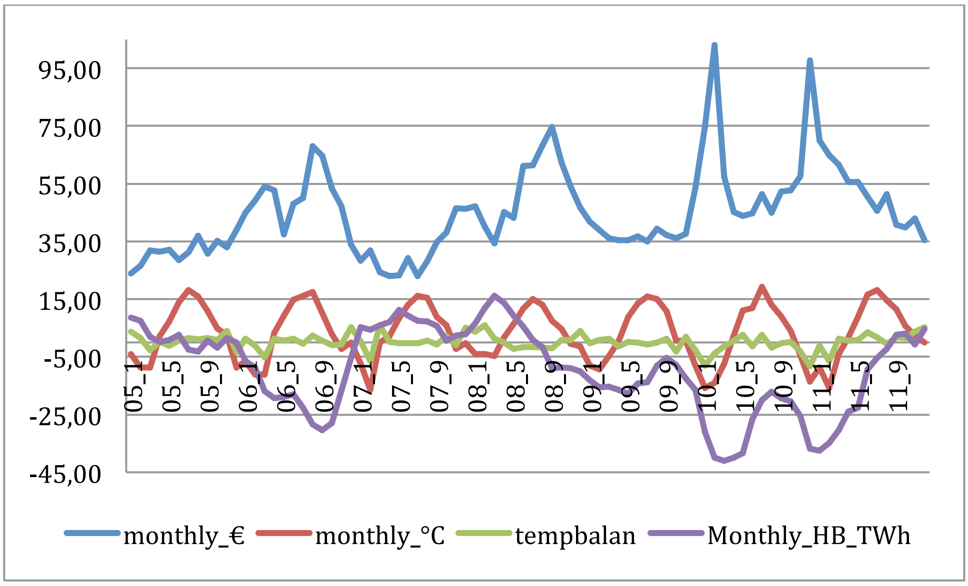

Figure 4.2. Monthly averages 2005–2011: Finnish spot price, Scandinavian hydro balance, Oulu temperature and Oulu temperature balance.

Especially the hydro balance draws a clear reflection to spot price, confirming the assumptions that hydro balance plays a key role setting the price level on the marginal pricing theory as it presents the cheapest as well as most utilized fuel in the region. Seasonally cyclic temperature building the demand drives the generation capacity and exposes the market price for risks when the supply side shocks occur. The temperature balance used in the research acts like hydro balance stretching the seasonal temperature cycle, though affecting in shorter term explaining the daily and monthly price deviations from the hydro balance built price levels.

As temperature and hydro balance has been sloping down during the research period, the spot prices have developed opposite with rising trend not forgetting the most extreme observations have occurred during the last years. During the last year in the inspection period the variables reverted to normal levels simultaneously with decreasing prices confirming the assumptions.

The distributional characteristics and basic statistics of the variables are provided in the following statistics sheet with the distributional percentiles used in quantile regression approach. To keep the mind work simple, the data is analysed within 5 percentage intervals, meaning 20 quantiles. Table 4.1 is also referred to later in the analysis.

Table 4.1. Variable statistics.

		Spot	Temperature	Hydro balance	Temperature balance
N	Valid	1785	1785	1785	1785
	Missing	0	0	0	0
Mean		45,2176	3,4502	-9,23416	,0496
Median		41,8600	3,5000	-6,55640	,4000
Std. Deviation		20,45457	10,38163	14,692023	4,83686
Variance		418,389	107,778	215,856	23,395
Skewness		8,638	-,468	-,469	-,828
Std. Error of Skewness		,058	,058	,058	,058
Kurtosis		162,913	-,169	-,699	1,801
Std. Error of Kurtosis		,116	,116	,116	,116
Minimum		18,16	-30,80	-43,071	-23,80
Maximum		505,68	25,90	16,984	13,50
Percentiles	5	24,1460	-16,0700	-37,73504	-9,1850
	10	27,8220	-10,7000	-31,30224	-5,4565
	15	30,0680	-7,1100	-26,42698	-4,2000
	20	31,9660	-4,8800	-21,41880	-3,1000
	25	33,9500	-3,0000	-19,05410	-2,4000
	30	35,6880	-1,4000	-17,45172	-1,8000
	35	37,1800	,0008	-15,30642	-1,2000
	40	38,3560	1,2000	-12,52060	-,6123
	45	40,2800	2,2000	-9,51564	-,1000
	50	41,8600	3,5000	-6,55640	,4000
	55	44,4660	5,1300	-4,44008	,9000
	60	46,4560	7,0633	-1,81432	1,3500
	65	48,6960	8,7000	-,02606	1,8970
	70	50,7020	10,2000	1,34480	2,4500
	75	52,9700	11,8000	2,61800	3,1589
	80	55,5240	13,3000	4,18196	3,8965
	85	59,0060	15,0100	6,22008	4,7000
	90	63,7080	16,4000	7,63296	5,8000
	95	71,4210	18,3700	10,15980	7,1000

Table 4.1 illustrates the variables’ distributional characteristics, differences between means and medians, standard deviations, skewness and kurtosis, and the percentiles from the lowest 5 per cent to 95 per cent. As can be seen, the 50 percentile equals median.

4.4.1. Nord Pool electricity spot price for Finland

Electricity prices in the liberated markets have become increasingly popular both in scientific research and public discussion as the market has matured and provided some rather alarming features. The uniqueness of electricity as a traded commodity builds on its direct link to physical delivery and a necessity status. The consumed electricity has to be purchased at a market-determined price that builds upon the generation cost structure of the used fuels. From the producers' point of view, the price has to be high enough to keep the business running and profitable. The price dynamics has become increasingly challenging for all market participants during the last few years, exhibiting extreme price jumps up to exchange limited 1500€/MWh and even daily average price spikes rising up to ten times the average price for MWh.

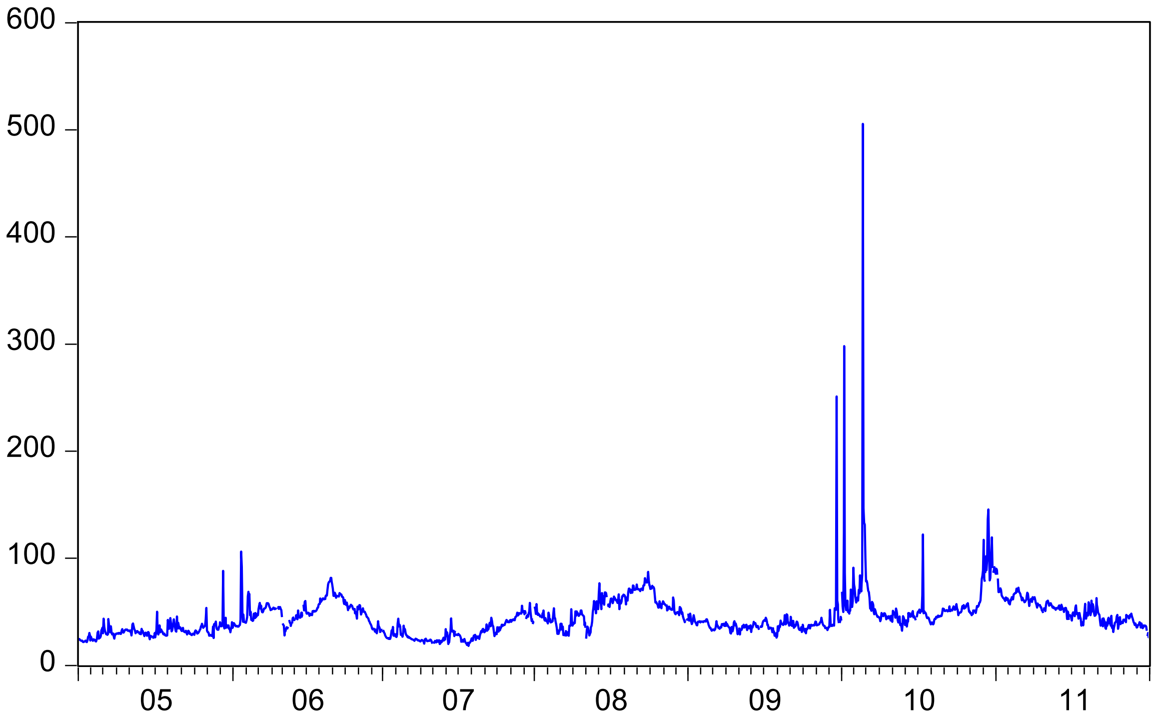

Figure 4.3. Nord Pool Spot's area price: Finland, 1.1.2005 – 31.12.2011.

Nord Pool electricity spot prices for Finland used in the research were first examined as a whole with all observations included, but after problem reasoning and first analysis, only weekdays were examined in the research resulting in 1785 observations of each variable. The weekends' systematic effect on spot price by demand decrease was excluded by manually removing weekends and other holidays with help of calendar and confirmed by the price reactions. The price reaction was -8% for the weekend, and slightly more back up for the next week, so the next week on average continued from where the last week ended. To demonstrate the problem in market price formulation, a closer look to price dynamics is necessary. To smoothen the most extreme price jumps from the figure 4.3 a logarithmic scaling for the spot provides a better illustration of the price development through the inspection period.

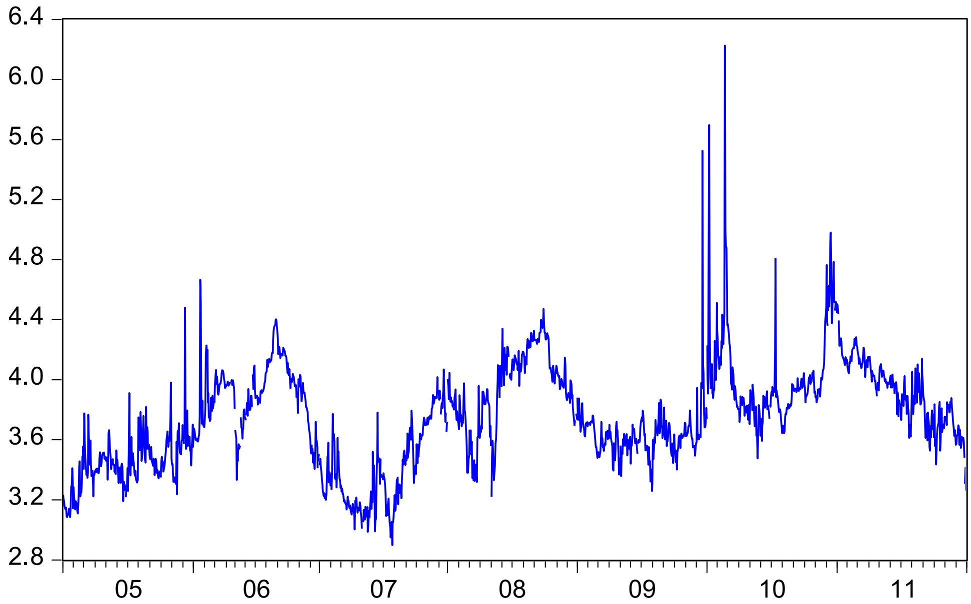

Figure 4.4. Logarithmic spot price.

The rising trend of spot price and the recent spikes illustrated in figure X are rather alarming for the market, at least for consumers. During the last year, spot price together with hydro balance reverted to normal levels after the dramatically expensive, cold, and dry 2009 and 1010 all of these have reverted to normal levels during 2011. The values up till the eighth quantile exhibit quite linear growth, and as acknowledged, the drama lies in the highest prices.

The statistics demonstrate the statistical challenges the spot price dynamics exhibit, as the distribution is extremely skewed and presents high kurtosis, as the 'outliers' mess up the distribution. The sample grows from the minimum at 18,16 €/MWh to a blistering 505,68 €/MWh on daily averages in the form of a hockey stick, explaining the arithmetic mean lying higher than the sample median.

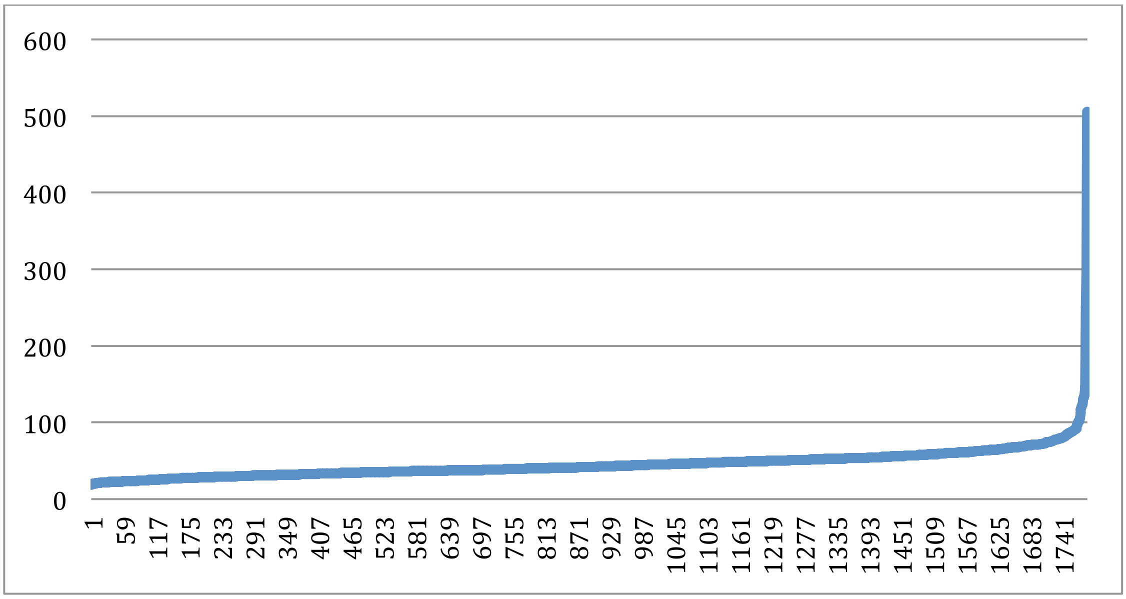

Figure 4.5. Spot distribution scale between 18,16 €/MWH to 505,68 €/MWh.

To set the price observations on scale, the most expensive prices represent only a small minority of all observations. Only 17 observations rise over 100 €/MWh limit, representing just less than one per cent. Then again, 24 days rise above 90 €/MWh and 47 days rise above 80/€/MWh.

4.4.2. Scandinavian hydro balance

Hydro balance was chosen to stand for the supply side explanatory variable as approximately half of the Nordic electricity is produced by hydropower, mostly in Norway and Sweden in their high altitude rivers. The precipitation in Norwegian and Swedish mountains is strong throughout the year, and most importantly provided free by Mother Nature. There are also several large reservoir lakes in Norway and Sweden for storing the water for production optimization, built to capture the massive rainfall and melting water stored for future use. The storability creates the opportunity cost for storable part of water used as fuel, as there are also dry seasons which prolonged cause serious problems as more than 90 per cent of Norwegian generation consists of hydro power. Hydropower represents only a small fraction of power generation in Finland and mostly builds upon freely flowing rivers instead of massive reservoirs. It could be interesting to examine as well, as precipitation also affects the fuel reserves for peat. But as precipitation has contrary effect on each fuel types: good for hydro and bad for peat, the Finnish hydro balance was left outside of this research.

Hydro balance builds upon the long-term average of seasonally cyclic actual amount of water above the hydro power plants. Hydro balance measures the potential energy of water in rivers, lakes, and even melting water of snow. The used measure for hydro balance is in terawatt hours (TWh) or megawatt hours (MWh), scaling between positive 20 and negative 50 TWh's or 20.000 and -50.000 MWh's. Values in the research are in TWh's. The actual water level and the entire hydro fuel capacity presents strongly cyclic wavelet motion in similar sense than temperature, but is not a widely used variable.

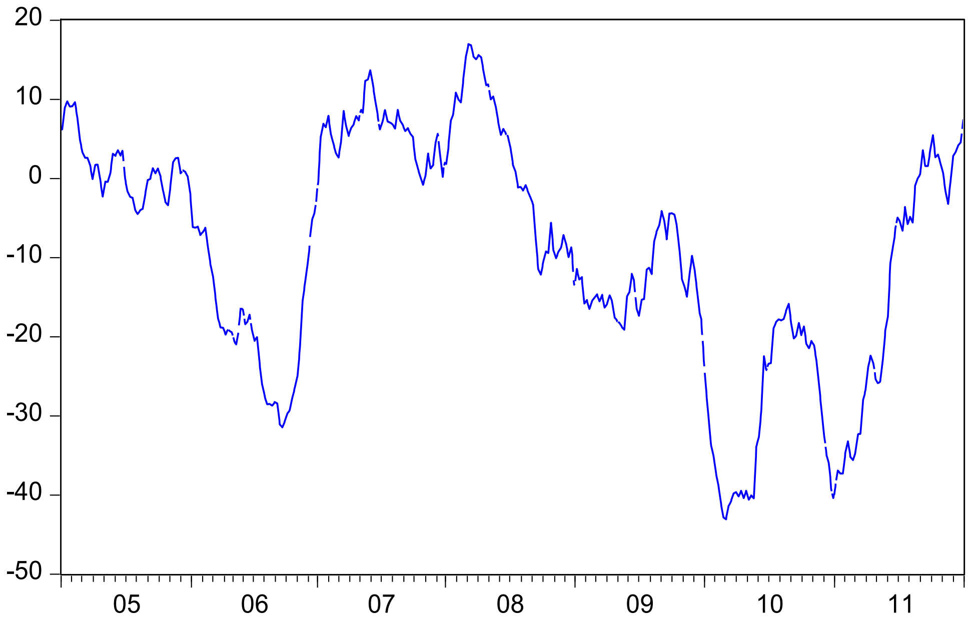

Figure 4.6. Scandinavian hydro balance: 1.1.2005-31.12.2011.

Figure 4.6 illustrates the Scandinavian hydro balance for the research period. The hydro balance draws big lines as the changes in to one way or back can be pretty strong. Hydro balance stayed within normal range only during the first year, other years more or less far from the normal. After the exceptionally dry 2010, the hydro balance reverted to normal levels towards the end of 2011.

For analysing the effects within the hydro balance range on the spot price, a quantile approach is desired. Table 4.1 illustrates the hydro balance distribution within research period as fifth quantile represents the median for hydro balance at -6,56 TWh. The hydro balance scales between 16,98 TWh and -43,07 TWh within the research period with a skewed distribution with a fat tail in negative end. The median lies closer to zero than arithmetic mean.

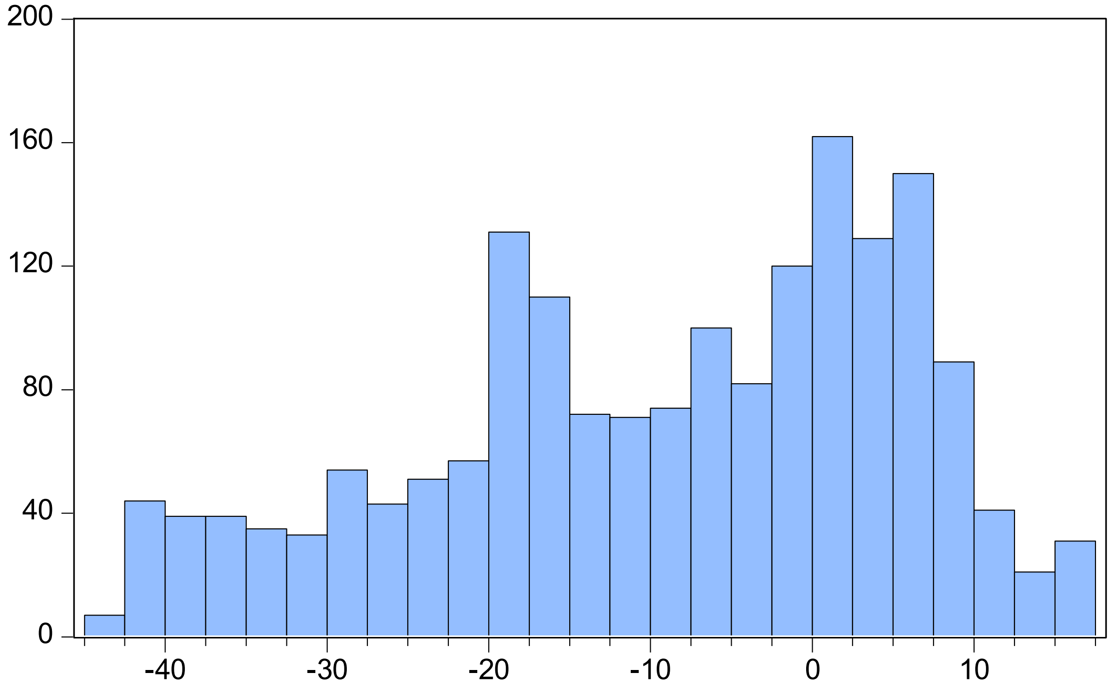

Figure 4.7. Distribution of hydro balance observations.

The range of the hydro balance observations obtains the thickest tail of all analysed variables. The scaling in histogram in the figure 4.7 is 2,5 TWh. The longer the research period would be, the closer this would probably get to normal distribution with higher piles around zero.

4.4.3. Temperature at Oulu Airport

The temperature data in the research covers daily averages in Celsius grading (˚C) from Oulu Airport measuring point gathered by Statistics Finland, the Finnish statistics authority. Oulu is located approximately in the middle of Finland on south-north line. Therefore the temperature figures and test results are not directly applicable to other regions in Finland. But the used methodology can be applied to other regions' temperatures as well, and as the temperature movements tend to be somewhat similar in nearby regions, the test results as well at some influential extent.

Data covers the most recent seven years with daily averages and gives a comprehensive review on the temperature dynamics throughout the entire period. Seasonal wavelet motion and differences between sample years are shown in the figure 4.8:

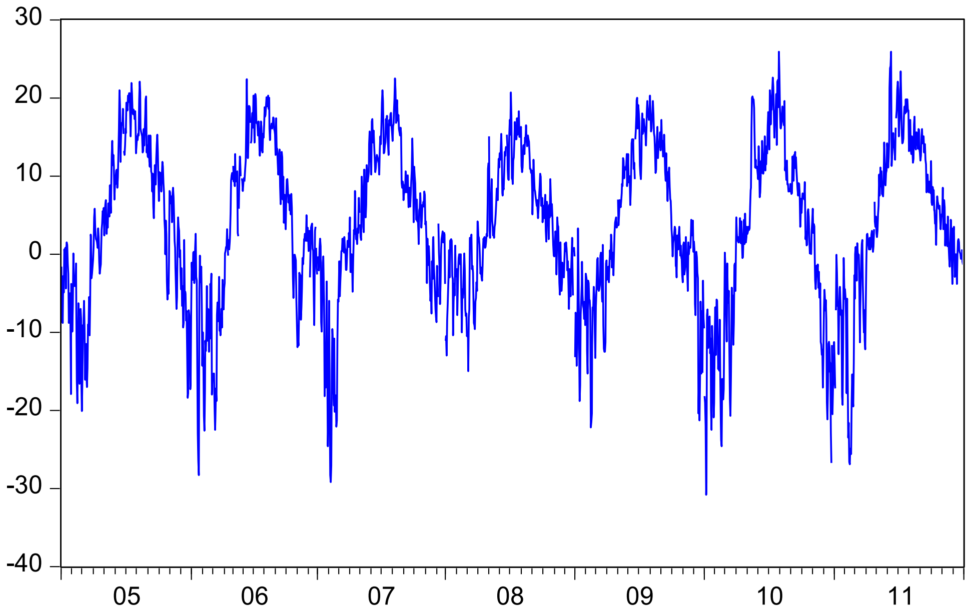

Figure 4.8. Temperature data: Oulu, 1.1.2005 - 31.12.2011.

The challenging climate of the Nordic region is presented in the temperature timeline for the research period in figure 4.8. The fact that the temperatures are gathered from Oulu, the magnitude of the temperature figure is similar in other parts of Nordic region as well, even though lies a little higher in south with warmer winters, earlier spring, warmer summer and later autumn. Figure 4.8 also illustrates the scale of the temperature cycle, from +25 ˚C in the summer to -30 ˚C in the winter with rather strong deviations. Especially from late 2007 throughout 2008 presented itself relatively warm in winter and not so warm in summer. As seen from the spot price and hydro balance figures, the same period resulted relatively cheap, and wet, and the winter especially did not reach significantly below -10 ˚C temperatures.

The quantile approach to temperature presents again the distribution of the values for the quantile regression method in analyzing the explanatory effect on electricity spot prices within certain variable values.

The temperature distribution is closest to normal distribution of the variables, even though the fat tail in negative end is observed. The arithmetic mean and distribution median both lie at +3,5 ˚C, suggesting that the cold winter season is shorter than the warm season. The same can be noticed from viewing the data. The most interesting observations lie below -10 ˚C, meaning the first two sample quantiles.

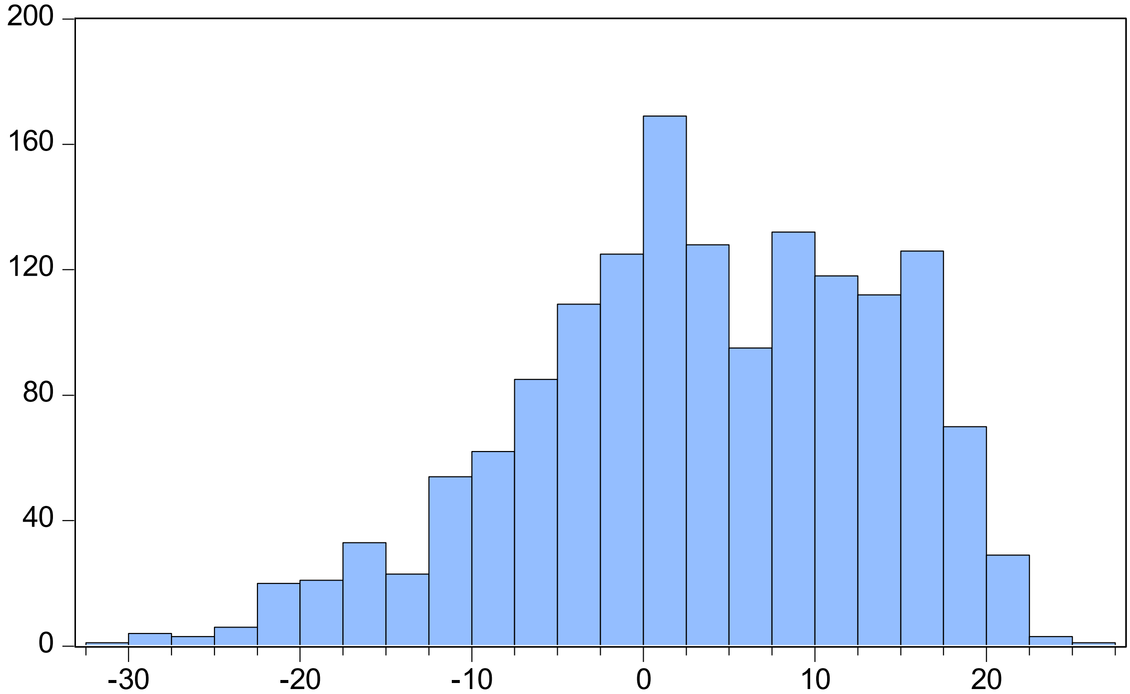

Figure 4.9. Distribution of temperature observations.

As seen in figure 4.9, the distribution tail is much steeper in the warm end than cold end suggesting that the temperature deviation is much greater during the winters.

4.4.4. Temperature balance

Temperature balance was created in the study as the problem setting progressed. As the hydro balance refers to the momentary difference to the long-term average in hydro reservoir, which exhibits a temperature-like wavelet cycle, a comparable variable for temperature was desired. In temperature balance the zero level presents the seasonally cyclic normal for each day of the year, the same as in hydro balance. The temperature balance minimizes the seasonal curve of temperature and illustrates even clearer the exceptional temperatures for each time frame.

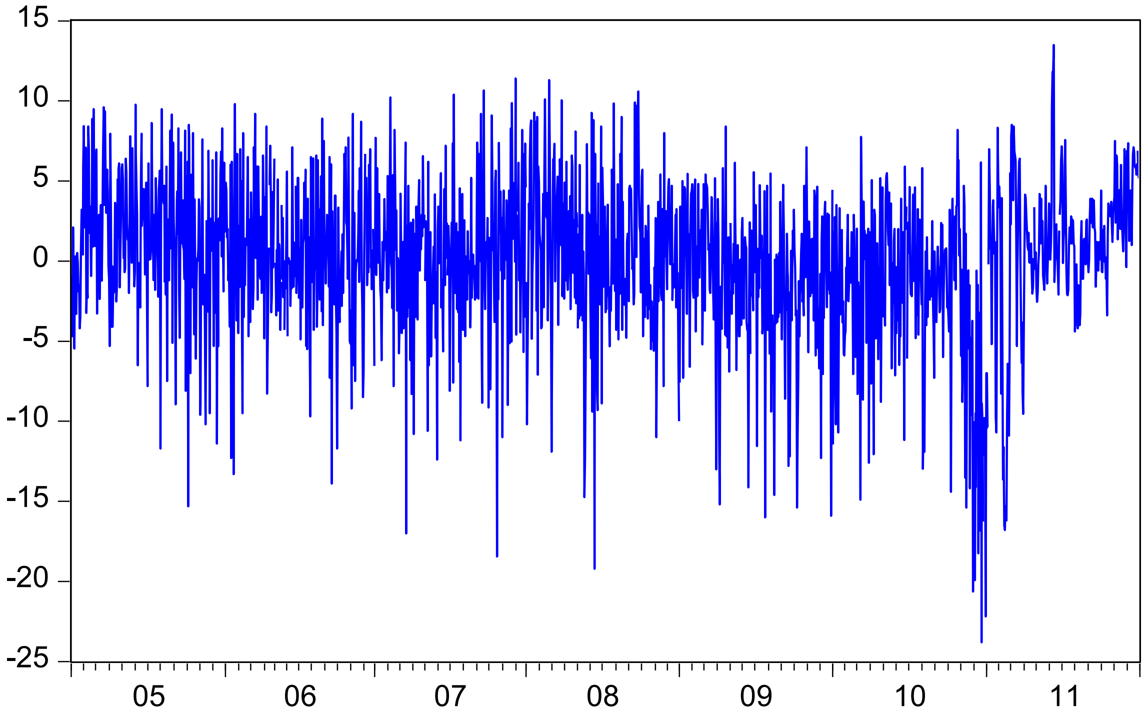

Figure 4.10. Temperature balance in Oulu: 1.1.2005-31.12.2011.

Temperature balance reveals that the most extreme and sharpest differences to the average have occurred during December, January and February. As mentioned in temperature description, the exceptionally warm winter 2007/2008 is clearly visible in the figure 4.10. As the dry is referred to obtain raising price effect within the whole seasonal scale from warm to cold, the temperature is not that linear, as during summer and winter the reactions are opposite. In the winter, warm reliefs the market tension, but warm in the summer increases the tension, in sense of the mentioned cooling degree days, CDD's. The distribution of temperature balance figures is illustrated in the following figure 4.11:

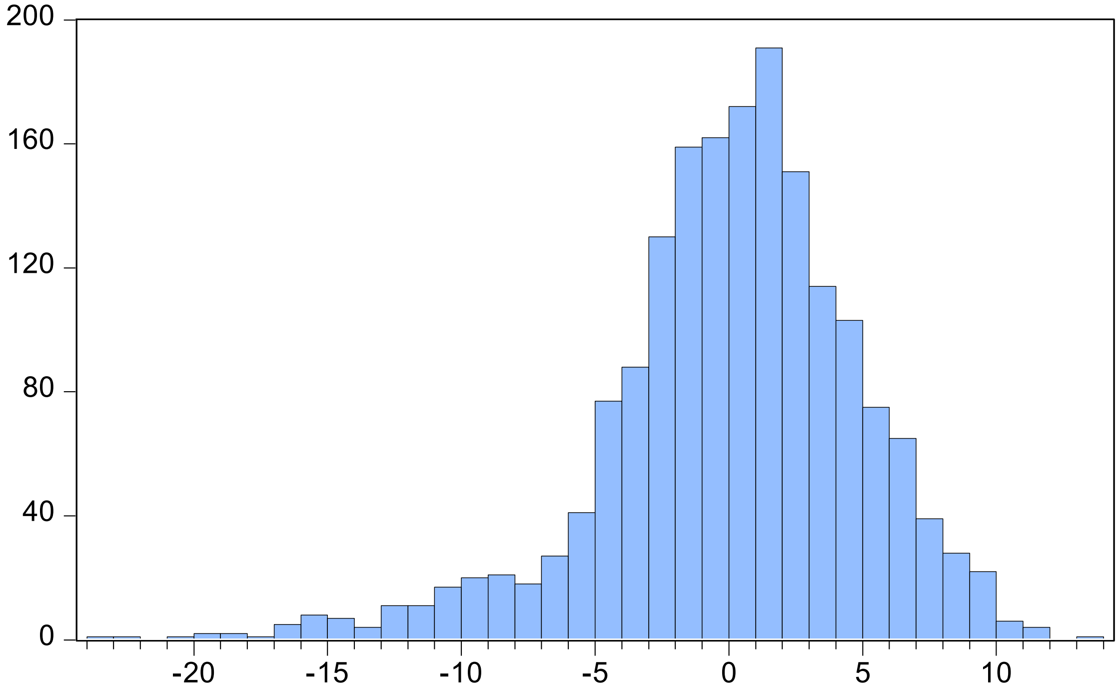

Figure 4.11. Distribution histogram of temperature balance observations.

The distribution histogram in figure 4.11 reveals that most of the observations lie between +-3 °C of the long-term average. Again, the cold end shows longer tail reaching down till 23,8 °C colder than the average of -7 °C, at -30,8 °C in January 7th, 2010. The long-term average for the 'normal' temperature curve was calculated from the seven-year data period used in the research. Even though if the 'normal' was calculated from a longer period, the exceptional days would obtain similar effect in quantile regression. Just the scale would adjust in one way or another.

4.5. Reliability and validity

In scientific research the credibility of the research is defined by its reliability and validity. In order to be reliable the research has to be repeatable with the same result with same kind of sample. This means that no matter how many times the research would be conducted; it would result in same kind of results. Since quantitative studies are usually conducted with large amount of observations compared to qualitative research, which is based on a rather small focus group, they can produce more absolutely certain conclusions. Concluding in reliability, it is important that the empirical tests used are suitable for analysing the relationship between the chosen research variables. (Hirsjärvi et al. 2007)

The validity of the research is defined by whether or not the results of the study can be generalised. In this paper the sample is rather large and can be considered to represent a sufficient amount of observations to be generalized. The temperature in nearby locations does differ naturally, but seasonal changes both in long-term and short-term are similar. Simplified, if it is exceptionally cold in Oulu, it most likely is the same in other parts of Finland as well. Temperature itself is some grades higher or lower, but temperature balance should perform in similarly. Validity also means that the methodology and tools chosen for the research really are capable and appropriate to measure and explain the subject and the phenomena. (Hirsjärvi et al. 2007) In this light this thesis can visualize a valid and reliable picture of the subject.

The chosen data series of Oulu temperature compared to the Nord Pool's Finnish spot price shows the results only valid in Oulu region. Other Finnish cities' temperatures and temperature balances compared to Finnish spot price will result somewhat differently, though similar results would be assumed. The hydro balance in the region reflects to the Nord Pool system price, which presents the whole market, of which the area prices deviate due to power grid problems. The system price is often more stable than area prices, and the spikes observed in Finnish spot price have been higher than in the system price. Due to the bottlenecks in the transmission grids, the Finnish hydro balance could be relevant, though the hydro storage capacity in Finland is not remarkable and the Finnish hydro power's share of the total generation capacity is not that dominant as Norway-Sweden's.

5. RESEARCH FINDINGS

The aim of the research is to investigate the explanatory effect of the chosen explanatory variables behind electricity spot price on the given demand and supply circumstances in the Nordic region, during the past seven years. The electricity spot price is settled at the intersection point of demand and supply in the Nord Pool Spot exchange with market participants representing consumers and producers, so the underlying circumstances for consumption and available production capacity challenge the market balance. The demand-based physical structure of the electricity market explains the price formulation of the commodity, as the seasonal changes are significant on both sides.

Temperature was chosen as the demand side explanatory variable, as it is known to be the number one factor behind the changes in electricity consumption. The hydro balance was chosen as the supply side explanatory variable as the storable hydro fuel reservoir is the most important and used factor behind the production structure. The research variables' monthly values with dependencies are presented in the figure 5.1 below for a clear illustration of the research problem. Variables are later paired with spot for closer inspection.

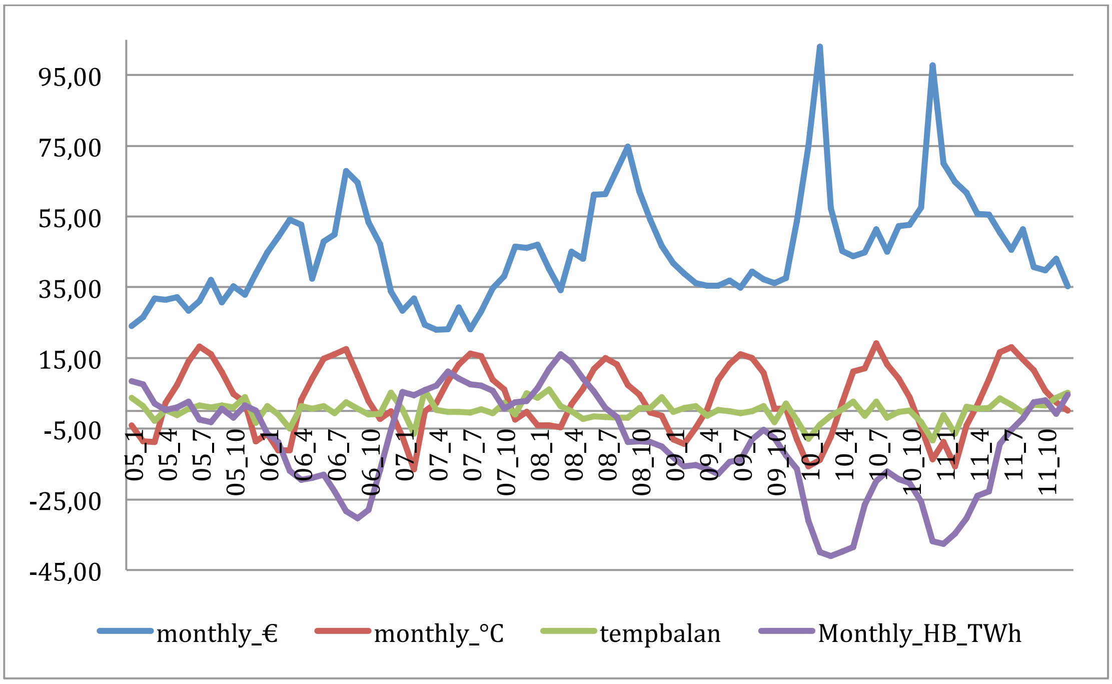

Figure 5.1. Monthly values of all test variables for 2005-2011: Nord Pool spot for Finland, Scandinavian hydro balance, Oulu temperature and temperature balance.

It is known that the market tension in the Nordic region reaches its high during the coldest and most energy intensive winter months while all of the production capacity is active and the rest imported from Russia and Germany. The available capacity on the production side therefore builds base to the problem, how tight the demand-supply balance becomes. On the other hand, low demand makes summers the season for service outages, increasing the price tension for temperature (i.e. demand) spikes. The focus in the study was to draw the dependence curve through the variable distributions. The following presents the test results organized by the test hypothesis starting from the basis.

5.1. Explanatory effect of variable values and changes on spot price

The explanatory effect of the test variables on the spot price were assumed by common sense, but naturally numerical proof is required. The effect of the variables on spot price was investigated through correlation analysis. As mentioned in the methodology chapter, correlation gives values between -1 and +1, with zero meaning no effect, and can also be referred as coefficient of determination at sample mean. In this case, as the test values lead into high prices at negative end, the desired correlations would be negative. The starting point in the research's empirical part was to determine whether the test variables should be investigated as values or changes in values. The first hypothesis stated that the explanatory effect is greater with values rather than changes in values and that the data should be investigated as observations pairs rather than time series.

The correlation test results were slightly surprising, as the effect of values was clearly stronger than the effect of changes. The relative effects were in line with assumptions. As seen from the correlation analysis table, the explanatory effect of changes in variable values were rather low compared to actual values:

Table 5.1. Correlations between spot price and research variables, values and changes.

D_corr	D_hb	D_hl	D_t	D_tb
D_spot	-0,0129	-0,0055	-0,0625	-0,0622
Corr	hb	hl	t	tb
Spot	-0,4795	-0,1075	-0,1944	-0,2821

Even though changes' correlation coefficients are quite low, these are in line with assumptions that the change in temperature explains the spot price changes better than changes in hydro balance. But for the values of variables, the determination coefficients are a lot higher: -0,4795 for the hydro balance and spot price, and -0,1944 for the temperature and spot price.

As hydro balance neutralizes the seasonal wavelet cycle of actual hydro fuel level, the actual hydro level was also examined, but left outside of the research with only -0,0055 correlation coefficient. To adjust seasonally cyclic temperature comparable with hydro balance's 'difference to normal for that time', a 'temperature balance' measure was developed for the research. Temperature balance works well in revealing and analyzing the exceptional temperature jumps out of the average temperature curve. The explanatory effect of temperature balance on spot price was at -0,2821 for the sample mean.

As these correlation coefficients are all negative, the assumptions of negative effects were correct and the investigation may continue with values rather than changes in time series. Time series analysis would suit better for some other aims of dynamics analysis. These coefficients were used as arguments for using variable values in the research.

The changes' effect was also investigated as several days in a row, but the explanatory effect for the whole data did not appear or increase notably. It was seen from the data time series that prolonged exceptionally cold period had rising effect on the spot price. These occasions appeared to exhibit individual characteristics and could not been generalized for larger comparative investigations for the complete period.

5.1.1. Hydro balance's effect on spot price

The hydro balance represents the supply side of the market as approximately half of the Nordic consumption is met by hydropower. The fuel balance for generation capacity of that caliber has understandably a strong effect on the market price formulation in a marginal value pricing market. The following illustrates the hydro balance's effect on the electricity spot prices.

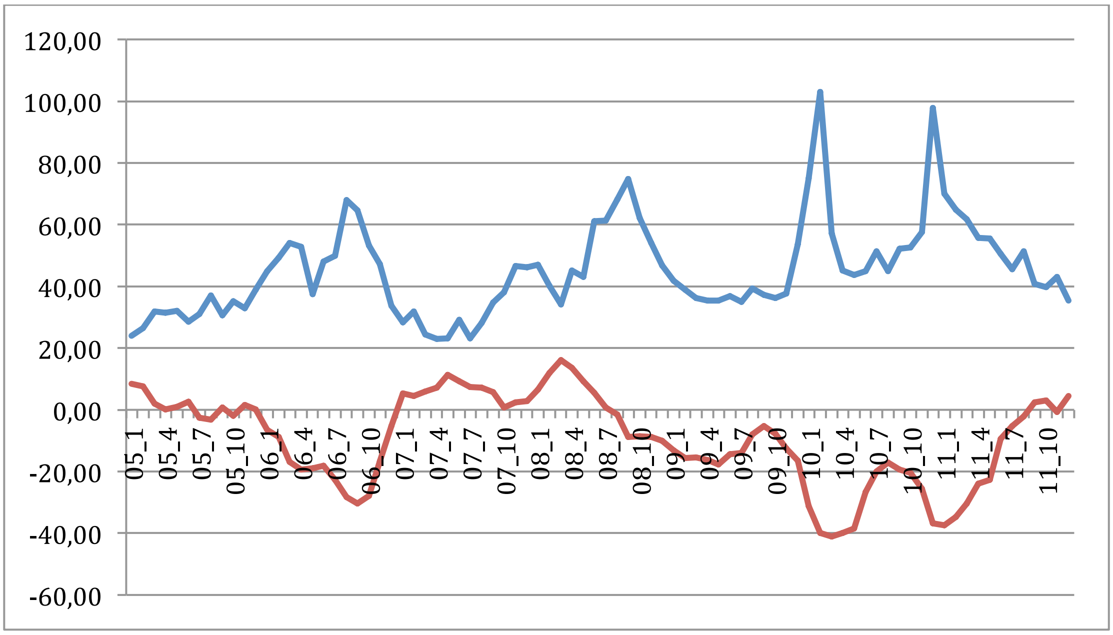

Figure 5.2. Monthly spot prices and hydro balance, 1/2005-12/2011.

The figure 5.2 illustrates the correlation coefficient of -0,4795 and confirms the assumptions that spot price does exhibit a strong reflection affected by hydro balance. The hydro balance explains well the level of spot price in the big picture: High spot prices are occur during low hydro balance and low prices during good hydro times. The changes in hydro balance are seen to move slowly with large trends in the dry and wet seasons lasting quite a long time.

5.1.2. Temperature's effect on spot price

As the temperature is known to be the driving force building the demand side of the market, the effect on the spot price is seen to exhibit seasonal effect by marginal value pricing of the commodity. The correlation between temperature and spot price for the period was -0,1944 meaning negative effect of 19,44 percent, as the scale is from -1 to +1. Figure 5.3 shows the monthly values for temperature and spot price during the inspection period 1.1.2005-31.12.2011.

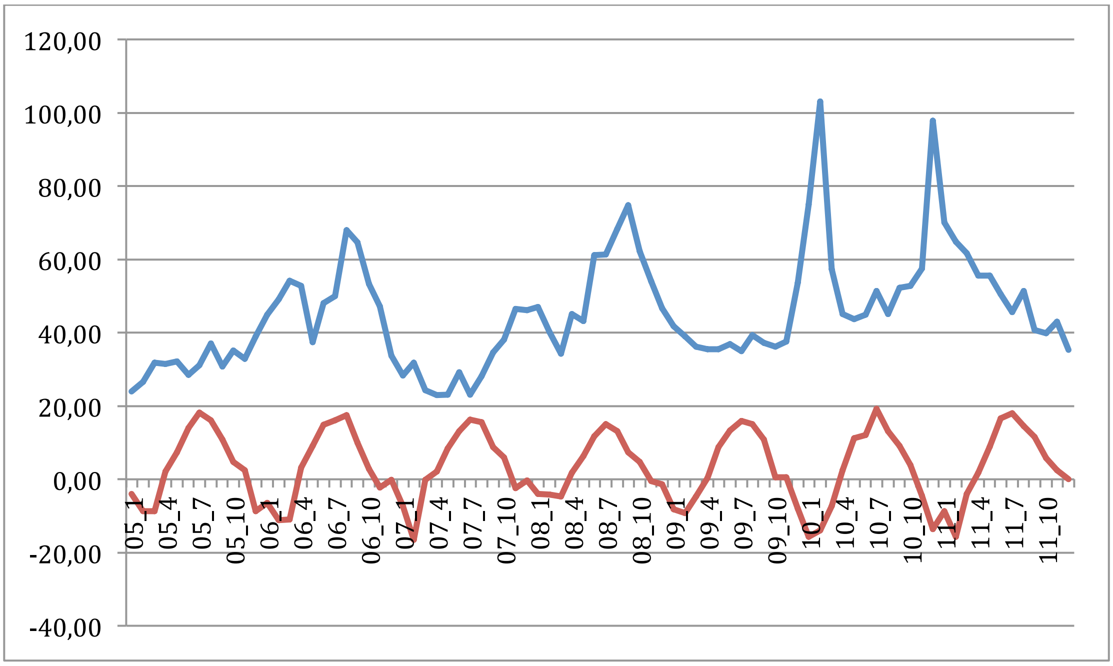

Figure 5.3. Monthly spot prices and temperature, 1/2005-12/2011.

The seasonal effect can be observed from the figure 5.3 as the warmer summer seasons tend to exhibit lower price levels. This can be reasoned by the temperature's consumption link. In the same sense, the price level increases for cold seasons are also observed lasting just few coldest months. The seasonal wavelet motion of temperature dependence in spot prices observed in Nord Pool before the inspection period and in other markets has not been so obvious through the entire investigation period, even though the recent price spikes are clearly collaborated by cold seasons. This observation with the hydro balance versus hydro level effects lead into rethinking the temperature and, resulting in the temperature balance variable. As the hydro balance tended to explain the big lines in the spot price much better than temperature, the temperature balance gave the alternative approach to short term price fluctuation.

The dynamics in variable values during the sample period cannot be underestimated, as the first winters were rather warm and the last two winters were exceptionally cold, the period ending to an exceptionally warm December. Simultaneously the hydro balance has performed a dramatically decreasing trend until the last few months. These observations justify the variables chosen as the prices have increased as both variables have been at negative extreme, individually and simultaneously.

In normal demand and supply circumstances the effect is neutral and somewhat non-observable. The seasonal effect of temperature was investigated within 5 ˚C intervals also to express the nature for normal circumstances and to base the statistically qualified quantile regression approach.

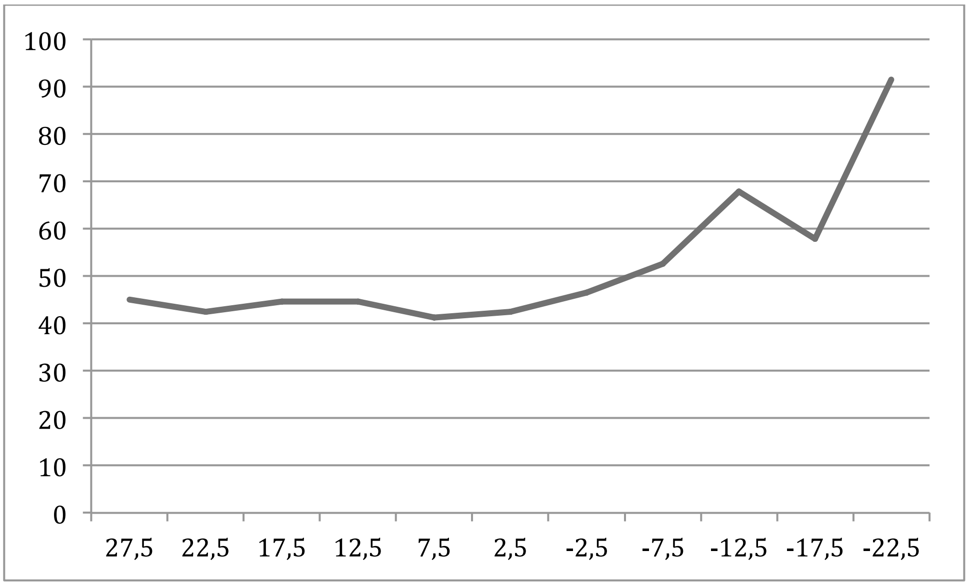

Figure 5.4. Spot mean within temperature's 5 °C intervals.

The previous statements for temperature's seasonal effect on the electricity spot price can easily be observed from the figure 5.4 above. The figure also confirms the price formulation model based on the marginal costs of power generation, and draws a similar line as the marginal costs in Figure 1.3. Throughout the seven-year data, the effect seasonality is clear: the temperature does not affect much above zero, but starts to affect the price when temperatures drop, magnifying as the temperature decreases. Interestingly the average price level does not seem to change significantly as the temperature rises. Supply elasticity into downshifting and planned service outages in summer time are behind this phenomenom.

The statistically challenging problem of outlier observations must be illustrated from the data separately. Outliers are often excluded from the statistical investigations, but in the case of electricity, these outliers form the very core of the market imperfection issues, and severe financial risk for market operators trying to secure their trades.

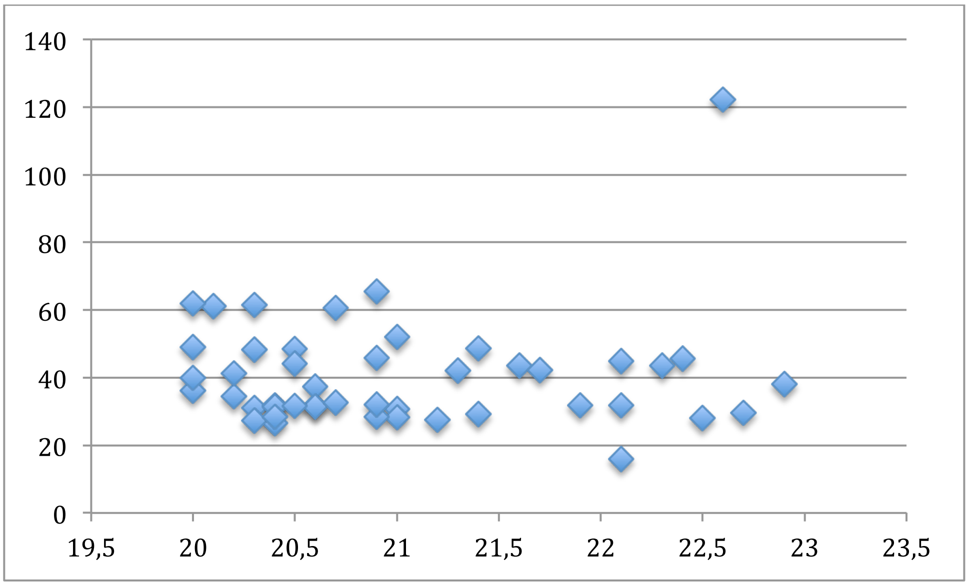

Figure 5.5. Spot prices €/MWh within +20˚C to +25˚C.

As seen on the figure 5.5, the outlier disturbs the otherwise cleanly decreasing price trend. This exceptionally expensive, warm day occurred during a historically low hydro balance season as the market balance was jeopardized. Figure 5.5 also confirms that the temperature in the Nordic circumstances has effect on the warm end as well as in warmer markets, as this particular day was a lot warmer than the days before and after, and the consumption jump lead into price spike.

5.1.3. Temperature balance's effect on spot price

Temperature balance variable was created to match better with the hydro balance with neutralized seasonal wavelet cycle leaving just the differences to the long-term average temperatures. Temperature and temperature balance exhibit quite a high frequency compared to the slow fluctuation of the hydro balance. Temperature balance illustrates this effect better than the seasonally cyclic raw temperature curve, as temperature balance bounces across zero (mean-reversion) making it easier to put on scale. And as the fact of higher correlation coefficient, the temperature balance results in better dependence effect.

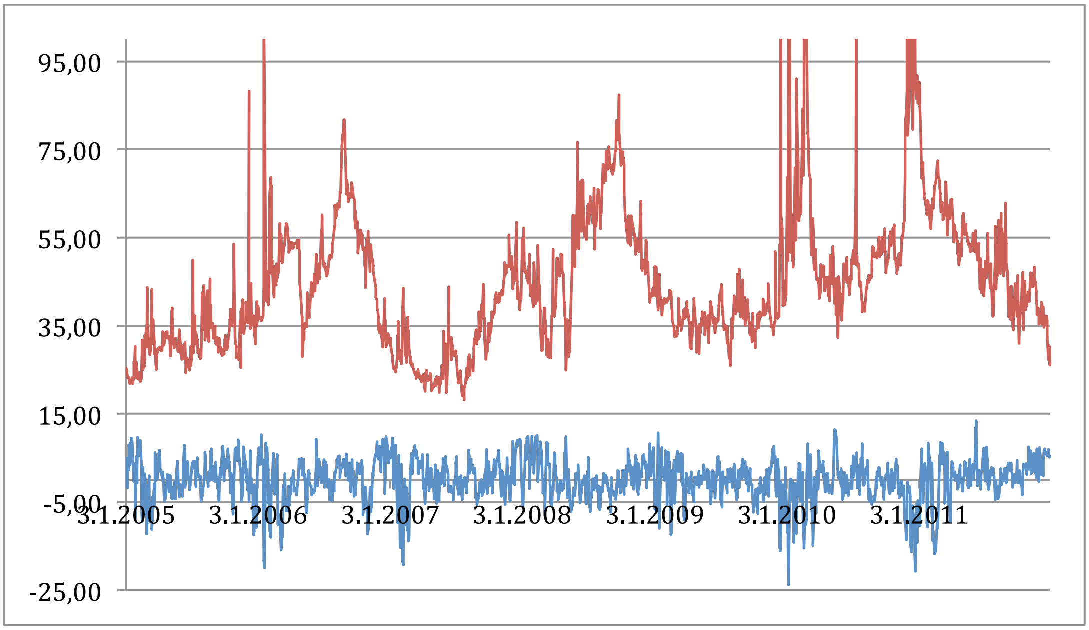

Figure 5.6. Temperature balance and electricity spot prices. 1/2005-12/2011.

The correlation efficient of temperature balance and spot price for the entire period was -0,2821 demonstrating the dependence effect between these variables to be over 0,1 higher than between spot price and raw temperature. As the slowly fluctuating hydro balance was seen to affect the price levels in 'the big picture', temperature balance clearly illustrates the spikes and the short-term deviations from the normal levels. Once again the explanation comes from physics of the market. The generation is planned to meet the 'normal' demand circumstances with certain marginal in both ways and sudden demand ups and downs affect the market balance. Figure 5.6 clearly visualizes the spikes dynamics, as the negative temperature balance spikes clearly jeopardize the market balance causing spiky jumps in the price. On the positive temperature balance jumps with surprisingly decreased consumption, the price tension is momentarily gone and the prices fall. The same reason also creates the zero or even negative hourly prices in the lowest demand times, as the stiffest (ad often cheapest) parts of the generation palette are kept on even though there would be momentary shortages of the demand.

The monthly investigation for temperature balance does not provide such a good tool for examining the whole data as sample, because the relative temperature rises to critical levels in effect only during the coldest months. This will be examined in the end of the chapter when the individual months are examined. Temperature balance does measure the short-term temperature mean reversion rather clearly, as temperatures may jump or drop by up to 20 degrees within one day.

5.1.4. Combined effect

In many cases, single risks are not necessarily severe and lethal, but in combination with other risks occurring at the same time, the total effect is probably stronger. Especially in this case, where hydro balance affects the supply cost structure and temperature (and temperature balance) affect the demand. The individual variable regressions showed that hydro balance reflects the larger price trends, while temperature was seen to reflect the short-term price dynamics. These two combined, the total reflection was assumed to draw a better reflection to spot price. As the starting point in the thesis process was the simultaneous risk from both market sides, it is interesting to see whether the effect of variables combined create a more obvious and clearer results.

Hydro balance was paired with both temperature variables to see whether there is difference between these two. Raw temperature data combined with hydro balance was first ran through quantile regression process, and after with temperature balance and hydro balance.

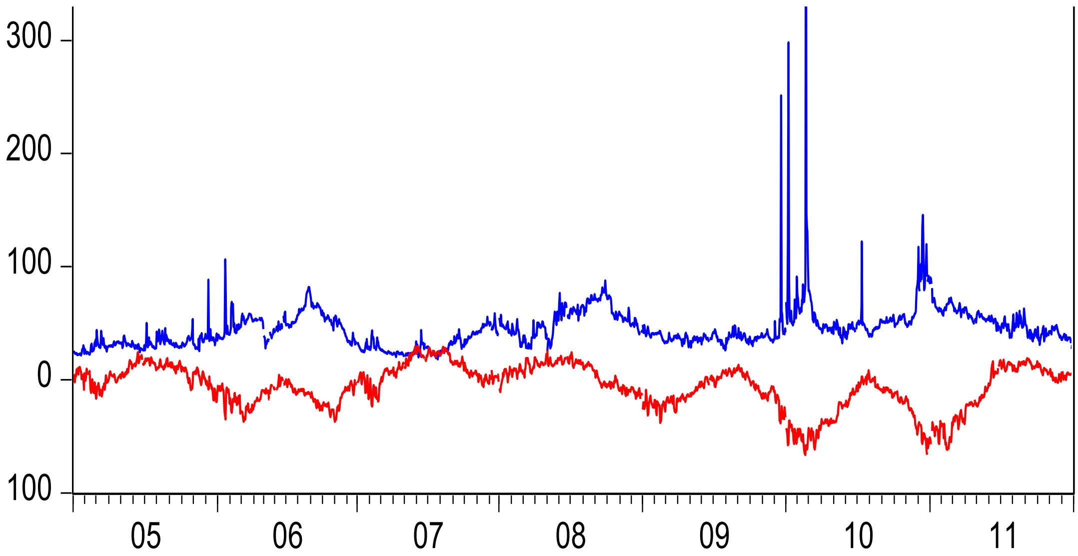

Figure 5.7. Spot price and hydro balance combined with temperature (*HBTEM*).

Noteworthy in figure 5.7, is that price tension visibly heats up, as the *HBTEM* is lowest, with temperature's deviations strongest during winters. In even closer inspection the price spikes occur simultaneously with temperature jumps. These lead into investigating the combination of hydro balance and temperature balance:

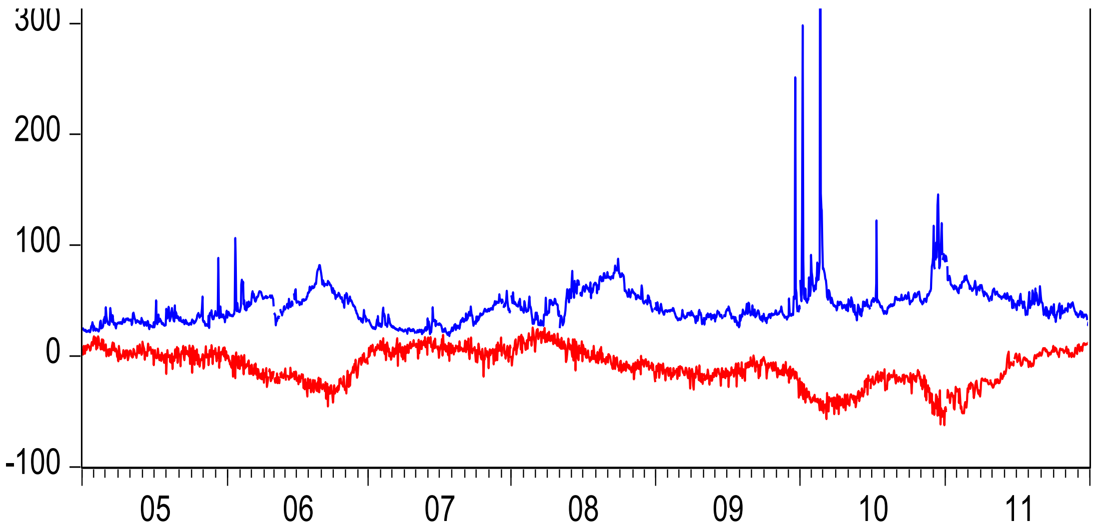

Figure 5.8. Spot price and hydro balance combined with temperature balance*(HBTB)*.

Hydro balance combined with temperature balance also draws a momentarily reflecting line to spot price, and the most tense moments in price are seen to occur when hydro balance drops simultaneously with temperature, for instance December-January in 09/10 and 10/11.

These combinations differ as the temperature balance presents the temperature without the seasonal effect. It is just the deviation from the seasonally cyclic line so therefore identical to hydro balance. The correlations between these two variable combinations and spot are quite equal: -0,465 for hbtb and spot, and -0,473 for hbtem and spot.

5.2. Quantile regression: spot quantiles

The quantile regression divides the dependent variable in equally sized quantiles and estimates the effect of independent variables within the dependent variable quantiles. For example, if the sample is divided in ten quantiles, each quantile represents ten percentiles. This research investigates variables in 20 quantiles, each representing 5 percentiles (90 observations) of the sample (1785 observations). The quantile regression approach was first examined based on spot price quantiles to configure that the effects are the strongest in the highest price quantiles, and not so strong in the lowest price quantiles. The coefficients in the study scale mostly between zero and -1, suggesting contrary effect on between variables and spot prices, in sense that low hydro balance, low temperature and negative temperature balances all lead into high prices, and vice versa.

Table 5.2. Spot price quantiles.

Quantile	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Spot	27,82	31,97	35,69	38,36	41,86	46,46	50,7	55,52	63,71

The 1785 observations were divided in 20 quantiles with the 0,5 (892nd observation) quantile representing the median. The quantiles on X-axis in figure 5.9 illustrate the spot price scale from the cheapest 0,0 to the most expensive 1,0. The regression coefficient lies on the Y-axis and the regression line is surrounded by the standard error.

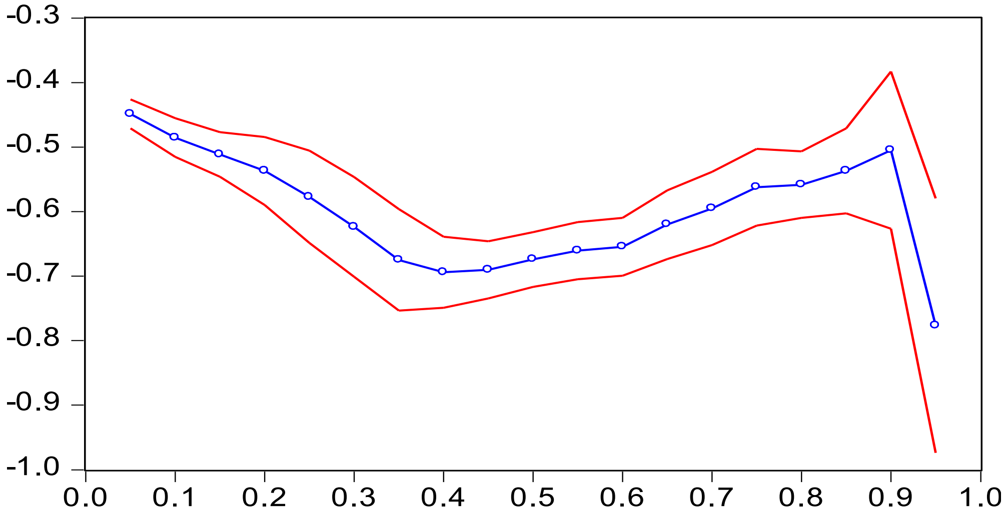

Figure 5.9. Quantile process estimates for hydro balance on spot price quantiles.

The regression coefficients of hydro balance on spot price quantiles illustrated in figure 5.9 and listed on table 5.3 show that the hydro balance plays a key role in price formulation throughout the entire price spectrum. The regression coefficients start increasing (negatively) from the lowest prices with coefficients starting from -0,45. The direction is quite linear up till the median price of 41,86 €/MWh at 0,5 quantile reaching regression coefficient -0,674. Above median price, the coefficients for hydro balance decrease up till 0,8 quantile after which the coefficients drop dramatically as spot prices reach the highest quantiles. The change around 50 €/MWh could be explained by some other, more expensive production methods joining the total supply stack. Highest price quantile above 70 €/MWh suggests that the hydro balance gains the power back after the initial saturation created by excessive power plants. The standard errors stay quite low, below 0,05 until the highest quantile, while still maintaining clear relative coefficient.

Table 5.3. Quantile process estimates for hydro balance on spot price quantiles.

	Quantile	Coefficient	Std. Error	Prob.
H_BALANCE	0.050	-0.4487	0.0114	0.0000
	0.100	-0.4853	0.0154	0.0000
	0.150	-0.5114	0.0175	0.0000
	0.200	-0.5369	0.0268	0.0000
	0.250	-0.5772	0.0366	0.0000
	0.300	-0.6236	0.0394	0.0000
	0.350	-0.6749	0.0401	0.0000
	0.400	-0.6940	0.0282	0.0000
	0.450	-0.6900	0.0226	0.0000
	0.500	-0.6743	0.0217	0.0000
	0.550	-0.6604	0.0226	0.0000
	0.600	-0.6546	0.0228	0.0000
	0.650	-0.6202	0.0270	0.0000
	0.700	-0.5953	0.0289	0.0000
	0.750	-0.5623	0.0304	0.0000
	0.800	-0.5583	0.0263	0.0000
	0.850	-0.5368	0.0336	0.0000
	0.900	-0.5047	0.0620	0.0000
	0.950	-0.7767	0.1005	0.0000

Temperatures effect within spot price spectrum examined by quantile regression resulted slightly disappointing with nigh non-existent effect combined with relatively high standard error, illustrated in figure 5.10:

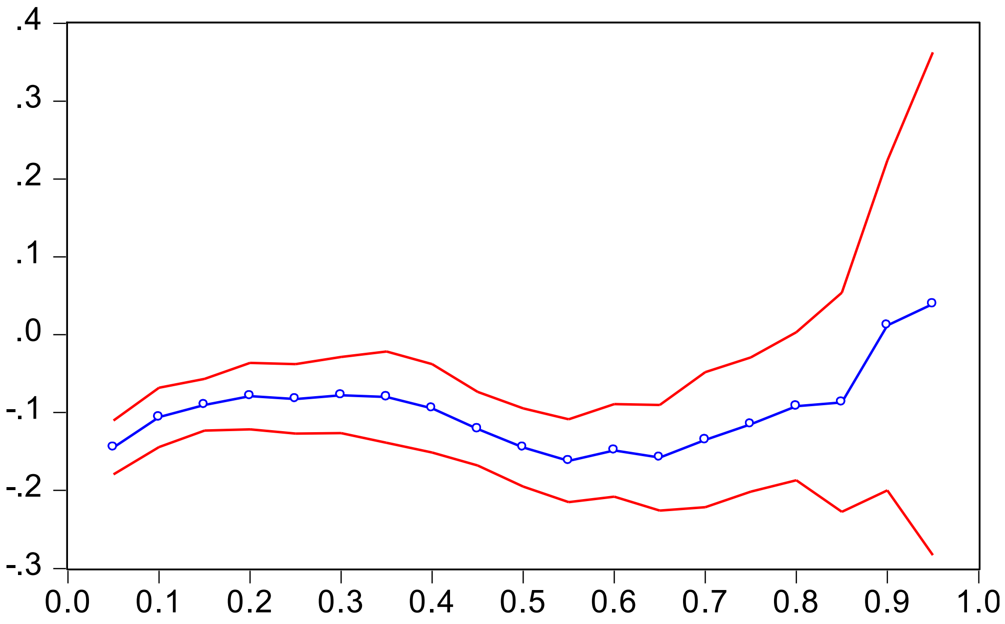

Figure 5.10. Quantile process estimates for temperature on spot price quantiles.

Temperature exhibits interestingly the largest value-adjusted standard error terms throughout the spot scale with the closest-to-zero coefficients, suggesting that temperature is not that relevant as an explanatory variable for spot prices.

Table 5.4. Quantile process estimates for temperature on spot price quantiles.

	Quantile	Coefficient	Std. Error	Prob.
TEMPERATURE	0.050	-0.1447	0.0177	0.0000
	0.100	-0.1061	0.0194	0.0000
	0.150	-0.0901	0.0169	0.0000
	0.200	-0.0789	0.0218	0.0003
	0.250	-0.0824	0.0227	0.0003
	0.300	-0.0775	0.0249	0.0019
	0.350	-0.0800	0.0298	0.0074
	0.400	-0.0944	0.0289	0.0011
	0.450	-0.1208	0.0242	0.0000
	0.500	-0.1447	0.0255	0.0000
	0.550	-0.1619	0.0272	0.0000
	0.600	-0.1485	0.0304	0.0000
	0.650	-0.1579	0.0347	0.0000
	0.700	-0.1349	0.0442	0.0023
	0.750	-0.1152	0.0440	0.0089
	0.800	-0.0919	0.0485	0.0585
	0.850	-0.0867	0.0718	0.2276
	0.900	0.0121	0.1080	0.9105
	0.950	0.0397	0.1646	0.8093

Up till the 0,6 and 0,75 quantiles at 50 €/MWh the regression coefficients stay a little below zero but above that 50 €/MWh, temperature's effect and most of all the standard error explodes and temperature loses its meaning.

At the same spot quantiles, the temperature balance gained effect, even though with very high standard errors. Interestingly the quantile process results changed quite a bit when 2011 values were added to the 2005–2010 examination. The following two figures present the change in temperature balance's effect. In short, without 2011 the temperature balance's effect was a lot higher.

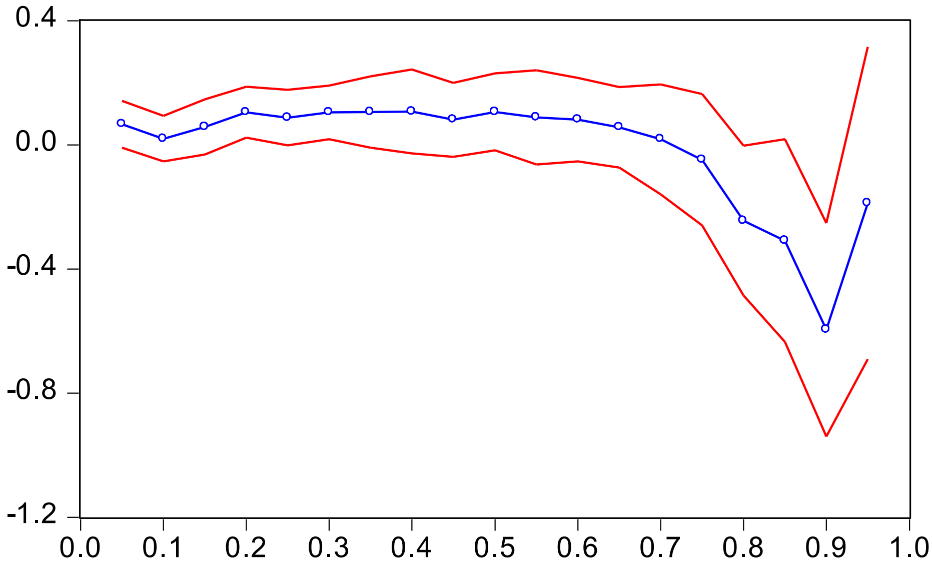

Figure 5.11. Quantile process estimates for temperature balance on spot price quantiles.

The quantile process estimates for temperature balance on spot quantiles became pretty much useless when 2011 values were added to the investigation. The figure above and table below show that the only location in the spot price distribution where temperature balance shows some effect is at 0,9 quantile at the spot price spectrum. Around that the error terms are simply way too high.

Table 5.5. Quantile process estimates for temperature balance on spot price quantiles.

	Quantile	Coefficient	Std. Error	Prob.
TEMBAL	0.050	0.0657	0.0385	0.0883
	0.100	0.0195	0.0375	0.6037
	0.150	0.0576	0.0452	0.2025
	0.200	0.1048	0.0419	0.0125
	0.250	0.0875	0.0456	0.0552
	0.300	0.1041	0.0439	0.0179
	0.350	0.1056	0.0589	0.0731
	0.400	0.1073	0.0691	0.1207
	0.450	0.0804	0.0607	0.1853
	0.500	0.1061	0.0635	0.0951
	0.550	0.0883	0.0776	0.2552
	0.600	0.0808	0.0689	0.2409
	0.650	0.0566	0.0661	0.3924
	0.700	0.0175	0.0906	0.8471
	0.750	-0.0483	0.1079	0.6544
	0.800	-0.2448	0.1232	0.0472
	0.850	-0.3087	0.1667	0.0641
	0.900	-0.5958	0.1755	0.0007
	0.950	-0.1877	0.2568	0.4649

With data from 2005 to 2010, the late arrival variable in the research, temperature balance, outperformed other variables in explanatory effect in the extreme end of spot price spectrum. The regression line in figure 5.12 seems quite stable slightly below zero within the spot quantiles up till 0,7. Spot price quantiles from 0,8, and above, were strongly affected by temperature balance.

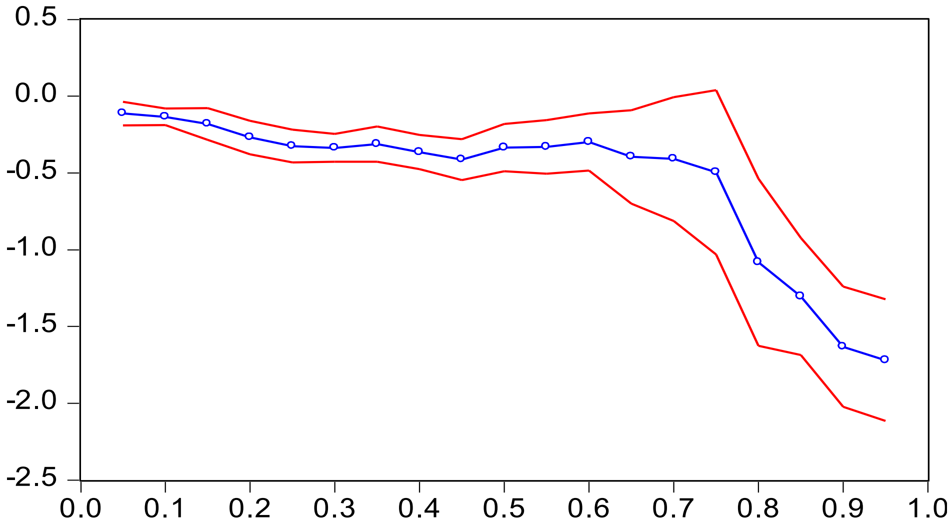

Figure 5.12. Quantile process estimates for temperature balance on spot price quantiles: 2005-2010.

Table 5.5. Quantile process estimates for temperature balance on spot price quantiles: 2005-2010.

	Quantile	Coefficient	Std. Error	Prob.
TEMBAL	0.050	-0.1132	0.0396	0.0042
	0.100	-0.1347	0.0275	0.0000
	0.150	-0.1805	0.0528	0.0006
	0.200	-0.2695	0.0555	0.0000
	0.250	-0.3248	0.0546	0.0000
	0.300	-0.3362	0.0458	0.0000
	0.350	-0.3114	0.0586	0.0000
	0.400	-0.3642	0.0570	0.0000
	0.450	-0.4136	0.0677	0.0000
	0.500	-0.3352	0.0789	0.0000
	0.550	-0.3309	0.0889	0.0002
	0.600	-0.2991	0.0950	0.0017
	0.650	-0.3950	0.1554	0.0111
	0.700	-0.4095	0.2058	0.0468
	0.750	-0.4954	0.2731	0.0699
	0.800	-1.0825	0.2777	0.0001
	0.850	-1.3043	0.1941	0.0000
	0.900	-1.6323	0.2000	0.0000
	0.950	-1.7192	0.2019	0.0000

but the coefficient scale must be taken into account, as it stays slightly above zero up till 0,7 in the lowest 5 per cent of spot price observations up to -1,72 at the highest 5 per cent of spot prices observed, and -0,5 at 0,75 (around 50 €/MWh). The coefficients thereby suggest that temperature balance is relevant even from the low price quantiles, reaching sky-high coefficients at the highest 20 per cent of the spot price observations meaning that the highest prices occur simultaneously with exceptional temperatures (temperature jumps).

The quantile regression approach used for examining the explanatory effects of chosen variables through the spot price spectrum resulted in strongest effects within the highest quantiles as was assumed and stated in hypothesis. Quantile regression is next run on variable quantiles, to test the explanatory effect on spot prices.

5.3. Quantile regression: hydro balance's effect on spot price

The explanatory effect of variable values to spot price, is examined by variable quantiles. Hydro balance's sample distribution is listed in table 5.6 and illustrated in figure 4.9. Early assumptions stated that the effect is strongest in the lowest seasonally adjusted hydro fuel circumstances, rising linearly towards zero in the normal hydro circumstances.

Table 5.6. Hydro balance quantiles.

Quantile	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Hydro balance	-31,30	-21,42	-17,45	-12,52	-6,56	-1,81	1,34	4,18	7,63

Table 5.6 shows that the hydro balance quantiles and observations are quite evenly distributed, and weighted on the negative side with median at -6,556 TWh and zero TWh at 0,65 quantile. Figure 5.13 illustrates the spot price's dependency regarding hydro balance level in quantiles on X-axis and regression coefficient on Y-axis, while regression line is surrounded by standard error.

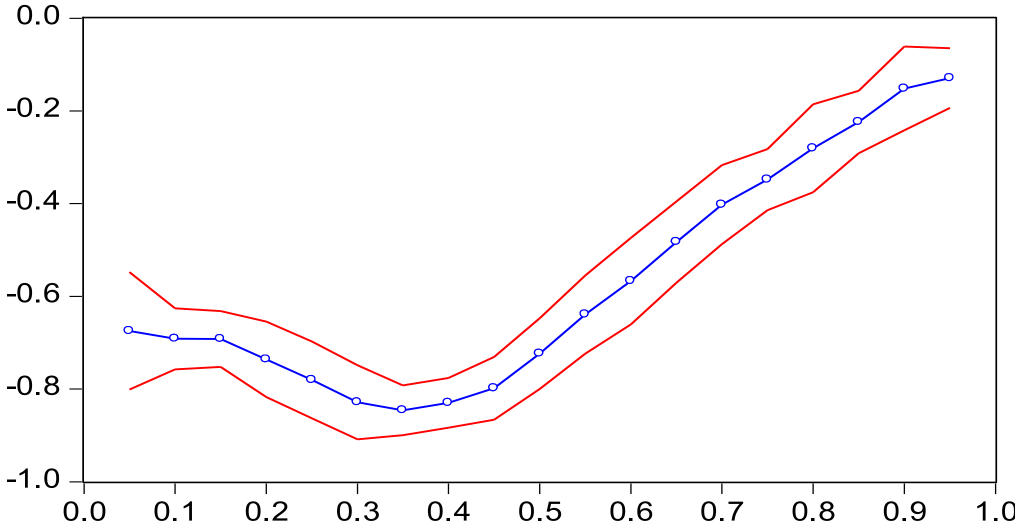

Figure 5.13. Quantile process estimates for spot on hydro balance quantiles.

The effect of hydro balance on spot price is illustrated in the figure 5.12 showing negative effects throughout the entire hydro balance scale, meaning raising effect at below zero and negative effect above zero.

Table 5.7. Quantile process estimates for spot on hydro balance quantiles.

	Quantile	Coefficient	Std. Error	Prob.
SPOT	0.050	-0.6744	0.0647	0.0000
	0.100	-0.6917	0.0337	0.0000
	0.150	-0.6921	0.0308	0.0000
	0.200	-0.7359	0.0415	0.0000
	0.250	-0.7804	0.0424	0.0000
	0.300	-0.8286	0.0407	0.0000
	0.350	-0.8459	0.0273	0.0000
	0.400	-0.8300	0.0274	0.0000
	0.450	-0.7984	0.0346	0.0000
	0.500	-0.7235	0.0390	0.0000
	0.550	-0.6391	0.0431	0.0000
	0.600	-0.5671	0.0475	0.0000
	0.650	-0.4826	0.0447	0.0000
	0.700	-0.4021	0.0435	0.0000
	0.750	-0.3481	0.0336	0.0000
	0.800	-0.2806	0.0483	0.0000
	0.850	-0.2240	0.0345	0.0000
	0.900	-0.1516	0.0462	0.0010
	0.950	-0.1288	0.0329	0.0001

Table 5.7 provides the numerical values for coefficients graphically illustrated in figure 5.13. The regression coefficient for median at 0,5 is -0,72. As 0,1 quantile includes 178 observations, 0,05 includes 89 observations. The coefficient at the lowest 5% is -0,67 and stays below -0,5 up till the 0,65 quantile meaning zero point in hydro balance value. The effect strength reaches a saturation point at 0,35 (-15 TWh) after which the effect effect slightly decreases until reaching the lowest 5%. The saturation in hydro balance coefficients could be explained by other production methods entering the supply stack and decreasing hydro balance's effect, in same sense as the examination based on spot quantiles. In the worst hydro balance circumstances the effect rises again. Up from the 0,35 the coefficient linearly rises up until the very last quantile. The highest hydro balances during the period do not rise over 20 TWh on the positive side, but the effect is assumed to stay negative even if the hydro balance would rise even further. If the hydro balance would climb exceptionally high, there would be no more possibilities to store water meaning forced generation and thereby lowering pressure in spot prices. The standard error decreases straightforward from 0,04 (at 0,1) up to the highest quantile's 0,024, after an initial 0,11 at the lowest 5%.

5.4. Quantile regression: temperature's effect on spot price

The temperature represents the demand side building the big picture for seasonal consumption changes included with the short-term demand peaks, the latter more precisely examined in temperature balance analysis. 5.1.2 suggested that the temperature starts to affect the spot price as temperature slides below zero and onwards with a marginal-price like, increasing curve. The quantile regression approach provides a closer look to temperatures effect. The quantile division builds upon the following table, where the median is at 0,5. Table 5.8 together with figure 4.9 show that the weigh of temperature is on the positive values, as both mean and median are about 3,5 ˚C.

Table 5.8. Temperature quantiles.

Quantile	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Temperature	-10,7	-4,88	-1,4	1,2	3,5	7,06	10,2	13,3	16,4

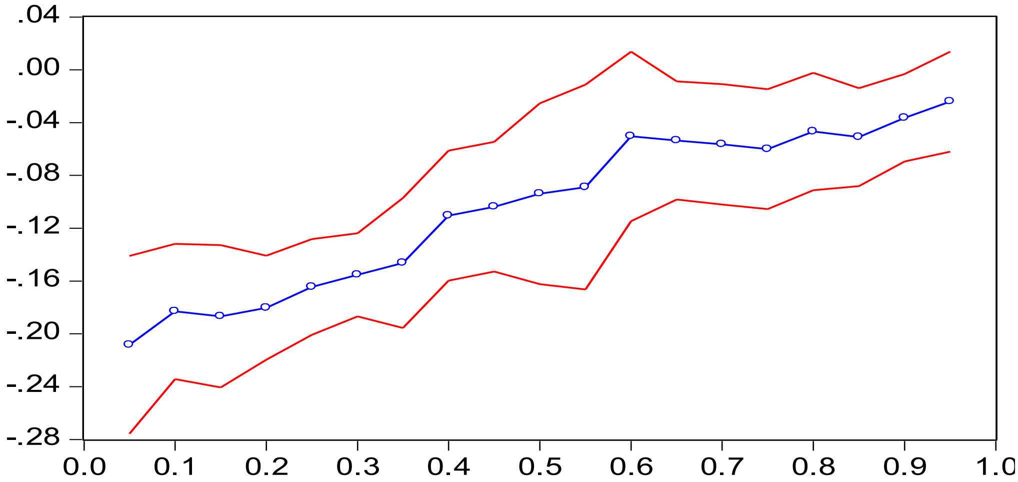

Figure 5.14. Quantile process estimates for spot on temperature quantiles.

Figure 5.14 illustrates the temperature's effect on spot price through the entire temperature distribution while numerical regression coefficients are provided in the table 5.9.

Table 5.9. Quantile process estimates for spot on temperature quantiles.

	Quantile	Coefficient	Std. Error	Prob.
SPOT	0.050	-0.2084	0.0343	0.0000
	0.100	-0.1830	0.0262	0.0000
	0.150	-0.1867	0.0275	0.0000
	0.200	-0.1803	0.0201	0.0000
	0.250	-0.1645	0.0185	0.0000
	0.300	-0.1553	0.0161	0.0000
	0.350	-0.1464	0.0251	0.0000
	0.400	-0.1104	0.0251	0.0000
	0.450	-0.1037	0.0250	0.0000
	0.500	-0.0939	0.0350	0.0073
	0.550	-0.0889	0.0396	0.0248
	0.600	-0.0504	0.0328	0.1241
	0.650	-0.0536	0.0228	0.0192
	0.700	-0.0564	0.0232	0.0152
	0.750	-0.0601	0.0232	0.0097
	0.800	-0.0467	0.0227	0.0398
	0.850	-0.0510	0.0189	0.0071
	0.900	-0.0364	0.0169	0.0313
	0.950	-0.0241	0.0193	0.2125

Considering the relatively high standard errors through the temperature quantiles for spot price's temperature dependence, the effect exhibits quite linear line. On more precise examination, the changes in coefficients within certain quantiles do exhibit variation from the line. The coefficients are all negative throughout the whole scale of temperature values starting from negative end at -0,2 and finishing slightly negative at the highest temperatures.

5.5. Quantile regression: temperature balance's effect on spot price

Temperature balance was created in the research process to examine the effect of aberrations from the long-term temperatures, in the same sense as hydro balance from the actual hydro level. In the temperature balance, the quantiles in both ends rise to the focus as they were assumed to have the strongest effect while the mid quantiles were assumed to result quite flat in coefficients.

Table 5.10. Temperature balance quantiles.

Quantile	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
Temperature balance	-5,456	-3,1	-1,8	-0,612	0,4	1,35	2,45	3,8965	5,8

Table 5.10 illustrates the distribution structure of the temperature balance observations, together with histogram in figure 4.11. The distribution is quite even between the 0,1 and 0,9 quantiles, but especially at the negative end, the values reach -23,8 °C below average curve, but the maximum positive aberration "only" 11,4 °C. The regression coefficients by quantiles are illustrated in figure 5.15 where X-axis covers temperature balance quantiles and Y-axis the coefficients. The regression line is surrounded by the standard error.

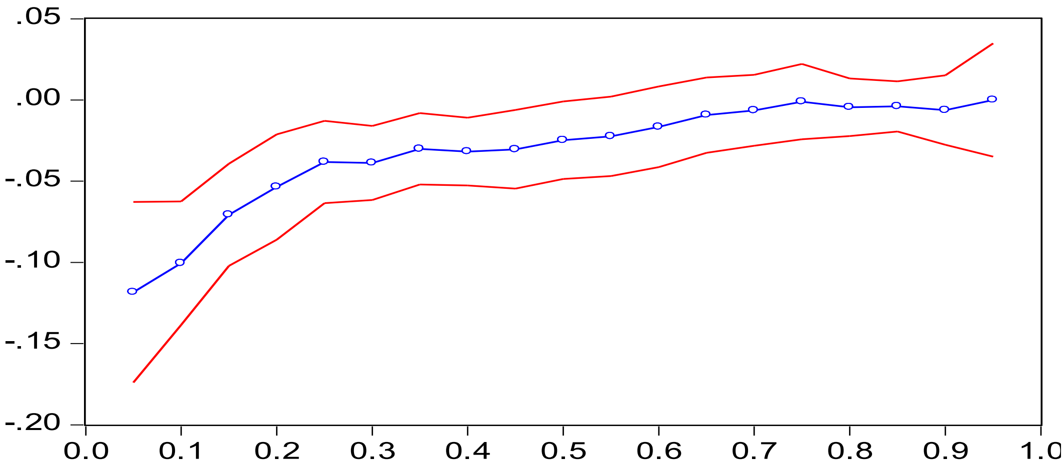

Figure 5.15. Quantile process estimates for spot on temperature balance quantiles.

Figure 5.15 illustrates the temperature balance's effect on spot price through the entire temperature balance distribution while numerical regression coefficients are provided in the table 5.11.

Table 5.11. Quantile process estimates for spot on temperature balance quantiles.

	Quantile	Coefficient	Std. Error	Prob.
SPOT	0.050	-0.1184	0.0284	0.0000
	0.100	-0.1005	0.0194	0.0000
	0.150	-0.0706	0.0160	0.0000
	0.200	-0.0536	0.0165	0.0012
	0.250	-0.0382	0.0129	0.0032
	0.300	-0.0388	0.0116	0.0009
	0.350	-0.0301	0.0112	0.0074
	0.400	-0.0318	0.0106	0.0028
	0.450	-0.0304	0.0124	0.0140
	0.500	-0.0248	0.0122	0.0417
	0.550	-0.0224	0.0125	0.0727
	0.600	-0.0165	0.0127	0.1918
	0.650	-0.0093	0.0118	0.4322
	0.700	-0.0064	0.0112	0.5694
	0.750	-0.0010	0.0118	0.9317
	0.800	-0.0044	0.0091	0.6236
	0.850	-0.0040	0.0079	0.6146
	0.900	-0.0062	0.0109	0.5683
	0.950	0,0000	0.0178	1.0000

Regression coefficients are once again all negative suggesting contrary effect within the entire spectrum of temperature balance values. The coefficients are quite solid through the quantiles above 0,25 resulting in coefficient values between -0,04 and zero. The error term increases in the negative end of the distribution as the coefficients decrease towards the negative end, meaning strongest effect in the relatively coldest observations. The relative error terms are again high throughout the temperature balance spectrum, but results are acceptable below median, with p values below 0,05. The effect of temperature balance was also lighter with 2011 values included, but still similar.

5.6. Quantile regression: combined effect on spot price

To investigate the simultaneous effect of temperature and hydro balance tells a more linear story throughout the scale. Hydro balance was seen to affect the price trends in bigger picture and temperature causing the daily deviations from the hydro balance driven lines, these combined might together form a better reflection to the price index.

As seen on single variable tests, hydro balance shows higher dependencies to the spot price than local temperature, or temperature balance. It was assumed that both variables combined at the negative end simultaneously would form a greater and clearer risk. For the big picture in risk management, several risks are always investigated together. In this case when especially the temperature's and temperature balance's effects were somewhat disappointing, combined with the hydro balance the effect was expected to hold smaller errors. In the following combinations the hydro balance's terawatts (scaling -45 to +20 TWh) were simply added with temperature (-30 to +25 ˚C) and temperature balance (-26 to 12 ˚C) values. Temperatures, and temperature balance's effect was highest at the negative end and somewhat negligible at other levels. These two combined with hydro balance, the quantile process estimates are shown in following graphs and tables.

5.6.1. Quantile regression: combined HBTEM

The combination effect of the two variables was seen interesting as either affected different features in the price dynamics, temperature the short-term and hydro balance the long-term dynamics. First combination test investigates the raw temperature values combined with hydro balance, and the quantile process estimates are shown below.

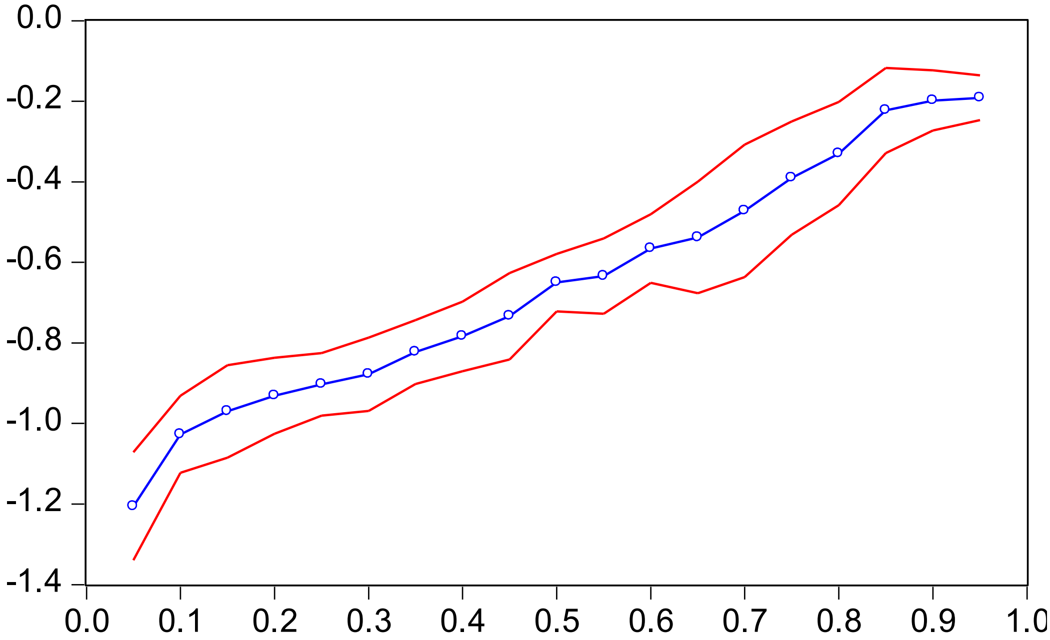

Figure 5.16. Quantile process estimates for spot on HBTEM quantiles.

Table 5.12. Quantile process estimates for spot on HBTEM quantiles.

	Quantile	Coefficient	Std. Error	Prob.
SPOT	0.050	-1.2055	0.0684	0.0000
	0.100	-1.0271	0.0488	0.0000
	0.150	-0.9699	0.0584	0.0000
	0.200	-0.9313	0.0480	0.0000
	0.250	-0.9027	0.0395	0.0000
	0.300	-0.8776	0.0464	0.0000
	0.350	-0.8228	0.0403	0.0000
	0.400	-0.7838	0.0440	0.0000
	0.450	-0.7336	0.0548	0.0000
	0.500	-0.6502	0.0363	0.0000
	0.550	-0.6337	0.0477	0.0000
	0.600	-0.5657	0.0435	0.0000
	0.650	-0.5384	0.0708	0.0000
	0.700	-0.4717	0.0839	0.0000
	0.750	-0.3907	0.0716	0.0000
	0.800	-0.3301	0.0654	0.0000
	0.850	-0.2228	0.0539	0.0000
	0.900	-0.1979	0.0380	0.0000
	0.950	-0.1913	0.0284	0.0000

The quantile process estimates illustrated in figure and table above show what was expected: The combination coefficients are quite indisputable with low errors and 0,0000 p-values in every quantile. Besides the coefficient significance, the coefficients rise quite linearly from the most extreme negative values towards the highest quantiles. The difference to hydro balance’ regression coefficients is quite small in the quantiles above 0,3. The combination effect is highest in the lowest 30 per cents of the distribution suggesting that cold winter temperatures simultaneously with bad hydro reservoir is truly the problem the thesis discusses.

5.6.2. Quantile regression: combined HBTB

In comparison with the temperature added hydro balance, HBTB combines temperature balance with hydro balance. It was known that the temperature balance values are quite close to zero in most of the middle quantiles and deviate more only in the lowest and highest quantiles. Therefore the difference to hydro balance individually, is observable in the lowest quantiles. The following graph illustrates the quantile process coefficients that table lists.

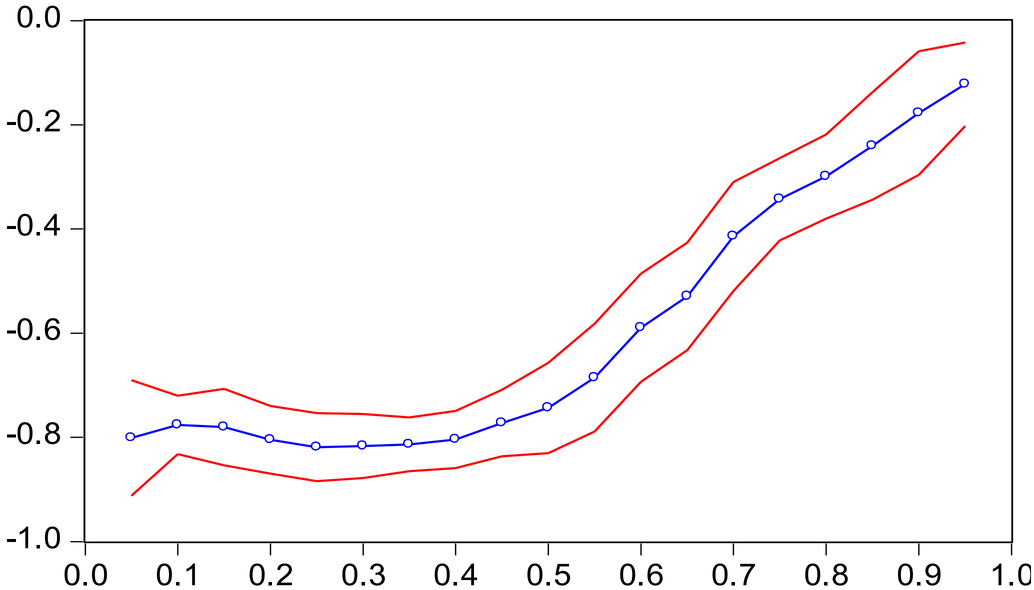

Figure 5.17. Quantile process estimates for spot on HBTB quantiles.

As seen on figure 5.17 above and confirmed in the table 5.13 below, the difference to hydro balance regression is quite minimal. Only during the lowest quantiles the slope of coefficients is kept at -0,8 in quantiles 0,3 and below with temperature balances effect.

Table 5.13. Quantile process estimates for spot on HBTB quantiles.

	Quantile	Coefficient	Std. Error	Prob.
SPOT	0.050	-0.8011	0.0565	0.0000
	0.100	-0.7760	0.0285	0.0000
	0.150	-0.7802	0.0374	0.0000
	0.200	-0.8049	0.0332	0.0000
	0.250	-0.8189	0.0333	0.0000
	0.300	-0.8165	0.0314	0.0000
	0.350	-0.8135	0.0263	0.0000
	0.400	-0.8040	0.0281	0.0000
	0.450	-0.7727	0.0325	0.0000
	0.500	-0.7434	0.0443	0.0000
	0.550	-0.6853	0.0528	0.0000
	0.600	-0.5896	0.0529	0.0000
	0.650	-0.5291	0.0527	0.0000
	0.700	-0.4143	0.0534	0.0000
	0.750	-0.3429	0.0403	0.0000
	0.800	-0.2993	0.0412	0.0000
	0.850	-0.2405	0.0525	0.0000
	0.900	-0.1776	0.0605	0.0034
	0.950	-0.1222	0.0409	0.0029

5.7. Electricity spot price sensitivity during winter months

The electricity spot price sensitivity to research variables was assumed and confirmed by the tests to result in highest values at the lowest hydro balance circumstances and coldest temperatures, actual and relative. These observations result in most extreme price deviations in the coldest winter with the market tension between demand and supply at its high. Closer examination of the coldest winter months of December, January and February was also included in the research.

Table 5.12. Monthly averages: December, January and February

year_month	€	°C	hb	tb
05_1	24,00	-4,00	8,53	-0,85
05_2	26,54	-8,66	7,50	3,26
05_12	38,91	-8,64	-0,07	1,14
06_1	44,86	-6,45	-6,33	0,09
06_2	49,20	-11,15	-8,71	0,36
06_12	33,79	-0,08	-5,29	1,70
07_1	28,32	-7,29	5,25	0,81
07_2	31,84	-16,51	4,47	1,09
07_12	46,22	-0,32	2,69	1,60
08_1	47,08	-4,00	6,53	2,25
08_2	40,16	-4,10	11,92	1,43
08_12	46,72	-1,33	-9,90	0,16
09_1	41,77	-8,12	-13,18	0,50
09_2	38,95	-9,24	-15,62	0,61
09_12	53,72	-7,99	-16,57	-1,52
10_1	74,92	-15,74	-31,07	-2,71
10_2	103,01	-13,94	-39,90	-1,54
10_12	97,81	-13,63	-36,88	-10,64
11_1	70,03	-8,76	-37,52	-1,13
11_2	64,85	-15,70	-34,74	-6,38
11_12	35,32	0,03	4,55	5,23

Separately investigated the correlation between the variables and spot prices reached their highs when these three months were selected. Other months from more neutral circumstances resulted in weaker correlation effects. Table 5.12 shows that these variables can be examined individually, but the analysis requires all variables to be included for the best outcome. Table 5.12 also illustrates the common variable characteristics within the research period with rising prices, decreasing hydro balance and decreasing temperatures until 2011 when variables returned to their normal levels. Averages smoothen the sharpest jumps in variable values, but still represent the total distribution quite well for that short period.

Table 5.13. Correlations for monthly averages: December, January and February

Correlation with spot	
Temperature	-0,5226
Hydro balance	-0,8742
Temperature balance	-0,718

Correlations for these coldest, most energy intensive months were significantly higher than for the entire period, as the prices stayed even cheap for the warm and wet winter months, and peaked during exceptionally cold and dry months. Table 5.13 also shows that the temperature balance has better explanation effect on spot than raw temperature data. These coefficients are in line with previous assumptions and test results, as the hydro balance tends to settle the price levels which the temperature mean reversion then draws up or down.

6. CONCLUSIONS

Electricity markets have been introduced all over the world to bring transparency to the pricing for the essential, and often vital, commodity. The main goal has been connecting sufficiently large areas into the same pool to stabilize the prices, but that goal is clearly not achieved. The number of price zones is still too high and sizes too small, and the market prices are far from stable. Even though the Nordic wholesale electricity market is globally one of the best functioning international electricity markets, it still exhibits price dynamics that perfectly functioning free market simply should not. Electricity is by nature a tricky commodity for market trade with its fixed bound to time and physical delivery, and. The Nord Pool market area is exposed to extreme circumstances within seasonal weather cycle as well as in a unique generation structure.

Electricity market builds on demand, i.e. electricity consumption, which the production as supply is supposed to satisfy to keep the market in balance. Deliberating the electricity markets is a noble idea by its basis, but the market has not quite been as effective as it was planned to be. The market prices perform quite rationally in normal circumstances, but when problems occur, price behavior becomes extremely volatile and "spiky", and severely harmful for the market participants, often publicly owned.

The wholesale electricity spot prices also in Nord Pool were known to reflect the demand and supply circumstances, mainly temperature changes on demand side and production capacity changes on supply side. On supply side the hydro fuel reservoir situation is the most important factor besides overall capacity limitations, as for market structure, hydropower represents half of the entire Nordic generation. From variable graphs can be observed that to some extent spot prices follow hydro balance reflection in long trends, as hydro balance changes are quite slow. Explanation behind this is that in marginal pricing models the cheapest generation methods are utilized first, and as water is the most utilized fuels and 'cheap' as well, the changes in free provided fuel have dramatic effects on the price. On the other hand the short-term price dynamics can be seen caused by sudden consumption variation by temperature (*daily prices without weekends); temperature can easily vary over 10 ˚C during just one day, one way or another. Temperature explains the largest day-to-day changes in consumption, so the dependence rationalization can be confirmed.

The electiricty price dynamics is statistically explained to revert to mean, which in extreme sense can be described as spikes, and exhibit occasional jumps when circumstance tension peaks. Models handle these features in different ways, but all agree that both market sides, demand and supply, exhibit mean reversion individually, that can become severe in simultaneous shocks. When demand peaks simultaneously with supply side problems, the price tends to react and jump up. With overload in production and demand dropping, the prices drop as well.

The dependencies between spot price and research variables temperature and hydro balance, were examined by quantile regression. Depart from standard regression analysis focusing on the sample mean, quantile approach examines the variables by their distribution, divided into desired number of quantiles. Quantile regression enables investigation based on certain problem levels of variables, and is considered especially useful in analyzing electricity spot prices and, its dependencies with explanatory variables.

The quantile regression was first run by spot quantiles to verify that the problems rise towards the highest prices. After problem reasoning the regression was run by variable quantiles to verify that the strongest effects lie in the lowest hydro balance, temperature and temperature balance quantiles, from where the effect starts to loosen up towards the normal and good circumstances. The sample of 1785 weekday observations for each variable was divided into 20 quantiles each of which holding 89 observations, which resulted optimal in sense of result accuracy and statistical significance. Different quantile partition was also tested, but the results and graphs did not change significantly, even though dividing the sample into 50 or hundred quantiles. Only the error terms got worse as the quantile sizes got smaller.

The regression coefficients on spot quantiles resulted highest overall for hydro balance, throughout the entire spot price spectrum. Temperature performed surprisingly weak as an explanatory variable on spot price quantiles with quite low coefficients combined with extremely high standard errors in the most important highest price quantiles. In fact, temperature seems quite irrelevant in price dependence to spot price in this test. Quite the same way as the actual hydro level. Temperature balance's effect significance changed quite dramatically when year 2011 was added to the examination. On 2005–2010 data temperature balance performed quite as expected on spot price quantiles with nigh non-existent error terms throughout the entire price spectrum. With years 2005–2011 in analysis, the coefficients were close to zero with extremely high errors even when the coefficients departed from zero.

The regression analysis on hydro balance quantiles performed well, and in line with assumptions, strongest at the negative end and rising towards normal and good hydro circumstances. The coefficients were quite high, and significant all the way up towards the good hydro circumstances with very low standard errors. The quantile process coefficients remained quite stable around -0,7 up until the median, after which the coefficients started to approach zero, though never reaching it.

The quantile process estimates for spot on temperature quantiles performed better than the other way around. Up till the median, the coefficients were statistically significant with low enough standard errors. Also the explanatory effect approached zero quite linearly as the temperature rose. In the most interesting cold end the coefficients reached -0,2.

The hydro balance-like temperature mean reversion, aberration from the seasonally cyclic long-term normal temperature, temperature balance, performed quite as expected with strongest coefficients in the lowest end of temperature aberration. In more neutral temperature aberrations, the temperature balance started to loose its explanatory effect, and the significance was lost above the sample median.

As the combination effect of hydro balance and temperature (and temperature balance) was considered dramatic in the first place, the hydro balance TWh's was simply combined with the Celsius grades of temperature (and temperature balance) as the scales were quite similar. The combination effect was also interesting to investigate as the variable graphs suggested that hydro balance explained the price levels, while temperature's short-term dynamics reflected the day-to-day price dynamics. The combination figures were assumed to steepen the low-end coefficients as the price tension was seen highest in the cold seasons with extremely low hydro reservoirs. The variables HBTEM and HBTB were both run through quantile process and both resulted significantly well as assumed in hypothesis, with strongest effect in the negative end and low standard errors throughout the distribution. HBTEM resulted in a quite linearly rising coefficient line with high -1,2 coefficient in the lowest quantile and -0,2 in the highest three 5-percent quantiles. HBTB line did not differ that much from the hydro balance line, but the enhanced effect in the exceptionally cold end was clear and convincing. These variables create a useful combination for risk management in electricity trade. Temperature's slightly disappointing effect became increasingly interesting when combined with hydro balance, especially in the most severe low end.

The investigation on monthly basis emphasized the effect of temperature in the cold end. The tension in demand-supply balance peaked during the coldest winter months December, January and February, and especially when the temperatures fell lower than average simultaneously with low hydro balance. The lowest temperatures and hydro reservoirs both drove the prices and price volatilities up while price tension easened towards neutral circumstances.

The effect of temperature alone was surprisingly weak, nigh non-existent. But in combination with hydro balance, the effect is clearly there. Together these variables explain most of the extreme price dynamics observed during the investigation period. Temperature balance represents a fine-adjustment in temperatures seasonal effect, and alone explains the extreme price reactions quite well.

These results suggest that the most important factor behind Nord Pool's electricity spot price for Finland is Scandinavian hydro balance, which determines quite well the momentary price levels. As hydro balance changes with slower frequency, the rapid temperature changes draw the daily spot prices apart from one another creating the mean reversion effect to the price curve. These results can be ratified by the production structure in the Nordic region, and the marginal cost structure behind price formulation. This regression test should be tested on other area prices and locations as well, but there's no doubt, the effect exists there as well, where the hydro generation locally plays even larger role. The fuel circumstances determine the price levels in big picture and the short-term adjustments to temperature driven consumption high's and low's affect the short-term price dynamics.

Let us wish for a wet and warm future!

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