NORGES HANDELSHØYSKOLE
Bergen, Spring 2010

The Nordic Power Exchange - Analysis of the market efficiency

Eya Salmi

Thesis Advisor: Maytinee Wasumadee

Master Thesis within the main profile of International Business

NORGES HANDELSHØYSKOLE

This thesis was written as a part of the Master of Science in Economics and Business Administration program - Major in International Business. Neither the institution, nor the advisor is responsible for the theories and methods used, or the results and conclusions drawn, through the approval of this thesis.

Abstract

The aim of this thesis is to examine the market efficiency of the Nordic power exchange by analysing the electricity market, its structure and the pricing mechanisms. An empirical analysis of Nord Pool is carried during the recent period to investigate the predictability of electricity prices using the futures market. We have based our analysis on a traditional theory of futures pricing i.e. the storage theory. The limits of applying the cost of carry hypothesis on electricity markets are presented. In addition, the market efficiency is tested using modern econometrical tools such the cointegration technique and the Error Correction Model (ECM).

Preface

This thesis is written within the Master of Science in Economics and Business Administration.

In an effort to contribute to the research community and bring attention to the financial aspects of the power exchange, we have invested our interest in the Nordic power market in an attempt to test its efficiency through an analysis of the potential factors that could affect the competitiveness and the efficiency of the market. To complement this analysis, an empirical study was conducted using Nord Pool data during a ten-year-period. The empirical tests are considered statistically strong thanks to the sufficient amount of data.

The unique characteristics of electricity as a tradable commodity have motivated us to study these features and their impact on the market efficiency, a subject of interest to the different players in the power market.

We here acknowledge our much felted gratitude and thanks to our supervisor, Maytinee Wasumadee, for the valuable comments and guidance. Besides, we would like to thank Nord Pool ASA for giving us access to the Nord Pool FTP server and providing us with the data needed to accomplish this work.

We would like also to address our thanks to our family and friends for their support.

Bergen, 25. May 2010

Table of contents

ABSTRACT 2
PREFACE 3
TABLE OF CONTENTS 4
LIST OF FIGURES 6
LIST OF TABLES 6

1. INTRODUCTION 7

1.1 BACKGROUND 7
1.2 TARGET AND PURPOSE 8
1.3 RESEARCH MOTIVATION 8
1.4 RESEARCH METHOD 9
1.5 STRUCTURE 9

2. OVERVIEW OF THE ELECTRICITY MARKETS 10

2.1 INTRODUCTION 10
2.2 THE POWER MARKET IN THE NORDIC COUNTRIES 14
2.3 NORD POOL'S FINANCIAL MARKET 19

3. FUTURES PRICING AND MARKET EFFICIENCY 25

3.1 INTRODUCTION 25
3.2 FUTURES PRICING THEORY 25
3.3 MARKET EFFICIENCY 33
3.4 LIMITS FOR ELECTRICITY CONTRACTS 36
3.5 PREVIOUS STUDIES AND CONTRIBUTION OF THE THESIS 38

4. ELECTRICITY PRICING 39

4.1 INTRODUCTION 39
4.2 LITERATURE 44
4.3 MARKET STRUCTURE AND PRICES 45

5. VOLATILITY AND UNCERTAINTY IN THE POWER MARKET 48

5.1 INTRODUCTION 48
5.2 VOLATILITY IN THE ELECTRICITY MARKETS 48
5.3 THEORY TO ESTIMATE VOLATILITY 52

6. ECONOMETRIC TOOLS TO TEST THE MARKET EFFICIENCY 55

6.1 DESCRIBING PRICE DYNAMICS 55
6.2 STATIONARITY AND UNIT ROOT TESTING 58
6.3 SEASONALITY 62
6.4 COINTEGRATION 64

7. EMPIRICAL ANALYSIS 70

7.1 DATA 70
7.2 METHODOLOGY 71
7.3 LIMITS 78
7.4 CONCLUSIONS 79

8. CONCLUSIONS 80

9. REFERENCES **82**

10. APPENDICES **85**

APPENDIX 1: ORGANISATION OF NORD POOL 85
APPENDIX 2: KEY FIGURES 2008 IN THE NORDICS 85
APPENDIX 3: ESTIMATED NET[2] CONSUMPTION OF ELECTRICITY 2008 BY CONSUMER CATEGORY 86
APPENDIX 4: BREAKDOWN BY ELECTRICITY GENERATION 2008 (%) 86
APPENDIX 5: POWER VOLUMES (EUR MILLION) 1996-2008 87
APPENDIX 6: HHI THE HERFINDAHL-HIRSCHMAN INDEX 87
APPENDIX 7: THE BERA-JARQUE NORMALITY TEST 87
APPENDIX 8: STOCHASTIC PROCESSES 88
APPENDIX 9: PRODUCT CALENDAR 90

List of figures

Figure 2.1 World electricity generations by fuel (2006-2030) in TWH 11
Figure 2.2 Monthly generation and total consumption of electricity in Norway (2007-2008) GWh. 13
Figure 2.3 Exchange of electricity 2008, GWh.. 13
Figure 2.4 Futures contracts 20
Figure 2.5 Future contract settlement.. 21
Figure 2.6 Forward contracts... 22
Figure 3.1 Development of futures* and spot prices (2007-2009) 27
Figure 3.2 Development of one week ahead futures and spot prices (2007-2009).................. 28
Figure 3.3 Representation of Normal backwardation 32
Figure 4.1 Development of weekly System and area prices in Norway (2008-2009) 40
Figure 4.2 Prices of electric energy, taxes and grid rent excluded. Øre/KWh......................... 41
Figure 4.3 Prices of electric energy for households, taxes and grid rent excluded. Øre/KWh 41
Figure 5.1 Logarithmic returns for the spot market (1999-2009) 49
Data source: Nord Pool 49
Figure 5.2 The time dependent daily volatility 49

List of tables

Table 2.1 Traded volumes in Elspot and Elbas (TWh)... 18
Table 3.1 Market concentration index in the Nordic power market 37
Table 7.1 Descriptive statistics of daily spot prices 70
Table 7.2 Descriptive statistics of weekly spot prices 70
Table 7.3 Estimation of seasonality using dummy variables 72
Daily spot prices... 72
Weekly spot prices 72
Table 7.4 ADF test for daily and weekly spot prices 74
Table 7.5 ADF test of futures contracts 75
Table 7.6 ADF test of daily spot prices 2007-2009 75
Table 7.7 ADF test of the residuals... 77
Table 7.8 ECM results.. 77

1. Introduction

1.1 Background

The electricity market in the Nordic region has experienced significant developments towards the integration of the national markets and their deregulation by opening the trading and production of electricity to competition.

Norway has been the pioneering country to start the liberalization process and to establish the Nordic power exchange Nord Pool, nowadays, considered as the oldest power exchange in the world and the most liquid of the European power exchanges.

The electricity reforms influenced many aspects of the market such as its structure and design in addition to the introduction of regulated markets to trade electricity and related financial contracts in a competitive context.

Our interest in the power market focuses particularly on the efficiency of the power exchange in the recent period where the Nordic market is supposed to be in a stable phase after it has encountered a period of energy shock during 2002 and 2003 due to shortage of precipitation.

There has been an increasing interest in the topic. Gjølberg and Johnsen (2001) have been investigating the electricity futures and price relationships at Nord Pool and providing valuable information relative to the specific nature of hydro power in the Nordic market. A recent study by Yang et al. (2009) has concluded to the efficiency of the market on its weak form through an empirical analysis on the Nordic electricity futures market.

The main objective of this thesis is to examine the efficiency of the market through the empirical analysis of Nord Pool in addition to a thorough analysis of the different factors and constraints contributing to realize or limit the competitive aspect of the market such as the market power.

The unique nature of electricity and particularly hydro power makes it more interesting to investigate the specific aspects of this market and application of the traditional financial theories on the power derivatives and electricity pricing.

1.2 Target and purpose

The targeted audience of this paper is mainly students interested in the Nordic electricity market in its different aspects: history, structure, electricity pricing and particularly to the financial aspects of the market observed at Nord Pool the Nordic power exchange.

The methods and statistical techniques used can provide useful information about the relevant tools needed to investigate economical and financial relationships; in this case related to the concept of market efficiency and price predictability through the relationship between futures and spot prices.

The results of the empirical study can provide relevant insights to the different participants in the power market in addition to researchers for further improvements and future works.

1.3 Research motivation

The rationale behind studying the Nordic Power market is to understand the factors that contributed to the success of the market liberalization in the Nordic region and particularly in Norway without dismissing the possible barriers that could prevent from reaching the aimed goals for a competitive market.

Besides, we aim to explain the probable inefficiencies that might exist in the Nordic power market and their impact on the electricity pricing either on the physical or the financial market.

Generally, electricity markets are very young markets characterized with high levels of volatility with respect to more mature ones. The fact that Nord Pool is a well established power exchange makes the relative maturity of this market a desirable attribute to study the financial data and their dynamics.

The increasing interest in trading on the financial products offered on the power exchange by the different market participants represents a genuine reason to study the efficiency of this market and the possibilities for arbitrage opportunities.

1.4 Research method

The analysis of the power exchange market is supported by an empirical analysis that covers the recent period. The market efficiency is investigated in this work by using statistical and econometric tools such as the Ordinary Least Squares (OLS), the cointegration technique and the Error Correction Model (ECM) in order to examine the electricity price dynamics and the relationship between spot and futures prices. The financial theory behind our empirical analysis relies on futures pricing theory consisting of the cost of carry hypothesis. The expectation theory will also be presented in addition to the limits of both theories in order to have a more critical view on pricing dynamics in the electricity market.

1.5 Structure

The first part of the thesis presents relevant concepts related to electricity generation and the main characteristics of the Nordic power market followed by a description of the market design in the Nordic region.

In chapter 3, theories about futures pricing and the concept of market efficiency are presented followed by a focus on electricity pricing in chapter 4. Next, the characteristics of volatility are described in chapter 5. Finally, the theory and econometric tools used in our empirical analysis and the results of the tests are presented in chapter 6 and 7.

2. Overview of the electricity markets

2.1 Introduction

Power generation has been a central preoccupation to fuel the economic and daily life. At the present day, it became a challenging issue in order to confront environmental and ecological constraints.

The recent conference about climate change organized by the United Nations in Copenhagen, December 2009 evidenced the importance of global climate policies and Greenhouse effect closely related to power generation even though the outcome of the summit has disappointed many as reported by the press room of the summit.

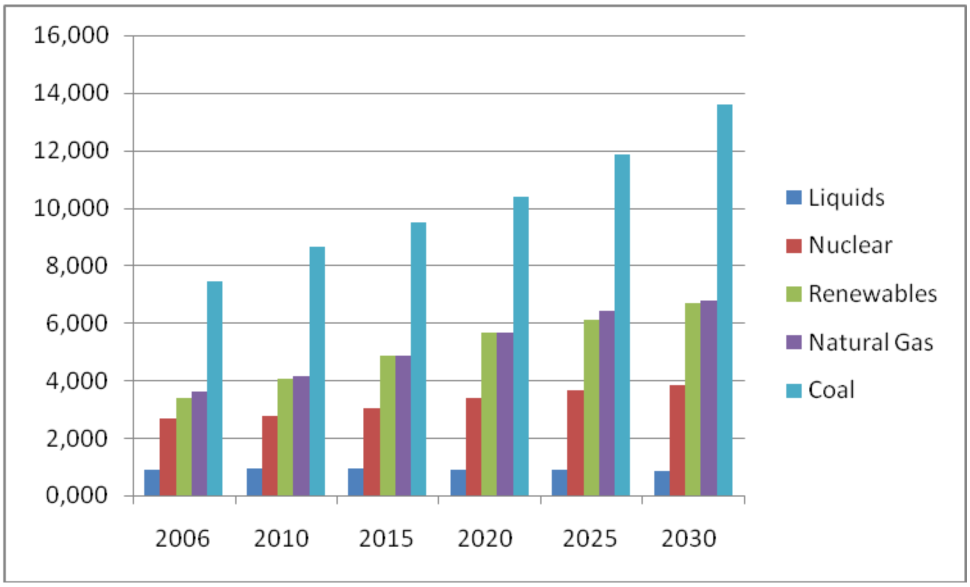
Next, we will introduce the power markets and their main characteristics in Europe and particularly in Norway.

2.1.1 Different sources of electricity generation

Electricity can be produced in different ways according to its source. Different power plants operate to generate power such as:

- Conventional Thermal Electric Power
- Hydroelectric Power
- Nuclear Electric Power
- Geothermal, Solar, Wind, and Wood and Waste Electric Power.

Figure 2.1 World electricity generations by fuel (2006-2030) in TWH



Source: EIA

From Figure 2.1, one can deduce that coal would be a prevalent and important source of energy in the future to ensure world electricity supply even if it is not consistent with the environmental conscience to produce cleaner energy.

2.1.2 Some definitions

Electricity is different from other sources of energy and fuels. It is not storable and its shipping is inefficient and costly compared to coal and oil that are easy and cheap to transport and store, while gas is still complex and costly to ship and store.

In the electricity sector, capacity is defined as the maximum output that a power generator can supply adjusted for ambient conditions. It is commonly expressed in megawatts (MW).

One should differentiate between two notions of capacity; the initial capacity and the nominal capacity.

The nominal capacity is generally used for gas turbines and combined cycle turbines and is expressed in ISO terms, i.e. a temperature of 15°C at an altitude of 0 meter above sea level.

Nominal capacity is reduced by 1% per each 1°C above 15°C and per each 100 m above sea levels. For instance, a nuclear power plant in Finland has much higher nominal capacity than the identical nuclear power plant located in Mexico.

The availability of a power plant differs depending on the source of energy. It consists of the number of hours in a calendar year when the power plant is actually generating electricity considering planned and unplanned outages.

For a hydroelectric power plant, availability is over 90% while it is lower for other types of power plants. It is approximately 80% for a nuclear power plant and between 70 and 80% for conventional thermal power plants.

2.1.3 Electricity statistics in the Nordic region

During 2008 the electricity production was 397,5 TWh in the Nordic area (Finland, Denmark, Norway and Sweden)

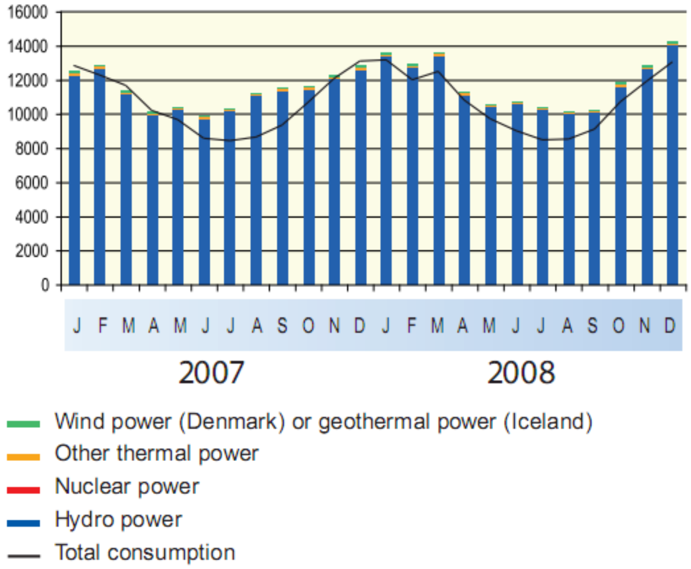
Almost 100% of Norway's power generation is based on Hydropower electricity and it amounts to 142,7 TWh for 2008. While the consumption totaled 128,9 TWh for the same year and is divided between Industry, Housing, trade and services and other sectors (including agriculture). See appendix 3.

Sweden and Finland use a combination of hydropower, nuclear power, and conventional thermal power. See Appendix 4 for the detailed breakdown by electricity generation source in the Nordics.

Hydropower stations are located mainly in northern areas, whereas thermal power prevails in the south. Denmark relies mainly on conventional thermal power, and increasing its wind power generation. The hydropower output in the Nordic region has a stochastic trend since the water flows vary significantly from season to season. It depends on the amount of water in the reservoirs. In Norway, the total water reservoir capacity for 2008 is 84 147 GWh.

The monthly generation of electricity has a seasonal pattern. It reaches its peak in the winter season.

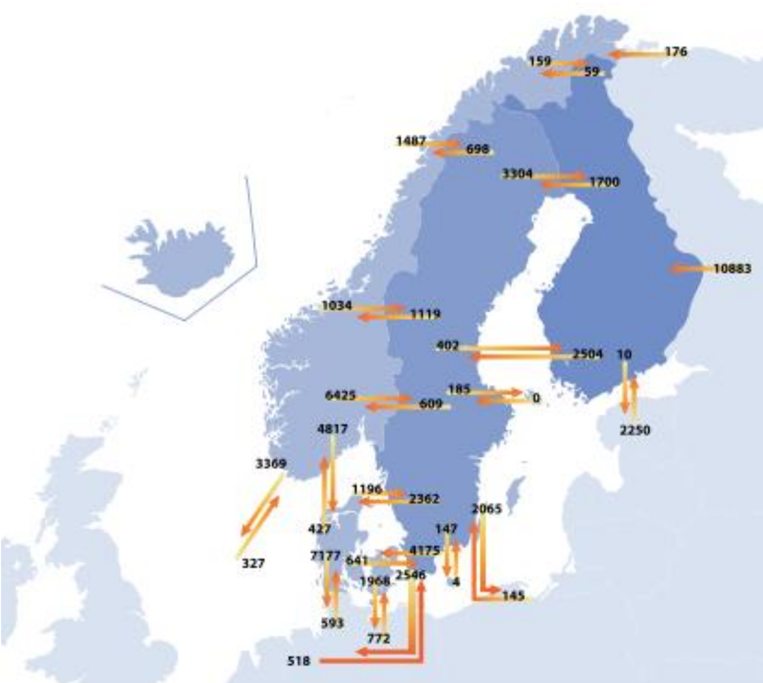
Figure 2.2 Monthly generation and total consumption of electricity in Norway (2007-2008) GWh.



Source: Nordel Annual statistics 2008

The transmission grid ensures the interconnection between the Nordic countries in order to secure the supply of electricity and the integration of the European power market. Grid networks have been strengthened through considerable investments in the Nordic transmission network rising to €600M per year. The following map illustrates the existing interconnections and the electricity exchange between the Nordic countries.

Figure 2.3 Exchange of electricity 2008, GWh



Source: Nordel Annual statistics 2008

2.2 The power market in the Nordic countries

Norway was the leading country to deregulate its electricity market. The rest of the Nordic countries followed the liberalization process to improve the performance, supply reliability and the economical efficiency of the sector based on the Energy Act of 1990. The market reform aimed also to improve the balance between power generation capacity and demand in addition to harmonize electricity prices across regions.

2.2.1 History

The structure and organisation of the electricity market in Norway before the liberalisation of the market was characterized by the dominance of state owned entities who accounted for about 85% of the electricity system and vertical integration between electricity production and the transmission grid as stressed by Hope et al. (1992).

Generally, the distribution of power was negotiated through long term bilateral and non standardized contracts. The lack of flexibility in the market represented some constraints to the market participants as Prices and important terms for the functioning of the market were set by administrative or political decrees.

A development of a market for occasional power (1972) was necessary to manage the variable hydropower generation. It included spot transactions on expected excess demand and supply not included in contracts. This step contributed significantly to prepare Norwegian market participants to the deregulation in 1991.

During the nineties, the power market was moving toward an integrated Nordic market through;

- First the separation of monopolistic and competitive activities or in other terms the transmission grid activities and power production, In Norway, Statkraft has been the national company responsible for the electricity generation while Statnett was the TSO responsible for monitoring and operating the transmission network locally and with the other countries. Second, the market was liberalised for third-party access.

- Sweden followed by opening the market for competition to new participants in 1996. Nord Pool ASA was developed as a Norwegian-Swedish power exchange, the world's first multinational exchange for trade in power contracts.

- Finland founded its electricity exchange EL-EX in 1996, merged its two grid companies into one national grid company “Fingrid”. It joined the Nordic power exchange market area in 1998.

- Denmark joined the power exchange by opening its trade in 1999 first through western Denmark (Jutland/Funen) and then Eastern Denmark in 2000.

The year 1993 was marked by the opening of the forward market (Statnett Marked AS).

During the last years, Nord pool, the Nordic power exchange, developed its activities in Germany and Netherland. It has recently merged with Nasdaq OMX commodities in order to expand its trading opportunities in the European power market.

Norway also joined the Elbas, the intra-day market, on March 2009 to secure cross-border intra-day trading between Norway and the other Nordic countries and Germany. (Nord Pool website)

2.2.2 Market design

The Norwegian power system is constituted of the following basic parts:

- **Power generators**: Statkraft the state-owned company represents the dominant player by providing around 35% of power consumption in Norway as stated in its latest annual report.

- **Transmission grid** controlled and operated by the TSO’s (Transmission system operators). In Norway, The TSO is the state-owned grid company Statnett SF.

- **Regulators** whose responsibilities include providing guidelines for the grid owners. (NCA the Norwegian competition Authority and the NVE (Norwegian Water Resources and Energy Directorate);

- **The power exchange** is an important element to ensure physical and financial trading of power ;
- **The market participants.**

The different roles in the Nordic power market:

Power generators: The supply of electricity is secured by large regional power companies established through mergers and acquisitions among local state-owned entities.

Statkraft remains the leading power producer in Norway who's continuously expanding through mergers and acquisitions.

a) The grid owners are monopolies monitored by appropriate regulatory bodies. Their main responsibilities include building, operating and maintaining the grid, setting grid transmission tariffs and connecting customers to the grid.

TSO (Transmission system operator): (Statnett, Svenska Kraftnat, Fingrid, Nord pool ASA, Eltra and Elkraft).

The TSO's are responsible for the management of imbalances and unpredictable events during real time system operations.

It manages the short term market for production capacity and is responsible for balancing supply and demand

c) The regulators are responsible for determining guidelines and by-laws for monopolies in the power market. In general, the regulatory regime is closely related to the grid owners' activities. It covers issues such as cost recovery through network tariffs, monitoring costs and profits and settlement of disputes.

d) The power exchange is the market place for trade in electricity. It includes the following basic functions:

- A market to trade electricity spot,

- Markets for risk hedging through derivatives trading,

- Markets for trade in environmental energy products,

- Clearing services.

The core responsibilities of the power exchange include providing a price reference to the power market, operating the spot market and an organised market for financial products. It also uses the available capacity in an optimal way in the spot market to alleviate grid congestion.

e) The market participants in the power exchange market are operators in the wholesale and/or retail market. They can be categorized as follows:

- Generators operate both in the wholesale market and power exchange market. They use the spot market to balance their generation schedules.

- Retailers serve directly end-users by utilizing their own generation or by purchasing power on the wholesale market.

- End-users may operate in the wholesale market if they have large power volume requirements. Small scale end-users are served by retailers.

- Traders operate in both physical and financial markets and trade to take advantage from price differences and volatility. Hence, all market participants are considered as traders in that sense. They can have hedging or speculative purposes from trading activities.

2.2.3 Organisation of Nord pool

Nord Pool provides the necessary market places for trading physical and financial contracts and the related following services:

a) A spot market for physical trading (Nord Pool Spot SA). More than 70 per cent of the total value of the Nordic region's power consumption is traded in the physical market.

NPS comprises two different markets:

- Elspot is the day-ahead market which provides physical electricity with next day delivery. Trading is based on an auction trade system where buyers and sellers bid for hourly power contracts that cover the 24 hours of the next days.

There exist three bidding types at Elspot: the hourly bids, block bids and flexible hourly bids.

For each power-delivery hour, the spot price is calculated by balancing the aggregate demand and supply of all the bidders. It is called the system price.

Insufficient transmission capacity or potential grid congestion is handled at the spot market and the flow of power across the interconnectors is adjusted by establishing different area prices so the grid congestions are alleviated.

Table 2.1 Traded volumes in Elspot and Elbas (TWh)

	2007	2008
Elspot	290,6	297,6
Elbas	1,6	1,8

- Elbas secures the physical balance adjustments in the Nordic and German power markets. It provides continuous intra-day trading within and across borders. It contributes to reduce the risk of the balancing market since the price is known prior to the hour of delivery rather than afterwards.

Trading is operated through a web based trading system 2 hours after day-ahead and 1 hour prior to delivery.

Elbas provides a substantial spread and possibilities to make profits thanks to better prices and a large selection of counterparts.

Table 2.1 shows the traded volumes in each market.

b) A financial derivatives market trading in standardized contracts wholly owned by Nord Pool ASA.

Contracts are of up to six years' duration. They include contracts for days, weeks, months, quarters and years.

c) Clearing services for financial electricity services (Nord Pool Clearing ASA) acquired by NASDAQ OMX.

d) Consulting services specialized in the development of power markets (Nord Pool Consulting AS) now owned by NASDAQ OMX.

See Appendix 1 for a formal description of Nord Pool organisation.

2.3 Nord Pool's financial market

The financial market helps the different participants to handle the risks related to price fluctuations in the physical markets and hedge their positions through the financial products offered by Nord Pool ASA.

Trading at the financial market is also important to provide the necessary liquidity to the market.

The volume traded in financial contracts is about four time's physical load (not including non-cleared financial contracts). Considering that the total generation in the Nordic power exchange is about 400 TWh per year. (Nord Pool Annual report 2008)

Nord Pool's clearing enters into contracts as a counterpart and takes responsibility for the future settlements of the financial contracts through Nord Pool or the OTC market. It reduces the financial risk for exchange members and ensures the effective settlement of the contracts.

The total volume of financial contracts traded at Nord Pool ASA rose from 1 060 to 1 406.5 TWh (excluding international contracts), an increase of 32.7 % from 2007 to 2008[1], and an increase in the number of transactions by 46% from 108 631 to 158 814. At the same year, the volume traded on the financial exchange was larger than through OTC brokers. The power exchange was attributed 55.5% of the total cleared volume of Nordic power.

Market concentration

There is an observed trend towards declining market concentration for Nordic power over the past few years. No member accounted for more than 8% of the total exchange-traded volume in 2008. Similarly, the number of members accounting for 80 % of total turnover increased to 31 in 2008.

[1] Nord Pool ASA annual report 2008

2.3.1 The financial contracts

The financial contracts traded at Nord Pool comprise:

a) Power Financial derivatives:

The contracts are peak and base load derivatives with the system price as a reference price and a maximum trading horizon of six years. There is no physical delivery but only financial settlement.

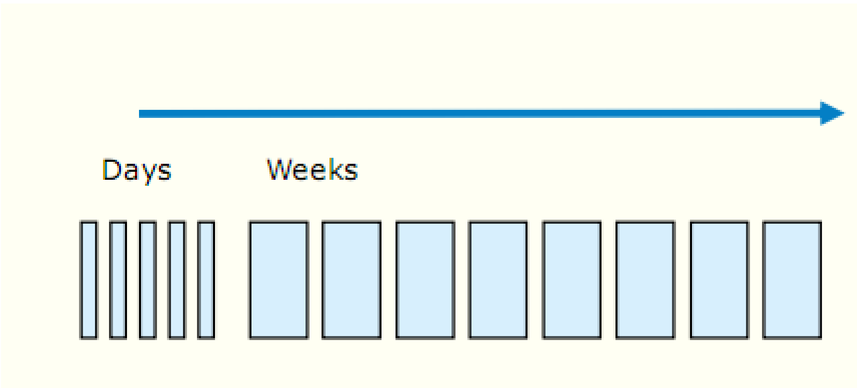
Producers, retailers and end-users use the financial products as risk management tools.

While traders would profit from volatility in the power market, and contribute to a high liquidity and active trade activity.

The derivatives comprise:

➢ Futures: Defined as an agreement between two parties to buy or sell a given asset at a certain time in the future for a specified price. They are normally traded on the exchange through standardized contracts.

Figure 2.4 Futures contracts

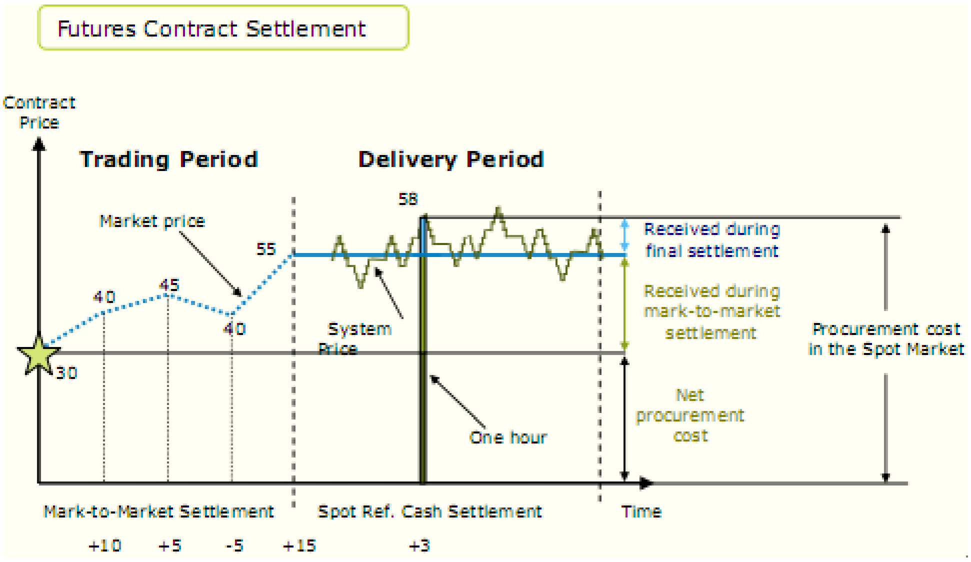


The Nordic week contracts are listed with 8 consecutive contracts, in a continuous rolling cycle. Simultaneously, the block futures contracts where replaced with forward month contracts. In 2005, Nord Pool reduced the number of weeks from 8 to 6 to focus liquidity.

Settlement of futures contracts requires a daily mark-to-market settlement and a final cash settlement based on the spot price at the maturity date. Final settlement starting maturity covers the difference between the final closing price of the futures contract and the System Price in the delivery period.

At Nord Pool, day and week futures contracts are listed

Figure 2.5 Future contract settlement



Source: Nord Pool

➢ Forwards: It is defined as an agreement to buy or sell a given asset at a certain time in the future for a specified price exactly like futures contracts but there are some differences:

Forwards are usually traded on the OTC market.

In the trading period prior to maturity, there is no daily mark-to market settlement, only daily margin call.

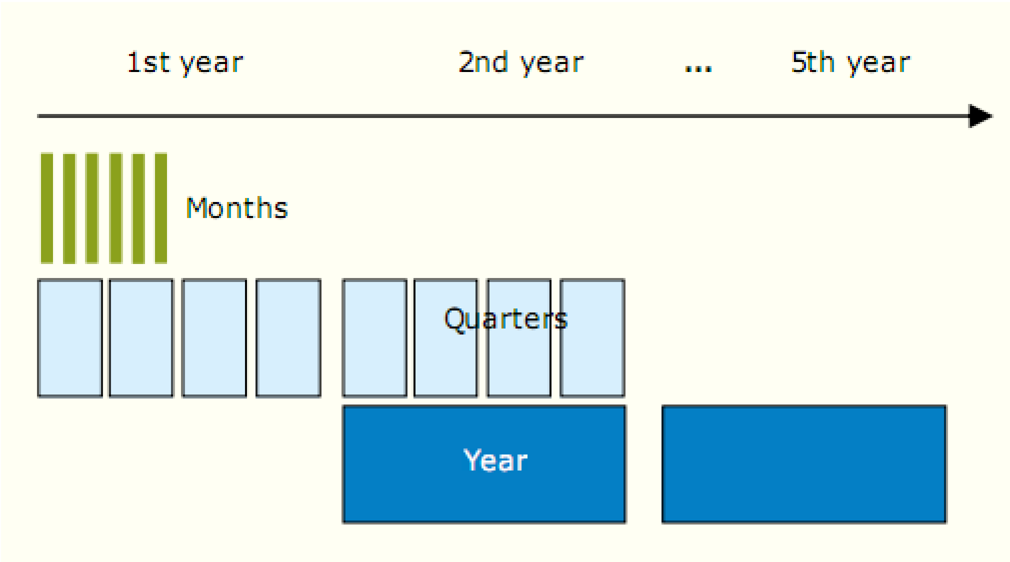
Holding a forward contract requires considerable up-front cash collateral.

The new product structure lists base load contracts for calendar months, quarters replacing seasons from 2004 and year contracts.

Peak contracts were introduced in 2007 by listing the nearest five weeks for trading.

As depicted in Figure 2.5, the Nordic Month contracts are listed on a 6 month continuous rolling basis, and are not subject to splitting. Quarters are split into month contracts. Year contracts are split into quarter contracts in accordance with product specification rules.

Figure 2.6 Forward contracts



Source: Nord Pool

The market seems to prefer short-term futures close to due date and the nearest quarter and year forwards. The main reason for this preference is the different margin calls for futures and forward contracts and the high liquidity. Financial settlement of futures requires a large amount of cash in pledged/non-pledged cash accounts due to the daily mark-to-market settlement, especially for the long period contracts at the far end of the time horizon.

➢ Options: It is defined as the right and not the obligation to buy or sell an underlying asset or contract at a specified price called strike at a certain date in the future.

The holder of a call option has the right to buy the underlying asset while the holder of a put has the right to sell.

At Nord Pool, options are European which means that they can only be exercised at the maturity. They are traded on forward contracts (quarters and year forward contracts) as the underlying contract. The strike is based on the closing price of the forward.

Another characteristic of options is the premium which represents the price to pay for the option. It is listed in EUR/MWh and the size of an option contract is calculated by multiplying the number of MW by the number of hours in the underlying contract.

➢ Contracts for difference: These contracts were introduced to allow hedging against the price area risk resulting from different area prices determined by the TSO’s in order to solve the capacity constraints in the transmission network.

Forwards and futures contracts cannot hedge against this risk since they doesn't take into account transmission grid congestions.

A CfD is a forward contract with reference to the difference between the Area Price and the Nord Pool Spot System Price. The market price of a CfD during the trading period reflects the market's prediction of the price difference during the delivery period. The CfD can be positive when expectations of the area prices are higher than the system price or negative in the opposite case.

The combination of these financial products can offer to the market participants valuable hedging strategies and efficient tools to manage the risk related to power trading.

b) European Union Allowances (EUAs): One EUA entitles the holder to emit one tonne of carbon dioxide or carbon-equivalent greenhouse gas. Nord Pool was the first exchange to list EUAs as standardized exchange contracts.

c) Certified emission reductions (CERs): Emission credits are obtained through the clean development mechanism such that a reduction corresponds to one tonne of carbon dioxide or carbon-equivalent greenhouse gas in a developing country.

In June 2007 Nord Pool was the pioneer exchange to offer trading global carbon contracts CERs through the Green Development Mechanism, organized by UN.

The contracts listed for carbon emissions are spot and forwards with physical delivery.

2.3.2 OTC versus regulated power exchange

The organised power exchange allows for better transparency in prices and offer reliable price reference for the future.

In addition the clearing services eliminate the counterparty risk by taking the responsibility of the effective financial settlement of the contracts traded through the power exchange or the OTC market.

While in the bilateral market, there is a lack of information about the overall position.

The over-the-counter market is an alternative to the power exchange where trades are done through telephone or the web network.

Volumes of trading in the OTC market are generally much larger than volumes in the regulated exchange. Almost 25% of the total contracts are traded on Nord Pool and the rest is handled by the bilateral market. The main characteristic in the OTC markets is that the contracts terms are not standardized but there is a predominant counterparty and credit risk that can be resolved by using a clearing house services.

The presence of a regulated power market is a crucial element in establishing competitive and efficient trading in electricity. The main question that we aim to answer in this thesis is to investigate its efficiency by exploring the various factors involved in the electricity pricing. In the next chapter, the theories of futures pricing will be presented in addition to their limits.

3. Futures pricing and market efficiency

3.1 Introduction

Considerable number of studies has been conducted to analyze the different functioning mechanisms of the financial markets, the hedging strategies and the various uses of financial instruments and derivatives and has provided a relevant theoretical background and useful tools for the market participants from the policy makers to the power producers, the financial institutions, speculators and etc…

To better understand the dynamics and roles of the financial instruments in the power market, we will review the main theories addressing forward and futures pricing in the first part of this section. It will constitute the theoretical background on which the empirical analysis will be built. In the second part of this section, we will approach the market efficiency concept and examines the results of relevant empirical studies in certain commodity and electricity markets and evidently previous studies on Nord Pool.

3.2 Futures pricing Theory

Two streams of theories about the pricing of forward and futures contracts have been developed in the literature. According to Fama and French (1987), the first theory consists of the cost of carry hypothesis also known as the theory of storage. It was first introduced by Kaldor (1939) then developed by several academics and practitioners (working (1948, 1949), Brennan (1958), Telser (1958), Deaton and Laroque (1992).

The second theory is based on the risk premium hypothesis or the expectation theory discussed in Hicks (1939).

First, in our pricing analysis, futures and forwards will be treated as equivalent even though there are some differences:

Futures contracts in the power market are traded more actively than the forward contracts mainly used in the OTC market. Futures are standardized contracts for a given quantity of power at a certain price in a specified time period while the forward contracts are usually non standardized. As mentioned previously, the settlement of futures contracts is realized daily on a market-to-market basis by a brokerage house and thus requires a significant cash commitment up-front whereas forwards settlement is realized at maturity and requires cash collateral only during the delivery period.

The futures markets play important roles such as hedging and price discovery. The classic economic rationale for using forward and futures contracts is to hedge against the price risk related to trading, particularly imminent in the electricity market characterized by high volatility. Furthermore, the different players on the market can use forward and futures prices in a price discovery process as an indication of price expectations and the economical trend in the short run.

3.2.1 Importance of futures market

The volume of trade on the financial market has increased of 32.7% from 2007 to 2008 with a rising number of transactions from 108 631 to 158 814 (Nord Pool ASA annual report 2008). See appendix 5 describing the increasing trend in power volumes.

The considerable trading activities in the futures market relatively to the spot market are important to ensure the market liquidity and its efficiency. In addition to providing the financial instruments needed to manage and hedge the price risk, an important role of the futures market is the price discovery function as pointed out by Garbade and Silber (1983). It provides information about the market anticipation of the future value. It consists of setting a reference price namely the futures price from which the spot price can be derived.

Futures' trading for a certain commodity also contributes to facilitate the allocation of supply and demand over time. It provides the market with indications about holding inventories. An illustration of this role can be seen in the following example;

Let's assume that we have two futures contracts with different maturities and consequently different prices. If the price of the contract with the larger time to maturity have a higher price than the contract with the early maturity, then postponement of the consumption for the given commodity is more attractive. We can observe then a correlation between the futures and spot prices resulting from the variation in the demand for the commodity.

In the Nordic electricity market mainly based on hydropower, futures market have the same role as it gives a price reference for the power market and anticipates the future value of water. There is an arbitrage mechanism between producing power today or in a later period. If the futures prices are higher than the current prices it is more sensible to store water for production at a later date when the prices will be higher. While lower production today would increase the spot prices and larger production volumes in the future would reduce the future prices. The optimization process goes on until there are no more arbitrage opportunities.

There is still a difference between the futures and spot prices due to uncertainty and a forgone expected rate of return from investing in storing water in addition to marginal cost for storing water (Gjølberg et al (2003)).

The relationship between futures and spot prices can be formalized as follows:

$F_{t,T} = (1+r_{t,T})\ S_t + w_{t,T} + \varepsilon_t$

where $F_{t,T}$ is the futures price at time t with maturity T,

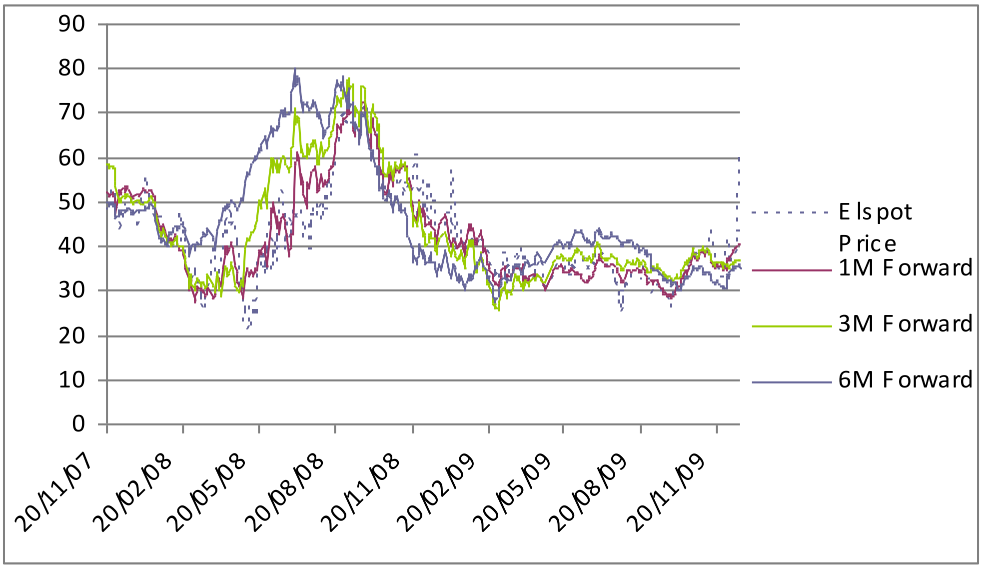
r_t the interest rate over the period T-t,

S_t the spot price,

w_t the storage cost over the period T-t,

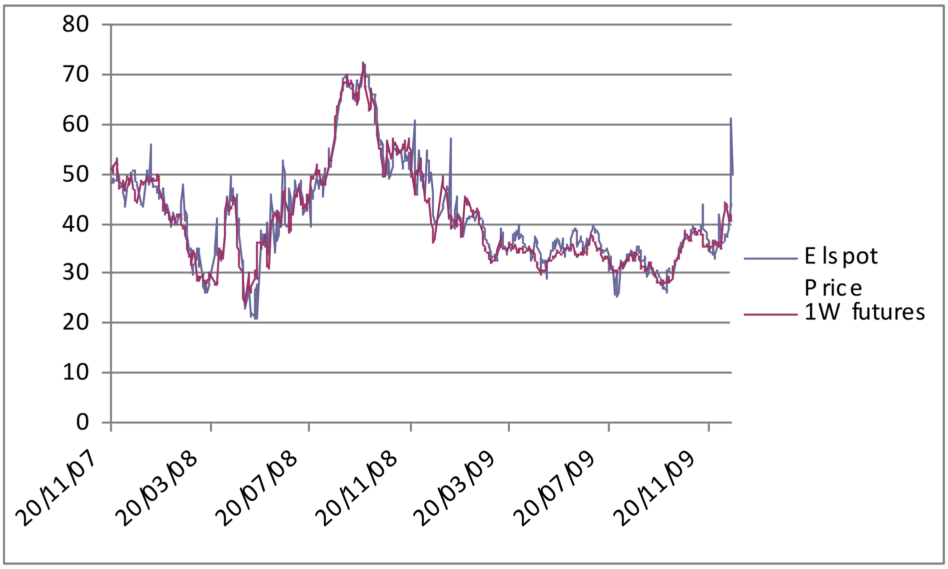
ε_t is the uncertainty factor.

Figure 3.1 Development of futures* and spot prices (2007-2009)



Source: Bloomberg data, Nord Pool
*1 month, 3 months and 6 months ahead futures contracts

Figure 3.2 Development of one week ahead futures and spot prices (2007-2009)



Source: Bloomberg data, Nord Pool

As can be observed from figure 3.1 and 3.2, the short term futures represented by futures contract for delivery the next week follow closely the spot prices while the one, three and six months ahead forward contracts show some deviations from the spot price which indicates lower prediction ability for spot prices. The longer is the time to maturity, the larger is the deviation from the spot prices. Spot prices seem to underestimate the forward price during the first nine months of 2008. The forward prices are higher when the time to maturity is longer (It is a contango[2] situation describing an upward sloping forward curve). Forward prices are overestimated during the next period until the spring of 2009 (backwardation). From April to October 2009, futures prices are higher again than spot prices and lower during the winter period.

Possible explanations of higher futures prices than the actual spot prices would be expectations of higher demand in the future and a negative risk premium for holding the futures contract.

Frequent switching from contango to backwardation and vice versa indicates the uncertainty of the market participants about the direction that the spot prices would follow.

[2] It describes an upward sloping forward curve with time to maturity, while backwardation describes a downward sloping forward curve.

3.2.2 Theories

Several studies have contributed to analyze the pricing of these contracts either for commodities, foreign currency, indices or interest-earning assets. The recognized literature developed in this field has formulated possible appropriate models to explain relationships between the forward and spot prices.

According to Fama and French (1987), there are two popular theories of forward and futures pricing, namely the cost of carry and the risk premium or unbiased expectations hypothesis.

a) The cost of carry hypothesis

First introduced by Kaldor (1939), the cost of carry hypothesis or the theory of storage has captured a high interest in the classical literature. Working (1948), Brennan (1958), Tesler (1958), and many others have contributed to extend the knowledge of this model and the no-arbitrage argument underlying it.

Fama and French (1987) explains the theory of storage as the difference between contemporaneous spot and futures prices in terms of three elements: the interest forgone in storing the given commodity; the different storage costs such as warehousing costs and a convenience yield from holding inventory.

This approach for pricing futures contracts considers the no-arbitrage hypothesis such that an investor can synthesize a forward contract by taking a long position in the underlying asset and holding it until the contract expiration date. If the forward price does not equal the price of the replicating portfolio, then arbitrage profits are possible. Thus, the forward price is linked directly to the current spot price.

The model[3] explains the difference between the current spot price and futures price as being due to the following factors:

-interest forgone in storing the commodity

-warehousing costs

-a convenience yield from holding inventory

[3] Chow et al (2000)

In other words, the futures price is equal to the spot price plus the carrying cost that could include the interest charges, insurance, warehousing rent and etc.

If the futures price is lower, the arbitrageur holding the commodity in inventory could sell it on the spot market and buy the futures contract and thus making risk profits.

An illustrative strategy of the no-arbitrage hypothesis in commodity trading would be the following:

There are two options in an arbitrage strategy:

1- Buying a futures contract at time t_0 and sell it at the future spot price at t_1 generating a cash flow of $S_1 – F_1$

2- Buying the commodity at t_0 and storing it to the end of selling it at the future spot price at t_1.

The cash flow would be $S_1 - S_0 (1+r) – W$

where r is the risk free interest rate and W is the storage cost during the period.

At the equilibrium, both cash flows are equalized as follows:

$F_1= S_0 (1+r) + W$

The convenience yield used also to explain the difference between the forward and the future spot price is an important concept in this approach.

Due to high volatility or irregular market movements, the holding of an underlying commodity or security may become more profitable than owning the contract or derivative instrument because of its relative scarcity versus high demand. It can be linked to a liquidity premium.

The equilibrium equation would be then the following:

$F_1= S_0 (1+r) + W- C$ where C is the convenience yield over the storage period.

A standardized formula is the following which is commonly used for empirical studies:

$F_{t,T}= S_t e^{(r-s)(T-t)}$

where $F_{t,T}$ is the futures price at time t for delivery in T, S_t is the spot price at time t, r is a constant interest rate and s is the convenience yield.

b) The Risk premium hypothesis

The second general approach used in the literature to model forward prices considers the futures price as the expected future spot price plus an expected risk premium. Earlier studies on this approach include Keynes (1930), Hicks (1939), Cootner (1960), Breeden (1980, 1984) and etc. Most of these studies addressed the implications for the relation between forward and expected spot prices. In particular, this literature has traditionally focused on what is termed the forward premium. Often, the forward premium is defined as the difference between the forward price and the expected spot price.

The expectation hypothesis relies on two key elements to explain the relationship between the futures price and the spot price: The expectations of future spot prices formulated by the economic players and the impact of risk aversion of the market participants in order to hedge their positions.

Normal backwardation theory

First, the theory of hedging and returns to speculators as the result of Keynes (1930) and Hicks (1939) works, is based on the normal backwardation theory.

In this situation, hedgers have net positions in the market, for instance a short position while speculators have long positions then the futures price is lower than the expected spot price because of the risk compensation required by the speculators. On the other hand hedgers will reduce risk. In the opposite situation where speculators have short positions and hedgers have long positions, the same reasoning applies and the futures price would be higher than the expected spot price.

In order to better understand this theory we will define some useful concepts closely related to commodity price movements and the market conditions.

Backwardation:

It is the situation when the futures price is below the expected spot price. When $F<E(S)$, it is appealing for speculators who are "net long" in their positions: they want the futures price to increase. Hence backwardation occurs when the futures prices are increasing.

Normal backwardation:

Backwardation in futures contracts was called "normal backwardation" by Keynes because he believed that a price movement like the one suggested by backwardation was not random but consistent with the prevailing market conditions.

Contango:

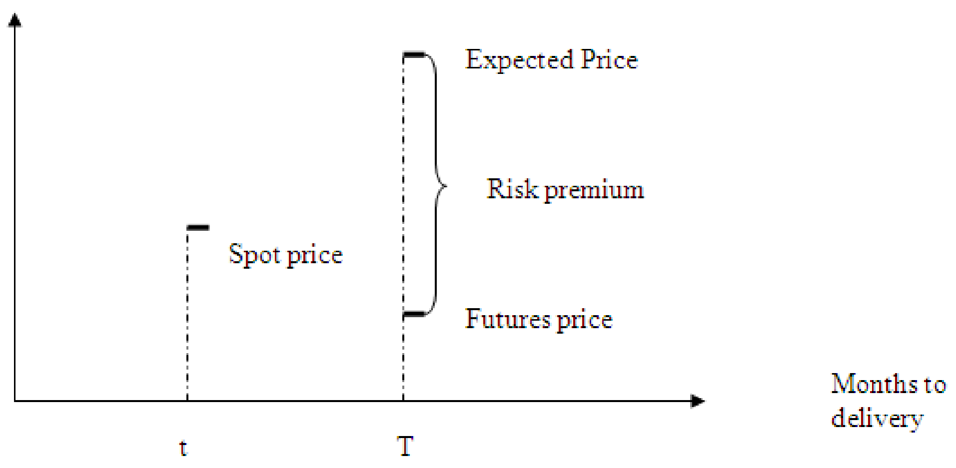
It is the opposite market condition of Backwardation. There is a situation of Contango when the futures price is above the expected spot price (F> E(S)). Since the futures price must converge to the expected future spot price, contango implies that futures prices are falling over time as new information brings them into line with the expected future spot price.

It is also worth noting that these concepts are used to refer to the position of futures prices with respect to the current spot prices rather than the expected future spot prices.

The theory of normal backwardation argued by Keynes (1930) tells us that “the spot price must exceed the forward price by the amount which the producer is ready to sacrifice in order to hedge himself, i.e. to avoid the risk of price fluctuations during this production period. Thus, in normal conditions the spot price exceeds the forward price and there is a backwardation.”

The following diagram from Geman (2005) describes the theory of normal backwardation:

Figure 3.3 Representation of Normal backwardation



Contango or backwardation cannot define a tendency in the market conditions and the price movements. As observed in the historical information about futures price development illustrated in figure 3.1, there is a frequent change from contango situation to backwardation in the electricity market during a short period from 2007 to 2009 and the situation could change from one day to another, however it seems to us that these changes are cyclical but we cannot conclude anything about it using such a short period of time.

Limits:

Electricity unlike other commodities is difficult to store. Therefore, the cost of carry theory may not describe accurately the price behaviour of electricity futures. For this reason, the theory might be inapplicable. However hydropower can be considered as a storable commodity by storing water in the reservoirs. In addition, gas can also be stored as proved in Statoil's project Aldbrough.

Electricity prices are characterized by seasonality and frequent spikes which exclude the mathematical reasoning of the storage model.

It might be more appropriate to use the risk premium theory to describe the relationship between spot and futures prices.

3.3 Market efficiency

The main theoretical background for market efficiency, initially applied to stock markets and then generalized to other markets, was introduced by Fama (1970).

The efficiency hypothesis is basically assuming that the market is functioning such that no excessive or abnormal returns are possible using readily available information. In other words, there is no privileged information that could contribute to make profits on the market. The large number of rational profit maximizing participants in an efficient market is supposed to use the available information for their forecasting in order to have a fair market assessment.

According to Fama (1970) on capital market efficiency, there is efficiency when the marginal profit of information is offset by its marginal cost.

We can identify three consequences resulting from the efficient market hypothesis (EMH):

First, there is a random fluctuation of prices with arrival of new information and the only price changes that can occur are the ones that result from new information. In addition, the new information is reflected in the movements of both spot and futures prices. Hence, spot and forward prices are expected to be highly correlated and move in the same direction. This related property of the efficient market hypothesis is of relevant importance as the forward prices can be seen as the best predictor of the next period price.

Second, efficiency implies the unpredictability of prices using the past data. Therefore, the market participants cannot forecast the future spot prices according to the behaviour of the current and past spot prices. It is therefore worth stressing that the behaviour of spot prices cannot be autoregressive[4].

Third, Forecast errors cannot be correlated since the market players would correct their errors from period to period. This means that if the investor has overestimated or underestimated the prices he will not repeat the same behaviour in the next period.

Fama has distinguished in his works three levels of market efficiency:

Weak, Semi strong and strong efficiency forms based on the form of information available to the investors which is reflected in the prices.

Weak efficiency:

Under the weak form of efficiency, the current price reflects the information contained in all past prices namely historical information. The new information must by definition be unrelated to previous information. In consequence, the movements of prices in response to new information cannot be predicted from the last movements of price. The development of the price assumes the characteristics of the random walk suggesting that charts and technical analyses that use past prices alone would not be useful in finding under-valued stocks and the future price cannot be predicted from a study of historic prices.

If a market is weak-form efficient, there is no correlation between successive prices, so that excess returns cannot consistently be achieved through the study of past price movements. This kind of study called *technical* or *chart* analysis, because it is based on the study of past price patterns without regard to any further background information.

The main feature of the weak form of market efficiency is that futures price is an unbiased estimator of future spot prices and is based on past events and past price movements.

[4] Autoregressive process is defined in Appendix 8.

Semi strong efficiency:

Under semi-strong form efficiency, the current prices reflect the information contained not only in past prices but all public information (including financial statements and news reports) relating either to past or expected events.

The EMH suggests that a market is efficient if all relevant publicly available information is quickly reflected in the market price by moving the price to a new equilibrium level that reflects the change in supply and demand caused by the emergence of that information. One problem with the semi-strong form lies with the identification of ‘relevant publicly available information

Strong efficiency:

In its strongest form, the EMH suggests that a market is efficient if all information whether or not public and generally available to existing or potential investors, is quickly reflected in the market price. The strong form of efficiency is the most compelling form of EMH in a theoretical sense, but it is difficult to confirm empirically.

If a market is strong-form efficient, the current market price is the best available unbiased predictor of a fair price, having regard to all relevant information, whether the information is in the public domain or the private one. As we have seen, this implies that excess returns cannot consistently be achieved even by trading on inside information.

Testing method:

The approach we are going to explore in analyzing the market efficiency uses the properties of forward and spot prices as moving in the same direction in response to new information. In this method, it is very important to bring to attention the statistical and stochastic characteristics of the series used in testing the market efficiency.

The spot and futures prices series have some properties that we are going to address carefully in chapter 5 and 6 in order to perform accurately our statistical tests and avoid spurious results.

3.4 Limits for electricity contracts

Electric power has unique characteristics that differ significantly from other traditional commodities. For instance, there is the necessity of an exact match of supply and demand which is amplified by electricity being virtually a non-storable commodity. This making the cost of carry model not efficiently applicable to electricity forward prices. Nevertheless, this approach is used in the literature (see e.g. Clewlow and Strickland (2000), Stoft et al. (1998) on arbitrage pricing of electricity futures).

Limited storing capacity represents an issue for hydropower producers who want to optimize the value of water inflow over time. In fact, the short term storing capacity that secures the transfer of water from one period to another is not sufficient. The result would be a distortion in the relationship between the future and the current price.

Uncertainty about inflow results from fluctuation in the water inflow and temperature changes that will affect the stability of demand. For the Norwegian hydropower reservoirs, the 90% confidence interval for annual inflow is 90-145 TWh in 2002. During the first 6 months of 2009, the inflow amounted to 51 TWh which was 14 TWh less than the previous year due to less snow in the mountains (Source: Statnett).

Limited production capacities can represent a constraint to sufficiently satisfy the demand. A maximum and minimum water flow is set to regulate the operating of a hydropower plant. To secure a balance between supply and demand, price differences will be implied over time and in different places.

Concentrated suppliers and market imperfections can lead to market power. According to Bye, Fehr, Riis and Sorgaard (2003), it is not significant in the Norwegian electricity market even though the several mergers and acquisitions[5] and cross-ownership suggests possible increase in market power that was closely followed by the NCA to avoid any abuse of market power.

In fact, Statkraft is considered as the most important supplier of power to industry in Norway with a total production capacity of 59.9 TWh in 2009 (Statkraft website).

[5] Statkraft acquisition of Agder energi a hydropower producer located in Kristiansand.
Takeover of Trondheim Energiverk by Statkraft in 2005.

Table 3.1 Market concentration index in the Nordic power market

	HHI	+ incentives	+ control
Norway	0,1634	0,1980	0,3325
Sweden	0,2893	0,2923	0,2988
Finland	0,1766	0,2037	0,3005
Nordic	0,0892	0,0989	0,1138

Source: Nordic competition authorities (2003)

HHI is the Hirschmann-Herfindahl concentration index based on direct ownership as reported by Bye et al. (2003) which is a traditional measure of market concentration. (See appendix 6 for a detailed definition of the index)

The second index includes incentive-based cross ownership, while the third one incorporates control for demand according to ownership share in addition to incentive-based cross-ownership.

According to table 3.1, Norway is considered as a non concentrated market with HHI equal to (0,163), however if the cross-ownership is included, the Norwegian market is relatively concentrated with an index of 0,332.

The market power is still a preoccupation of the Norwegian government and competition authorities.

Transmission constraints can arise between countries or across regions due to different production technologies and marginal costs which results in different prices in time and space and affects production strategies.

As suggested by Kittelsen (1993, 1994) and Forsund and Kittelsen (1998), testing for cost inefficiencies of the transmission networks resulted in an estimation of total efficiency losses between 0,16 and 0,27 billion USD which represents 25% of the annual resources used for electricity distribution.

The absence of these constraints ensures equal prices for electricity in space and time which is not the case in reality.

All these factors could explain a limited efficiency of trading in the Nordic power exchange which can help us understand the results of the empirical analysis based on the cost of carry theory.

The constraints to market efficiency are closely related to the nature of electricity. Therefore, a detailed description of electricity pricing in the Nordic region is necessary.

3.5 Previous studies and contribution of the thesis

There has been extensive interest in studying the commodity markets and their efficiency particularly in the oil and gas sector. One of the reasons underlying it would be the maturity of the markets and the availability of data. Regarding the power industry and particularly the Nordic market, the empirical studies of market efficiency are limited and mostly cover the period following the establishment of the power exchange such as Havn (1995) and Fløtre (1996) which confirmed the efficiency hypothesis. These studies are not very conclusive due to the low amount of data.

Gjølberg and Johnsen (2001) concluded that the market is not mature enough and tend to be inefficient. Deng (2006) has used cointegration tests to investigate the market efficiency at Nord Pool from 1995 to 2002 and rejects the market efficiency hypothesis based on the random walk theory.

The contribution of our thesis is to investigate the market efficiency of Nord Pool during the recent period from 2007 to 2009 in addition to a comprehensive overview of different previous periods by testing the stationarity of the data and the predictability of the spot prices which gives reliable results thanks to the extensive amount of data from 1999 to 2009.

Our analysis of the factors behind reaching a competitive and efficient market such as reliable regulations, the market concentration and structure in addition to the characteristics of hydro power would clarify the theoretical and economical reasoning behind confirming or rejecting the efficiency hypothesis.

4. Electricity pricing

Electricity has different characteristics than other commodities with respect to its storability and transport. Considered as a flow, it is difficult to store unlike oil and is complex to transport.

Consequently, the assumptions of the storage theory are not realistically applicable on pricing electricity forwards. Lucia and Schwartz (2001) confirms that the nature of electricity as a non storable commodity set some limitations to arbitrage and trading possibilities and hence to the application of the cost of carry hypothesis to effectively price derivatives contracts.

On the other hand, the Norwegian power market relies on Hydropower generation. Water, the principal source of energy production in Norway and the Nordic area[6], can be stored in the reservoirs; therefore suppliers have the possibility to store electricity. However, retailers and end-users cannot profit from this flexibility since they cannot store the flow of electricity after it is produced.

In this chapter we will first present the pricing mechanisms at Nord Pool and review the literature surrounding the electricity pricing theories and the case of hydropower production. Second, the structure of the Nordic power market will be presented in order to better understand its functioning and its role in securing the market efficiency and effective pricing.

4.1 Introduction

4.1.1 System and area prices

Some concepts about electricity pricing are to be defined in order to clearly comprehend the functioning mechanisms of the price formation in the Nordic power market.

The system price is the hour price set on the Elspot power exchange after balancing sellers and buyers' bids. It is the equilibrium price between supply and demand considering the absence of congestions and that the inter-connector capacities are sufficient.

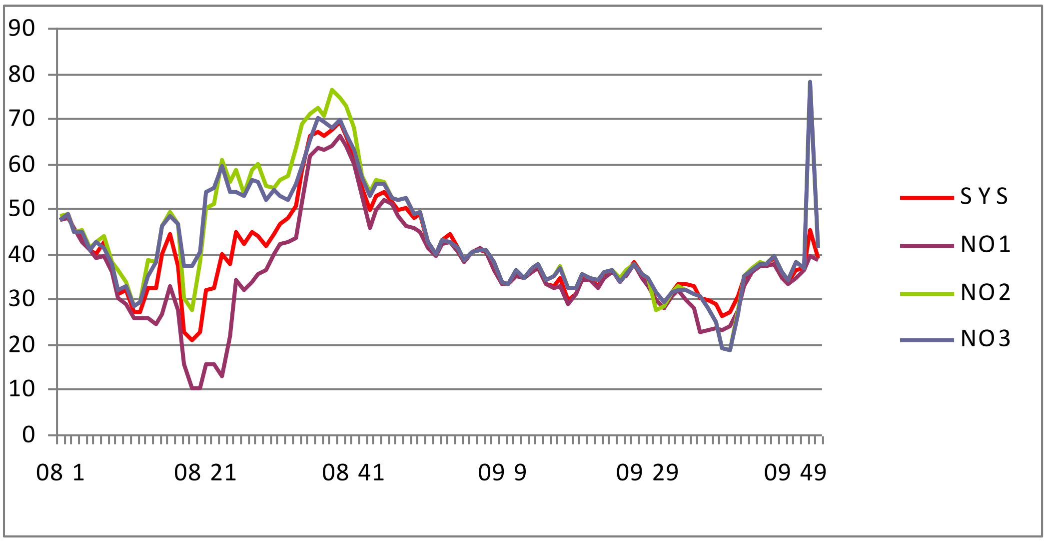
Nord Pool uses the arithmetic average of all hourly prices for a given day as the reference price in the cash-settlement calculations at expiration for derivative contracts.

[6] Hydropower represents 58% of the electricity production in the Nordic area (2008).

In the case of congestions, area prices are computed.

Area prices are the equilibrium prices based on the bidding units according to their locations.

Figure 4.1 Development of weekly System and area prices in Norway (2008-2009)



Source: Nord Pool

There has been a change in the Norwegian bidding areas. Since January 2010 there are four Elspot areas determined by Statnett according to physical conditions.

During the second half of 2008, area prices in Norway differ from the system prices, NO1 was below the system price which is a clear indication of inter-connector congestions.

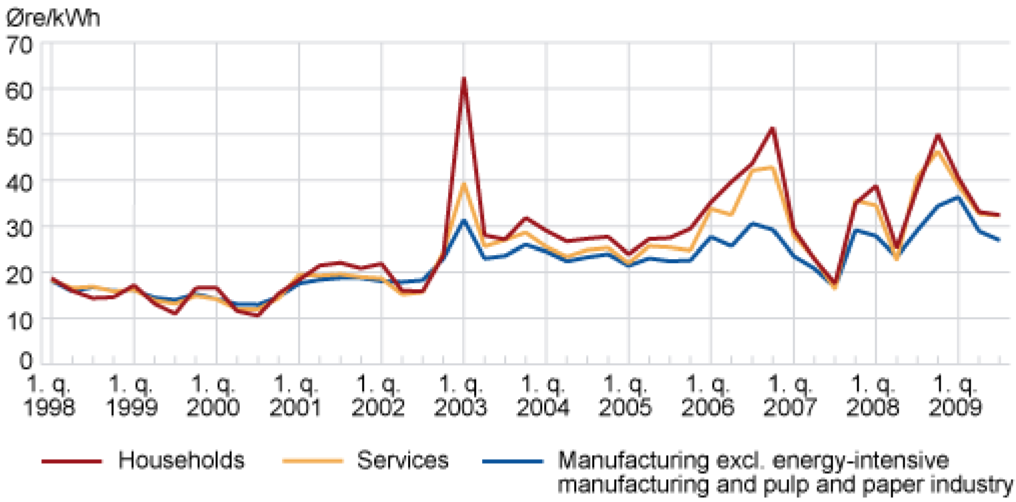
4.1.2 Wholesale and retail prices

a) Retail prices:

Buying or selling electricity in the retail market can be realized through fixed price contracts, variable price contracts or spot price contracts.

In Norway, the end-user price is composed of the wholesale price which account for one third of the total price, the grid-user rent and taxes and fees which represents each roughly one third of the final retail price.

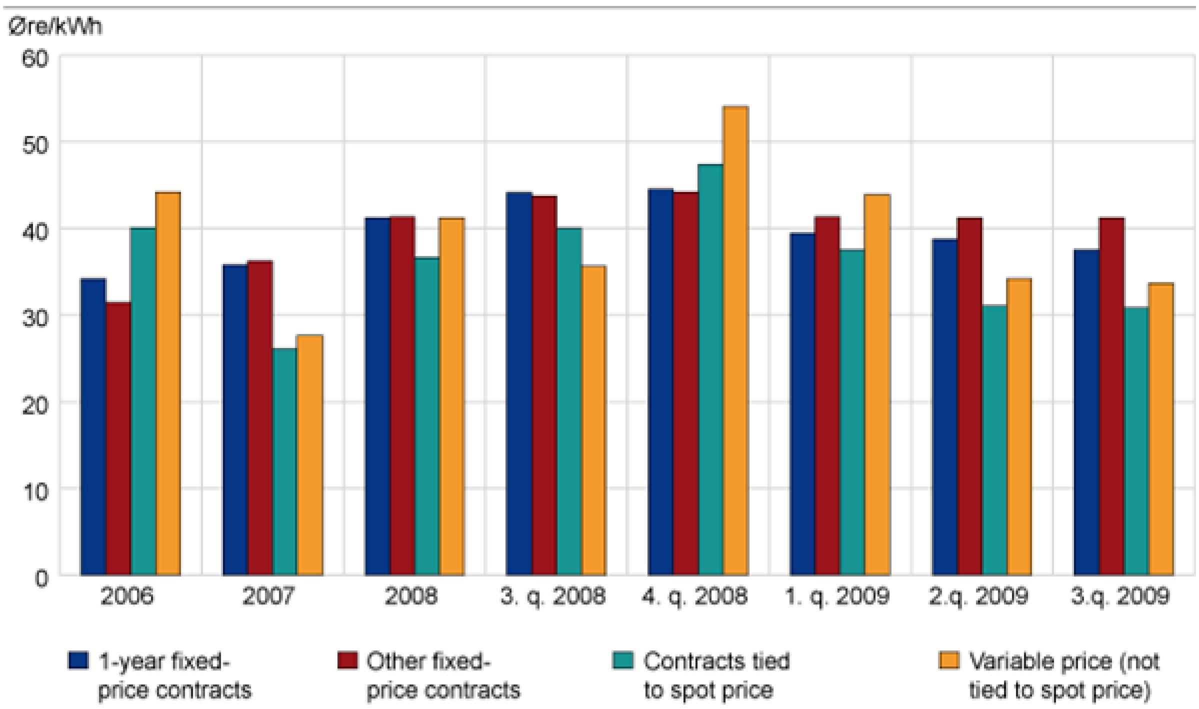
Figure 4.2 Prices of electric energy, taxes and grid rent excluded. Øre/KWh



Source: Statistics Norway (2010)

A decrease in electricity prices can be observed during the year 2009 for households, services and manufacturing excluding energy-intensive manufacturing and pulp and paper industry where the annual average price increased by 5.9 % compared to 2008 due to the fact that some of the old low-priced contracts have ended**.**

Figure 4.3 Prices of electric energy for households, taxes and grid rent excluded. Øre/KWh



Source: Statistics Norway (2010)

In 2009, contracts tied to spot prices were the cheapest type of contract while the other fixed price contracts were the most expensive.

b) Wholesale prices:

In the wholesale market, electricity trading is realized through bilateral contracts or on the power exchange Nord Pool. It is open for competition while the retail markets are basically national.

In Norway, the wholesale and retail markets are not highly concentrated except for the national company Statkraft who contributes with approximately 30% of the total Norwegian power generation.

In competitive markets, the marginal costs of production are relevant in the price formation of electricity.

4.1.3 Price determinants: What factors influence power prices?[7]

a) Weather and temperature conditions

- Precipitation

Hydropower accounts for half the Nordic electricity market which means that the level of precipitation is significant for pricing on the power exchange.

- Temperature conditions

Electricity provides about 30 per cent of space heating in Nordic homes. Temperatures therefore influence daily demand for power.

b) Electricity transmission

- Transmission capacity

Capacity shortages in the transmission network could increase prices if demand in one area exceeds supply.

- Exchanges with non-Nordic countries

[7] Source: Nord Pool

Since the Nordic market is also related to the Russian, German and Polish power markets. Supply and demand in these countries will therefore also influence Nordic prices.

c) Economic factors

- Generating capacity

Generating capacity is directly related to the supply of electricity, which could influence prices when it is expanded or decreased.

- Level of economic activity

Fluctuations in raw materials, other fuels and currency markets, primarily in Europe and to a certain extent worldwide, can affect the electricity market. Economic booms and recessions for instance impact electricity consumption and prices.

- Currency movements

Most raw materials and fuels are priced in US dollars which give a major importance to the exchange rate fluctuation. For instance, a lower exchange rate for the dollar would decrease the cost of coal, and would result in cheaper coal-fired German electricity. That could boost exports from the German power market to the Nordic region, and help to reduce prices there – assuming that Nordic prices were high.

- Prices of energy sources in power generation

Energy sources such as coal, gas and nuclear energy contribute significantly in electricity generation in Denmark, Sweden and Finland. Therefore, the cost of these raw materials plays an important part in the determination of power prices.

d) Prices for emission allowances

By the introduction of trading in carbon dioxide emission allowances EUAs on Nord Pool in 2005, power plants that release carbon emissions must buy EUAs to cover a possible shortage of such allowances. If the EUAs price is high, it is more expensive to generate electricity from fuels such as coal and gas and the cost could rise. The price could increase by the amount of the EUAs. The cheapest electricity is generated first, with more expensive generating modes included as consumption increases. The wholesale price is set by the most expensive generating mode. Since there are periods in the Nordic market when this is coal, the power price will also include the cost of EUAs.

d) Nuclear energy

Approximately 30 % of power production in the Nordic area is produced by nuclear power. Outages or generating cut-backs for nuclear power would reduce supply and could thereby increase prices.

e) Power consumption

Significant increase in electricity consumption that exceeds the expansion in generating capacity would result in the demand being higher than supply which can be balanced by increasing power prices.

Variability of electricity prices over time due to the volatility of both supply and demand influences the price movements. Hedging against this risk through forwards and futures can result in the optimisation of the value of water and equalize it through time (Torstein Bye, 2003).

4.2 Literature

In order to accurately assess the relationship between the futures and spot prices in the power exchange and the pricing of the derivatives, several studies have been conducted in the Nordic market and in the various international markets with the purpose of taking into consideration the specific characteristics of electricity and the impact on the price behaviour. The characteristic of electricity as a flow makes it different from other traditional traded commodities.

A number of researchers have explained that a time-varying volatility should be incorporated in the electricity pricing model as well as the possibility of jumps in prices (Kaminski (1997), Eydeland and Geman (1998), and Deng (2000)). On the other hand, in other studies, the periodic seasonal behavior of electricity prices was put forth in addition to its reversion to mean (possibly non stationary) levels (Pilipovic, 1998).

According to Lucia and Schwartz (2001), electricity prices are not perceived as homogenous due to the price differences in time and space. The power demand and supply and its determinants such as weather conditions and business activity play a major role in electricity pricing. Moreover, prices tend to be highly local due to the transportation constraints and capacity limits.

The limited arbitrage opportunities resulting from the non-storability and complex transportability of this commodity would have an impact on the relationship between the spot price and derivative prices and the behaviour of forward prices.

A deterministic component was included in their study to value power derivatives. It accounts for regularities in the behavior of electricity prices such as the seasonal pattern and it contributes in explaining the shape of the term structure of futures prices at Nord Pool.

Redl et al. (2007) analyses forward prices as built on fundamental expectations of market participants. The forward prices are updated by taking into consideration the risk or forward premiums in addition to the discounting element to account for opportunity costs. In their empirical study about forward and spot relationship in the European Energy Exchange and Nord Pool Power Exchange, they reject the use of the storage theory on electricity to determine a no-arbitrage condition between spot and futures prices.

Gjølberg and Johnsen (2001) conclude that hydro power can be stored indirectly by storing its energy source, water, in the reservoirs which gives the suppliers a flexibility of increasing or decreasing the production of electricity when needed. However these flexibilities are not present for the consumer side. It results therefore in a producer/consumer asymmetry.

Longstaff and Wang (2002) have studied the PJM[8] electricity market based on thermal production and concluded that the storage model is not applicable to price futures contracts which are related to the expected future spot prices.

4.3 Market structure and prices

Prior to the deregulation of the Nordic market, the power industry was characterized by a vertical integration with respect to the supply of electricity and its transmission. While the retail market, rather national, was based on fixed price contracts. Nowadays, the integrated Nordic market in the supply and generation side offers a competitive environment especially through trading at the power exchange Nord Pool.

[8] Pennsylvania, New Jersey and Maryland.

4.3.1 Retail market: Retail competition

Norway was a pioneer country to restructure the electricity sector. The Norwegian power market has now attained a mature stage.

The retailing market is believed to function efficiently thanks to some best practices and characteristics such as:

- Free entry on the supplier side
- Low degree of supplier concentration
- Transparent prices and conditions for electricity offered
- Free choice of supplier and contracts
- No charge for switching supplier

The increased market transparency and the abolition of switching fees bring more flexibility in the choices of consumers. Norwegian consumers tend to use the variable retail price contracts (approximately 75 percent of Norwegian consumers chose this type of contracts such as spot market contract or standard variable power price contracts) (Bye and Hope, 2006). This tendency, different from the Swedish preference for fixed price contracts may be explained by the total dependence on hydro power, risk preferences, different contract types or national traditions.

This flexibility in the retail market is a good feature of the Norwegian power market and may allow for more competition between the suppliers even though it is a sufficiently large number of consumers who will be determinant of fair competitive prices.

4.3.2 Wholesale market

The Norwegian wholesale market has gained more competitiveness since the liberalization and the integration of the Nordic Power market. However insufficient inter-connector capacities can lead to price inequalities across borders and possibilities to exercise market power for the large power producers (Bergman 2003). The integration of the national electricity markets in the Nordic area has contributed efficiently to dilute this market power. In fact, The Lerner Index[9], a measure of the degree of market power, is relatively low.

Some threats that may lead to potential market power can be perceived in the increasing mergers and acquisitions and cross-ownership among large power producers which closely followed by the regulating institutions.

The overall Nordic market has a relatively low degree of concentration according to commonly used concentration measures such as Hirschmann-Herfindahl concentration index (HHI)[10]. The Norwegian electricity market has been assessed as less concentrated than the neighbouring countries. The market share of each company generally does not exceed 5 or 6 percent.

After analyzing the factors contributing to reach a competitive power market, and consequently contributing to the efficiency of trading, the main research question of our thesis, an important feature of the electricity market should be pointed out. Volatility is a particularly interesting measure to study risks related to power trading and fluctuations in prices that might explain some of the price predictability and probable inefficiency.

[9] The Lerner index is defined as $\sum s_i$ (p-c)/p over all firms where p is the market price, s_i is the market share, and c_i is the marginal cost of the firm i.
[10] See Appendix 6 for the definition of the concentration measure (HHI).

5. Volatility and uncertainty in the power market

5.1 Introduction

Price volatility refers to the price fluctuations of a given asset or commodity over a specified period of time. Volatility is used to measure the risk associated with holding an asset. The spread of these fluctuations can give an indication about the future price uncertainty. The price risk is more likely associated with an undesirable outcome either a decrease or an increase in prices.

A detailed analysis of volatility in electricity markets is relevant to our study with respect to capturing the features of electricity prices, uncertainty related to trading in the power market and its impact on forward and futures pricing.

The particularly high volatility featuring the electricity markets in general creates a need for risk management and the use of financial derivatives. All the market participants are in some way exposed to the risk of price fluctuations; from the producers to the consumers of power, especially large industrial firms that need electricity for their daily operations. The main question that we will attempt to answer is “What are the volatility properties in these markets and their impacts on trading and derivatives pricing?”

Considering that the power market in Norway is dependent on hydro power and therefore on climatic factors (among other factors discussed in the previous chapter), an important question is raised: “How the market volatility and the behaviour of the power exchange participants is influenced by these factors, and what is the impact of the seasonality feature in electricity generation?”

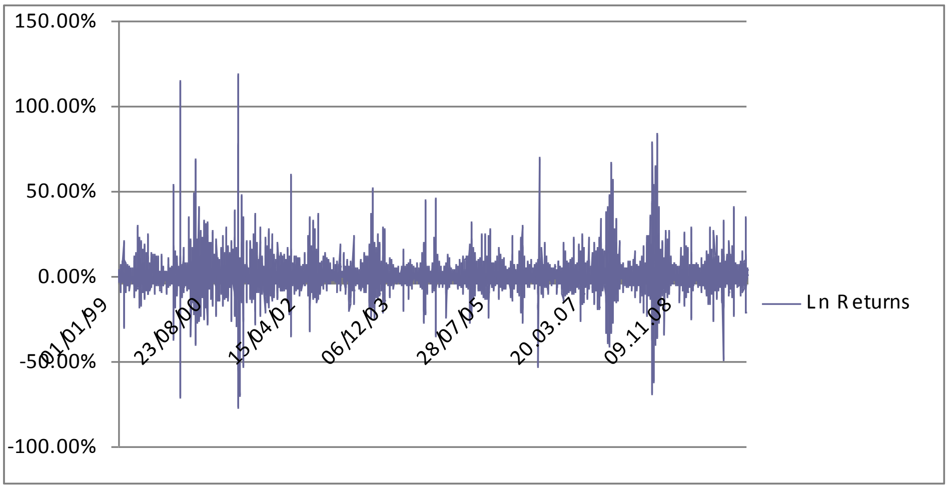
5.2 Volatility in the electricity markets

Price volatility is an indication of the level of risk and uncertainty in the market and is of great significance in risk management issues.

In the energy markets, electricity prices have the highest volatilities relatively to other energy sources. The maturity of the given market can explain the level of uncertainty and price fluctuations. Therefore, the electricity market considered as the younger and less mature than other common commodities (oil, metals, coal etc...) has a much higher price volatility especially hourly price. Instances of daily volatility vary between 1 and 1,5% for stock indices, between 2 and 3% for crude oil, and it is approximately 3-5% for natural gas (Bouchaud, 2002).

5.2.1 Development of prices and volatilities in Nord Pool

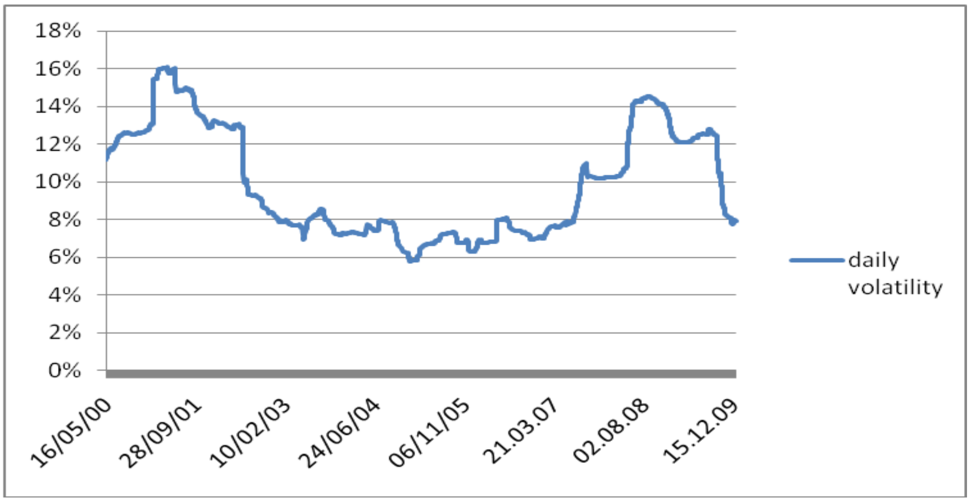
Figure 5.1 Logarithmic returns for the spot market (1999-2009)



Data source: Nord Pool

The data are the logarithmic returns of daily system prices for the spot market (Elspot) at the Nordic power exchange Nord Pool from January 1999 up to December 2009. The data set consists of 4016 data points.

Figure 5.2 The time dependent daily volatility



Data source: Nord Pool

The logarithmic returns $u_i = \text{Ln}\,(S_i/S_{i-1})$ i= 1,2…T

T is the size of the time window and is equal to 4017. The calculated empirical daily volatility over the sample period is about 10%. Empirically, the average return is rather small so that $\sigma_T = (\Sigma\, u_i^2/T)^{1/2}$ which is indeed the case in our calculations.

For the data set studied in this paper, the sample average of daily logarithmic returns is 1/500 of its standard deviation σ_t. The time dependent volatility σ_t is calculated as the standard deviation over a sample period of the previous 500 days. This daily quantity at Nord Pool market is depicted in Figure 5.2.

5.2.2 Characteristics of volatility in the electricity market in the Nordic market

a) General description

The price fluctuations in the Nordic power market and particularly the Norwegian power market is highly correlated with the variations in precipitations because of the importance of hydropower generation. (Approximately 50% of the total power generation in the Nordic market has hydro power sources.)

Furthermore, there is an observed increase in prices and volatility in the dry periods due to the dependence from other source of energy such as oil and gas.

In an integrated market, price volatility in the different markets should converge however several reasons can contribute to price fluctuations to differ between countries.

Historically, price volatility has been rather higher in Norway than in the neighbouring countries. The dependence of the Norwegian market on hydro power can represent an explicative factor of the higher volatility.

Most power exchanges have been established in the last decade after the deregulation introduced in many power markets. Therefore it is not unusual that the historical data available present only one or two years of "stationary" data due to the changes which are constantly taking place in many power markets. On the other hand, Nord Pool is "generally regarded as the most mature and "stable" power market in the world" as stated by Simonsen et al. (2004).

This relative maturity of the Nordic power market would be a reasonable explicative factor to lower volatility in the Nordic electricity market[11] than the other newly established markets in the world despite the overall high volatility characterizing the electricity markets in general.

b) Volatility dynamics

The Analysis conducted by Lucia and Schwartz (2001) of the system price in Nord Pool shows that the volatility is consistently different between winter and summer seasons.

They have considered mean reverting diffusion process for the volatility and another possible specification as to include jumps in spot prices.

Ingve Simonsen (2004) has studied the properties of volatility in the Nordic power market over a period of 12 years from 1992 until 2004 and has observed the following characteristics about the volatility at Nord Pool:

Volatility clustering, log-normal distribution and long-range correlations in addition to a cyclic behavior of the time-dependent volatility.

Volatility clustering can be observed in the power market in the following way: periods of high volatility followed by long periods of low volatility.

These are commonly observed features of other financial and commodity markets but electricity markets show some differences concerning its volatility.

Specific characteristics of volatility in the power markets are an overall high level of volatility, oscillating volatility–volatility correlations, daily volatility profiles, multi-seasonality, and price level-dependent volatility. The latter feature which is the dependence on the price level in addition to the higher level of volatility represent the most differentiating features from other markets.

The empirical analysis of Simonsen (2004) has shown that volatility has an annual cycle and reaches its highest levels during the summer period. The most probable reason for this phenomenon can be explained by the energy source itself which is mainly hydro power. The reservoirs reach their maximum levels and forces generators to produce electricity while the

[11] Daily logarithmic volatility at Nord Pool is approximately 16% (period from 1992-2004) (Simonsen, 2004).

consumption is low. There is a consequent drop in prices which makes the summer season more volatile.

c) Seasonal fluctuations:

The demand of electricity is subject to seasonal variations due mostly to climatic factors. In the Nordic region it reaches its peak in winter due to excessive heating. The demand varies during the week as well; it is lower during weekends and nights due to lower industrial activity.

In addition, the supply of electricity is also subject to fluctuations especially for hydro power production since it is dependent on the level of water in the reservoirs and consequently weather conditions. The variation of demand and supply of electricity would result automatically to the fluctuation of spot prices calculated by balancing supply and demand.

The behavior of the electricity prices was evidenced (Strozzi et al. , 2007) to be highly correlated to climatic factors in addition to an observed correlation of high volatility periods with historical and meteorological events.

5.3 Theory to estimate volatility

An overview of the models used to measure the volatility is presented in this part. The unique characteristics of the power markets and especially the Nordic power market lead us to a careful and detailed look at these models established through several empirical analyses on Nord Pool.

The traditional method to assess the volatility of a given set of data is to calculate the standard deviation, preferably of the data logarithmic returns for a more statistical accuracy and also when using the logarithm function, the data are additive stochastic variables which is not the case for simple returns.

The historical volatility is the standard deviation of the returns σ_T: $[1/(T-1)\ \Sigma(u_i-u)^2\ ]^{1/2}$

It is calculated over the sample period used in Figure 5.2.

Simonsen et al. (2004) used a mean reverting jump diffusion model to describe the dynamics of electricity spot prices at Nord Pool (mean reversion, seasonality and price spikes) which can be useful for risk management purposes and derivatives pricing.

On the other hand, the empirical volatility was computed by using the daily logarithmic volatility defined by its standard deviation.

The works of Strozzi et al. (2007) are interesting in the statistical method used and conclusions drawn with respect to evidencing the correlation of the electricity spot data dynamics with events such as the climatic factors. The Recurrence Quantification Analysis (RQA) was used to analyze the data and detecting changes related to weather conditions. The accuracy of this method was proved to be superior than measuring the times series standard deviation. We will not go through the detailed analysis; however the aim of pointing out the results of this study is to highlight the importance of the climatic factors in the dynamics of electricity prices and the continuous efforts to reveal the different aspects of volatility in this market.

The volatility of the electricity prices is an important element of our study in order to better understand and model the data and more precisely the spot prices representing the underlying of most traded derivatives in the studied market. It is of considerable importance to study the stochastic characteristics of the data we are using in order to perform an accurate analysis of the market efficiency at Nord Pool.

In addition, the analysis of volatility in the Nordic Power market is relevant to our main research question in investigating the market efficiency in terms of the stability of the market. The market is considered more efficient when the volatility is lower and arbitrage opportunities are limited.

From the volatility study, one would consider that the Nordic power exchange is relatively stable with an empirical daily volatility close to 10%. This seems to be an indication of relatively lower risk and therefore would be a more attractive market for investors which could contribute to the competitiveness of the market and enhance its efficiency by including a considerable number of participants.

In the next section, more recent data will be analyzed and the seasonality feature of the spot prices will be taken into consideration. The dynamics of the power prices will be investigated in the empirical part of this paper in order to test the price predictability and consequently the efficiency of the market. The long and short term relationship of spot and futures prices will be explored in order to answer the same question. The cost of carry hypothesis and the EMH presented in chapter three will build the theoretical background behind our analysis.

6. Econometric tools to test the market efficiency

The empirical study of the spot and futures electricity prices at Nord Pool requires the use of some advanced statistical tools and concepts that we will try to define in the beginning of this chapter and clarify the need and the goals of using such methods.

The market efficiency will be investigated empirically by using the ADF tests on spot and futures prices in addition to the cointegration and ECM test.

6.1 Describing price dynamics

6.1.1 Definitions

Some concepts describing the dynamics of financial data and the different econometric methods we will use in order to analyze the data of Nord Pool power exchange should be defined.

First, we will briefly present the regression method, the properties and assumptions of the Ordinary Least Squares OLS estimations that we are going to extensively use to achieve the empirical part of this paper.

Next we will define some common stochastic processes that were observed to closely describe financial data dynamics and that we will use in the econometrical analysis.

a) OLS method

Regressions are commonly used to describe the relationship between a certain “explained variable” (y) and one or several “explanatory variables” (the x’s) where it is assumed that the y is stochastic and the x variables are observable and non-stochastic.

The basic idea of modeling a regression is to estimate its parameters by minimizing the vertical distances from the actual plotted data points and the straight line constructed without errors. In other words, it consists of minimizing the sum of the squared error terms usually denoted $\hat{u}^2_t$.

The validity of the classical linear regression model relies on important assumptions that need to be reminded:

1. Zero mean of the errors: $E(u_t) = 0$
2. Constant and finite variance of the errors: $Var(u_t) = \sigma^2 < \infty$
3. Independence of the errors: $cov(u_i, u_j) = 0$
4. Independence of the error and the corresponding x : $cov(u_t, x_t)$
5. The error term u_t is normally distributed: $u_t \sim N(0,\sigma^2)$

The aim of respecting these assumptions is to obtain estimators with desirable properties also known as the BLUE estimator or the Best Linear Unbiased Estimator[12] that would lead us to conduct valid statistical inferences and hypothesis testing.

It is therefore crucial to verify these assumptions and apply the adequate solutions if one or more of these assumptions are not satisfied by the available data.

First, if there is an intercept in regression model, the mean value of the errors is always equal to zero, otherwise, if the model does not include a constant term according to the supporting financial theory and the mean value of the errors is different from zero, this could lead to biased estimators.

Second, if assumption 2 of homoscedaticity is not satisfied, the errors are heteroscedastic, and the estimators would be unbiased but does not have the minimum variance in order to obtain valid results.

To detect if there is heteroscedasticity, one could use the White's test[13] . In the case of heteroscedasticity, the Generalized Least Squares would be the appropriate solution to have a constant variance of the errors.

Third, if the errors are not uncorrelated or in other words they are autocorrelated and ignored in the regression, the estimators would be inefficient, and any statistical inferences could be wrong.

[12] The estimator has the minimum variance among the class of linear unbiased estimators.
[13] See Brooks (2008).

One could test the presence of autocorrelation using the Durbin-Watson (DW) test or the Breusch-Godfrey test.

In case, the error terms are autocorrelated, the use of lagged values could eliminate the problem. Per definition, a lagged value is the value of a variable during the previous period.

Some aspects of the model such as seasonality of the explained variable, omission of relevant variables that are autocorrelated or the non-linearity of the model can be reflected in the autocorrelation of the errors and cannot be solved by adding lagged variables.

The inclusion of lagged values can eliminate the autocorrelation due to the inertia of the explained variable y where the effect of a change in the explanatory variable will only be observed after a period of time. Another factor could be the overreaction of the given variable during the current period.

The fourth assumption states that the explanatory variables x and the errors u_t are independent.

If the x's are non stochastic which is a stronger assumption, the estimators are still unbiased. But if x and u are not uncorrelated, the estimator would be biased.

Finally, the disturbance terms should be normally distributed; otherwise one could not apply the hypothesis tests about the model coefficients. Non-normality can be detected by testing the coefficient of skewness and excess kurtosis[14]

Generally, with a large sample if data, the non-normality of the residuals does not affect the results of the tests. The use of dummy variables can contribute to eliminate extreme observations that caused the non-normality of the errors.

[Brooks (2008), chapter 4]

It is also necessary to have a regression that is not spurious. A spurious regression means that the measures used to evaluate the model such as R^2 and the parameters' estimators show significant results but are misleading and do not reflect the true and actual results. This can be due to the non-stationarity of the data and a common trend of the explanatory and explained variables.

[14] The excess kurtosis should equal to zero for a normal distribution.

It is then essential to test the stationarity of the data before applying the OLS. We will explain further the concept of stationarity in the next pages.

An important element of the empirical study is based on the data. Time series are used for our analysis from the Nord Pool power exchange.

Time series are defined as the value of one or more given variables over time. The variables are observed at a certain frequency or regular intervals that can be days, weeks or months and etc.

We will specify the nature of the data used for our analysis in the next section.

6.1.2 Common stochastic processes

We are interested in the dynamics of spot and futures prices at the Nordic power exchange. Certain stochastic processes are believed to describe many financial and economic data series.

Most common stochastic processes are the white noise, Autoregressive process, random walk, moving average.

First, a stochastic process also called random process as opposed to a deterministic process is characterized by unknown and random future variables in the time series that might be independent or show some statistical correlation.

The white noise concept is very important when using the OLS method. As pointed out by the assumptions of OLS, the residuals should follow a white noise process. In addition the random walk process is relevant to understand the stationarity concept.

See appendix 8 for a detailed definition of a white noise and other stochastic processes.

6.2 Stationarity and unit root testing

The concept of stationarity is crucial in our study in order to perform the OLS method since it affects the behavior and properties of the time series in addition to resulting in spurious regressions when the data are non-stationary, wrong measures like the t-ratio which does not follow a t-distribution anymore and F-statistic that does not follow an F-distribution because the assumptions for asymptotic analysis are not valid.

It is therefore an important step to determine whether a process is stationary or not by using the Dickey-Fuller (DF) or the Augmented Dickey Fuller (ADF) test.

6.2.1 Importance of stationarity testing

The stationarity testing contributes in studying the characteristics of spot and futures prices. The non stationarity of the data series is an indication of market efficiency. In other words the data follow a random walk and consequently arbitrage opportunities are limited.

The definition of a stationary process is determined according to two types: the strictly stationary process and the weakly stationary process.

The first one exists if the distribution of the series values does not change with time, which means that at any period of time, the probability that the variable's value falls at a certain interval is constant.

While the weakly stationary process, also called covariance stationary, is defined such that the considered time series has a constant mean, constant and finite variance and a constant autocovariance.

The autocovariance term defined as $E(y_t - E(y_t))(y_{t-s} - E(y_{t-s})) = \gamma_s$ (for s = 01,2,…) cannot give us immediate interpretations about the relationship of y and its previous values.

It is useful then to use the autocorrelation terms which are computed by dividing the autocovariance by the variance $\tau s = \gamma_s / \gamma_0$ where s = 0,1,2, …

The coefficients obtained lie in the interval [-1,1]

An example of a stationary model is a random walk with a drift where $\varphi < 1$

$y_t = \mu + \varphi y_{t-1} + u_t$ where $\varphi < 1$ and u_t is a white noise.

In this type of model the effect of an extreme events or shocks will die away with time as opposed to the same process with φ equal to the unity where the shocks would persist in time. It is therefore a non-stationary process. In the spot and futures market, the price series are expected to be non stationary and stationary in first differences to ensure the market efficiency.

Prices are not autocorrelated in a non stationary process which limits the price predictability and therefore contributes to the market efficiency.

It is important to mention that there are two types of non-stationary processes;

The stochastic non-stationarity characterized by a stochastic trend in the data and the deterministic non-stationarity characterized by a linear trend.

The first case is most commonly observed in the financial and economic time series according to Brooks (2008).

It requires differencing the model once or more times if necessary to obtain a stationary process. An example of a stochastic trend model $y_t = y_{t-1} + u_t$ where u_t is a white noise.

By applying the first difference operator $\Delta y_t = u_t$ we obtain a stationary variable. In this case, the initial equation contains one unit root and is integrated of order 1 to induce stationarity. It is noted $y_t \sim I(1)$ and $\Delta y_t \sim I(0)$ which is a process with no unit roots.

6.2.2 Testing for unit roots

As mentioned before, if a process contains d unit roots, it has to be integrated of order d to induce stationarity.

Testing for unit roots is consequently an essential step in order to perform the appropriate integration procedure.

Dickey and Fuller (1979) have contributed with their works to provide an appropriate test to detect unit roots.

The DF test is conducted as follows:

Considering the model: $y_t = \varphi y_{t-1} + u_t$ where u_t is a white noise.

We need to test the null hypothesis H_0: $\varphi = 1$ against H_1: $\varphi < 1$

H_0 states that the series is non-stationary and contains a unit root while H_1 states that the series is stationary.

The same test is written in a different way for more practicity:

$\Delta y_t = \psi\, y_{t-1} + u_t \quad (\psi = \varphi - 1)$

$H_0 : \psi = 0$

$H_1 : \psi < 0$

The test statistic = $\psi / SE(\psi)$ that follows a non-standard distribution.

The critical values were estimated and derived using simulations by Dickey and Fuller. For instance, with a significance level of 10% the CV is – 2,57 for a model with constant and no trend.

The null hypothesis is rejected if the test statistic is more negative than the critical value.

The DF test can also allow for an intercept or an intercept with a trend.

The model would be:

$\Delta y_t = \psi\, y_{t-1} + \mu + \lambda t + u_t$

The Augmented Dickey Fuller test ADF is superior to the DF test with respect to taking in consideration possible autocorrelation in the dependent variable Δy_t.

DF test assumes that the error term is a white noise. If some autocorrelation exists in the dependent variable that has been ignored, the error terms would be autocorrelated and the test oversized[15].

The ADF consists of adding lags of the dependent variable

$\Delta y_t = \psi\, y_{t-1} + \Sigma\alpha_i\, \Delta y_{t-i} + u_t \quad$ (i= 1...p (p lags))

And the same procedure is followed as in the DF test.

The optimal number of lags to be added could eliminate the error autocorrelation and at the same time not reduce significantly the power of the test through the increase of the number of parameters to be estimated. In fact too few lags would not eliminate the error autocorrelations

[15] The proportion of times a correct null hypothesis is wrongly rejected is higher than the nominal size of the test or the significance level.

and too many would lead to the reduction of the test statistics absolute values and hence the null hypothesis would be rejected less frequently for a stationary process.

Determining the appropriate number of lags can be conducted by two rules if thumb suggested by Brooks (2008).

The first consists of using the frequency of the data. (12 lags for monthly data, 4 lags for quarterly data and etc.)

The other method consists of finding the number of lags that minimizes an information criterion.

In this paper we will use the Schwartz information criterion also called the Bayesian information criterion (BIC) complemented by Akaike Information Criterion (AIC) to determine the appropriate number of lags.

These information criteria are the most commonly used in model selection and comparing maximum likelihood models by measuring fit and complexity. They are defined as follows:

AIC = -2*ln (likelihood) + 2*

BIC = -2*ln (likelihood) + ln(N)*k

Where k = model degrees of freedom and N = number of observations.

Fit is measured negatively by -2*ln (likelihood); the larger the value, the worse the fit. Complexity is measured positively, either by 2*k for AIC or ln(N)*k for BIC. Given two models fit on the same data, the model with the smaller value of the information criterion is considered to be better.

6.3 Seasonality

As mentioned in the previous section, the electricity prices at the Nordic market exhibit clear seasonality features. The time series can be perceived as presenting certain predictability in its dynamics due to this reason but it does not imply the inefficiency of the market.

In Jensen (1978) definition of market efficiency, inefficiency would not be attributed to such markets.

Arbitrage opportunities based on this kind of cyclical predictability would not be very successful due to several reasons such as:

The transaction costs would not allow for profits since the excess returns that can be observed are rather small.

Second, in financial markets, the time varying risk premiums can be an explaining factor of the differences in returns.

To take account of the seasonality property in the regression analysis, the use if dummy variables and an intercept would contribute to correctly model the behavior of the variables. Ignoring this feature when building the model would most probably lead to residual autocorrelation of the order of seasonality.

The number of dummy variables to include in the regression model generally depends on the frequency of the data. It is equal to seasonality frequency minus one in case an intercept is used in the regression so that we avoid perfect multicolinearity. For quarterly data, we should add three dummy variables.

At Nord Pool, the seasonality is evident throughout the year dividing it in three distinct periods: Winter 1 from January to April, Summer from May to August and Winter 2 from September to December.

Before testing the data for stationarity, we need to adjust for seasonality by incorporating the dummy variables and estimate the following regression equation: $s_t = \alpha_0 + \sum \alpha_i D_i + \hat{u}_t$

Where s_t is the logarithm of spot price, D_i is the dummy variable with i=1,2

According to Simonsen et al. (2004), the seasonal behaviour of spot electricity prices is directly affected by the seasonality in demand and supply of hydropower mainly related to climatic factors. They proposed a model to capture the seasonality and price jumps at Nord Pool by incorporating the periodicity in the form of an external, deterministic sinusoidal function:

$St = A \sin (2\pi /365 (t + B))+Ct$

The model includes jump components.

Lucia and Schwartz (2001) have examined the seasonal patterns in Nord Pool electricity prices and developed a simple sinusoidal function to describe the futures and forward curve in order to capture the seasonality feature.

6.4 Cointegration

Cointegration analysis is an established technique that would be used to detect the presence of a common trend between non-stationary time series and consequently the existence of a long run relationship between the given cointegrated variables. Financial theory suggests that spot and futures prices for a given commodity are expected to hold a long term relationship in an efficient market explained by the cost of carry. Spot and futures prices in a frictionless and efficiently functioning market would react similarly to new information and tend towards a long-run equilibrium state resulting from the no-arbitrage condition. Hence, cointegrated spot and futures prices are an indication of market efficiency.

Engle-Granger (1987) has proposed the theoretical background of the cointegration technique. Johansen technique was also developed to conduct the cointegration test in a multivariate analysis. The scope of this paper will include a univariate analysis, therefore it is appropriate to use the Engle-Granger methodology rather than the Johansen technique.

6.4.1 Definition

A linear combination of I(1) variables, in other words non stationary variables, would be I(0) and consequently stationary if the variables are cointegrated.

Generally, the linear combination of variables that are I(1) would be I(1) as well.

The following model will illustrate the discussed concept:

$y_t = \beta_1 + \beta_2 x_{2t} + \beta_3 x_{3t} + u_t$

(y_t, x_{2t}, x_{3t} are I(1))

The residual can be expressed as a linear combination of the variables:

$u_t = y_t - \beta_1 - \beta_2 x_{2t} - \beta_3 x_{3t}$

A desirable property would be to have stationary residuals u_t which cannot be true unless the variables are cointegrated and tend towards a long term equilibrium.

In the case the residuals are non stationary, the linear combination of the variables would not have a constant mean that is frequently crossed but the variables would deviate and drift apart over time.

6.4.2 Engle-Granger theory and ECM

According to Engle and Granger (1987), the components of a vector of variables w_t are integrated of order (d,b) if all components of w_t are integrated of order d and there is at least one vector of coefficients α such that $\alpha' w_t \sim I(d-b)$

The case were d=b=1 is most commonly observed in the financial and economic data. The variables are integrated of order 1, so contain one unit root.

A long term relationship is an interpretation of the common trending of the variables.

However, econometricians define the long run when the variables converge to the same value that remains constant resulting in $y_t = y_{t-1} = y$ and $x_t = x_{t-1} = x$

The traditional approach to induce the stationarity of the variables by differencing them is no longer valid since there is no long run solution in the model:

$\Delta y_t = \beta \Delta x_t + u_t$

$\Delta y_t = 0$ and $\Delta x_t = 0$

The solution to this problem is provided by the Error Correction model also called the Equilibrium correction model (ECM).

It simply consists of using a combination of first differenced and lagged levels of the cointegrated variables.

Considering two variables x_t and y_t that are I(1)

$\Delta y_t = \beta_1 \Delta x_t + \beta_2 (y_{t-1} - \gamma x_{t-1}) + u_t$

$(y_{t-1} - \gamma x_{t-1})$ is the error correction term.

According to Engle-Granger (1987), if the cointegration test proved that x_t and y_t are cointegrated with coefficient γ, then the error correction term would be I(0) and therefore stationary. Consequently, the OLS method can be carried out and resulting in valid statistical measures and inferences.

An interpretation of the model parameters is given in Brooks (2008) stating that:

γ describes the long run relationship between x and y,

β_1 describes the short run relationship between Δy_t and Δx_t .

β_2 describes the speed of adjustment to the equilibrium.

The ECM can allow for an intercept if it is necessary. Furthermore, more variables could be included in the model to be estimated.

The Engle-Granger technique steps:

The initial model is $y_t = \beta_1 + \beta_2 x_{2t} + u_t$

Step 1:

Firstly, the time series studied should be tested for non-stationarity. x_t and y_t are supposed to contain one unit root.

Using OLS, one could estimate the parameters of the cointegrating regression but still not conclude any statistical inferences.

The obtained residuals $\hat{u}_t$ are to be tested for unit roots.

H_0: $\hat{u}_t \sim I(1)$

H_1: $\hat{u}_t \sim I(0)$

Two outcomes can be observed;

If the residuals are I(1) , the null hypothesis of non-stationarity is not rejected. The variables are not cointegrated which means that there is no long term relationship. The next step would be to estimate a model containing first differences only.

If the residuals are I(0), the null hypothesis is rejected which means that $\hat{u}_t$ are stationary, and the variables are cointegrated.

The next step is to estimate the ECM as detailed in the following:

Step 2:

The obtained residuals $\hat{u}_t$ would be incorporated in our ECM model such that:

$\Delta y_t = \beta_1 \Delta x_{t-1} + \beta_2 \hat{u}_{t-1} + v_t$

Where $\hat{u}_{t-1} = y_{t-1} - \hat{t}x_{t-1}$

The cointegrating vector $[1 - \hat{t}]$ represents the stationary linear combination of non-stationary data.

At this point, the inferences from OLS about the model coefficients β_1 and β_2 would be statistically valid.

Limits:

This method represents some limits worth mentioning[16]:

a) There is always the issue of limited sample data since the sample is finite. This would obviously result in a lack of power concerning the tests of unit roots and cointegration.

b) Possibility of encountering a simultaneous equation bias if there is both-way causality between the explained and explanatory variable. It can be remedied by treating x and y asymmetrically even if it is not the case in reality. In other words, one needs to specify one variable as the dependent variable and the rest of the variables as independent. In addition, the sequential nature of this methodology would result in carrying out errors if present the initial model specifications.

c) The hypothesis tests cannot be conducted on the actual cointegration relationship.

[16] Limits i. and ii. are sample problems that would disappear asymptotically.

6.4.3 Application on Spot and Futures market

The main purpose of this study is to investigate the market efficiency of the Nordic power exchange. The concept of predictability of changes in the prices is commonly used to evaluate it. According to the definition of market efficiency, arbitrage opportunities should not arise using available information.

The predictability of prices is evaluated using the ADF test to examine their stationarity. If the series are stationary, the market is considered inefficient since the future prices could be calculated using the current prices because the mean, variance and autocorrelation of the data are independent of time. On the other hand, if the series contain a unit root, they are non stationary and consequently follow a random walk which implies the absence of arbitrage opportunities.

The cointegration method to test the empirical data at Nord Pool provides a suitable technique to investigate the spot price predictability and the arbitrage opportunities. In an efficient market, the spot and futures prices should present a long term equilibrium relationship according to the cost of carry theory formulated as follows:

$$F_t = S_t \, e^{(r-s)(T-t)}$$

where F_t is the futures price, S_t the spot price, r a risk free interest rate, s is the convenience yield, (T-t) is the time to maturity of the futures contract.

Taking logarithms

$$f_t = s_t + (r-s)(T-t) \quad \text{where } f_t = \ln(F_t) \text{ and } s_t = \ln(S_t)$$

In order to prove the long term relationship between the logs of spot and futures prices, one needs to confirm that the difference between the spot and futures prices is stationary using OLS and cointegration tests.

The underlying intuition behind the test is to investigate whether spot and futures prices cointegrate, or in other words the difference between the two prices is stationary. It means that there are no arbitrage opportunities arising from a lead lag relationship between spot and futures prices. Consequently the hypothesis of market efficiency can be confirmed. The cointegration of futures and spot prices reflected in a common trend would confirm the market efficiency since a shock in the futures price would be observed in the spot price as well, and hence eliminating differences in the expected returns that might lead to arbitrage opportunities.

The logarithms of the spot and futures prices are used and the returns (change in the price logarithm) are preferred to prices for a statistically valid model.

The use of logged prices would reduce the effect of extreme jumps in the prices. We will consequently use the natural logarithm of prices in our empirical analysis.

To detect the presence of a long term relationship between the f_t and s_t, one should examine the stationarity of the residuals z_t in the following model using the ADF test:

$$s_{t+1} = \gamma_0 + \gamma_1 f_t + z_t$$

According to theory γ_1 should be equal to 1 so that the futures prices can be an unbiased estimator of the future spot price according the expectation hypothesis.

The next step is to perform the ECM and use lagged values of the residuals z_t in the following model:

$$\Delta \ln S_t = \beta_0 + \delta z_{t-1} + \beta_1 \Delta \ln S_{t-1} + \alpha_1 \Delta \ln F_{t-1} + v_t$$

where v_t is an error term.

Including lagged values of f and s in the ECM can help us investigate the short term dynamics since the short run deviations would be corrected by the model.

The reason behind examining the short run dynamics is to avoid claiming the market efficiency when arbitrage opportunities may arise in the short run.

7. Empirical analysis

7.1 Data

In order to analyze the Nordic Power Exchange and test its efficiency through analysing the price predictability, we will use the daily and weekly spot price also known as the system price during the period from 1999 until 2009. The total number of observations of daily spot prices amount to 4017 observations while the weekly spot prices amount to 572 observations.

The daily and weekly prices of base load futures contracts will constitute the data set for different maturities of the contracts (week (5 contracts), month (6 contracts) and quarter (7 contracts) for different maturities) from 2007 up to 2009.

The number of observations for each future contract amounts to 521 observations (only trading days).

A specification of the futures and forward contracts analysed is detailed in Appendix 9.

Table 7.1 Descriptive statistics of daily spot prices

Period	1999-2009	1999-2001	2002-2004	2005-2007	2008-2009	2000-2004	2005-2009
Observations	4017	1096	1096	1095	730	1827	1825
Mean	29.77	16.45	30.84	35.28	39.88	25.68	37.12
Median	28.45	15.70	29.10	31.74	37.72	24.63	34.96
Std Dev	14.24	6.27	13.74	12.81	10.61	13.11	12.18
Kurtosis	2.79	8.83	11.22	0.19	0.89	11.40	0.29
Skewness	1.18	1.47	2.82	0.76	0.85	2.55	0.67

Table 7.2 Descriptive statistics of weekly spot prices

Period	1999-2009	1999-2001	2002-2004	2005-2007	2008-2009	2000-2004	2005-2009
Observations	572	156	156	156	104	260	260
Mean	29.78	16.44	30.86	35.30	39.88	25.69	37.13
Median	28.57	15.88	28.97	31.56	37.41	24.96	34.66
Std Dev	14.03	5.80	13.54	12.63	10.19	12.86	11.91
Kurtosis	2.56	-0.41	10.58	0.14	1.07	10.95	0.30
Skewness	1.14	0.43	2.76	0.78	1.04	2.50	0.70

The sample of daily spot prices includes a sufficient number of data to obtain desirables statistical properties using the regressions and OLS method. However, the strength of the tests would diminish with the weekly prices and with a lower number of data.

The average spot price has varied significantly during the sample period 1999-2009 with an evident increase over the years.

The volatility captured by the standard deviation seems to be at the highest during 2002-2003 a period where there was a shortage in power supply.

The kurtosis[17] measures whether the data are peaked or flat relative to a normal distribution. It seems that the data constitute a high peak and heavy tails during 2002-2004 which reflects extreme electricity prices while it tends to be flat during the next years which indicates more homogeneity in the prices.

Skewness is a measure of symmetry. We observe a positive coefficient of skewness during all periods which means that the data have a longer right tail or are right-skewed and deviations from the mean are positive.

The normality of the error term can be tested using the Bera-Jarque test (Brooks 2008) based on kurtosis and skewness. It tests for the coefficients of skewness and excess kurtosis being jointly equal to 0: The null hypothesis is that the distribution is normal.

$$BJ = n[\frac{S^2}{6} + \frac{(K-3)^2}{24}] \sim \chi^2(2)$$

S – coefficient of skewness

K – coefficient of excess kurtosis

n – number of observations

The test resulted in rejecting the normality hypothesis at 5% significance level. See appendix 7 for the Bera-Jarque test results.

7.2 Methodology

7.2.1 Test for stationarity

a) Spot prices

First of all, one should examine the stationarity of the time series by using the ADF to test for unit roots.

[17] The kurtosis for a normal distribution is equal to 3

The efficiency of the market can be tested by evaluating the predictability of the spot prices. If the series are stationary (mean, variance and autocorrelation are independent of time), this implies that the futures values can be forecasted using the current values. The stationarity in spot prices or futures prices does not necessarily imply inefficiency due to the non-storability of electricity which could lead to some predictability in price variation over time according to Eydeland and Geman (1998). However, arbitrage opportunities can arise if the two markets are stationary and there is a multi-settlement system that runs binding forward markets (Cameron and Cramton (1999)).

Before testing the stationarity of the data, we will adjust the daily and weekly spot prices for seasonality by estimating the following regression and measure their effects on prices:

$$s_t = \alpha_0 + \sum \alpha_i D_i + \hat{u}_t$$

The residual is considered as the de-seasonalized value of the daily and weekly spot prices that would be used to perform the ADF tests.

Table 7.3 Estimation of seasonality using dummy variables
Daily spot prices

Period	α_0	t-statistic	F	α_1	t-statistic	F	α_2	t-statistic	F
1999-2009	3.41	258.39	0.000	-0.13	-7.19	0.000	-0.27	-14.53	0.000
2000-2004	3.26	179.5	0.000	-0.08	-3.26	0.001	-0.29	-11.33	0.000
2005-2009	3.69	282.15	0.000	-0.17	-9.29	0.000	-0.22	-11.86	0.000
1999-2001	2.86	152.56	0.000	-0.08	-3.12	0.002	-0.31	-11.74	0.000
2002-2004	3.51	199.8	0.000	-0.12	-4.99	0.000	-0.32	-12.88	0.000
2005-2007	3.64	199.84	0.000	-0.19	-7.31	0.000	-0.24	-9.52	0.000
2008-2009	3.76	232.14	0.000	-0.15	-6.44	0.000	-0.18	-7.87	0.000

Weekly spot prices

Period	α_0	t-statistic	F	α_1	t-statistic	F	α_2	t-statistic	F
1999-2009	3.42	98.12	0.000	-0.13	-2.66	0.008	-0.27	-5.49	0.000
2000-2004	3.27	68.32	0.000	-0.08	-1.15	0.253	-0.29	-4.34	0.000
2005-2009	3.69	109.75	0.000	-0.17	-3.54	0.000	-0.21	-4.57	0.000
1999-2001	2.87	58.65	0.000	-0.08	-1.22	0.225	-0.30	-4.44	0.000
2002-2004	3.51	75.63	0.000	-0.12	-1.77	0.079	-0.32	-4.91	0.000
2005-2007	3.65	76.45	0.000	-0.19	-2.78	0.006	-0.24	-3.60	0.000
2008-2009	3.76	94.35	0.000	-0.14	-2.48	0.015	-0.18	-3.17	0.002

According to table 7.3 the coefficients of the dummy variables are highly significant except for the three highlighted values. One can conclude that they play a role in the considered season even though the adjusted R-squared is relatively low (around 9%).

Both coefficients of season “winter 1” and season “summer” are negative which means that the price would decrease in comparison with the omitted season “Winter 2” with and evident higher decrease in the summer season.

The following regression equation will be estimated to test the stationarity of the time series:

$\Delta s_t = \mu + \lambda t + \psi\, s_{t-1} + \Sigma\alpha_i\, \Delta s_{t-i} + u_t$

where

$s_t = \ln S_t$

μ, ψ, α_i are the coefficients and u_t the residual is a white noise.

λt represents a trend term.

μ is expected to be equal to zero.

The choice of the appropriate number of lags i to be used in the ADF test is determined by minimizing the Schwarz Bayesian information criterion BIC and the Akaike information criterion AIC.

The null hypothesis H_0: $\psi = 0$

The alternative hypothesis H_1: $\psi < 0$

If the null hypothesis is not rejected, the time series is non stationary and contains one unit root. The market can be considered as efficient.

If the null hypothesis is rejected against the alternative hypothesis, the series is stationary.

The non stationarity of the series reveals that the price follows a random walk which is an indication of market efficiency since the price differences are unpredictable and the prices are not autocorrelated. Future values cannot be forecasted using the current values. Therefore arbitrage opportunities would not be possible.

Table 7.4 ADF test for daily and weekly spot prices
5% CV= -2.86 5% CV= -2.88

Period	Test statistics for daily prices	lags	Test statistics for weekly prices	lags
1999-2009	-2.739	29	-2.665	2
2000-2004	-1.95	21	-2.095	4
2005-2009	-3.166	21	-3.03	1
1999-2001	-2.087	14	-2.143	0
2002-2004	-2.193	14	-1.646	2
2005-2007	-2.129	14	-1.7	0
2008-2009	-3.062	9	-2.278	0

The null hypothesis of a unit root is rejected when the test statistic is more negative than the critical value CV.

Table 7.4 shows that the daily spot prices are stationary and consequently the market is considered inefficient during the periods 2005-2009 and 2008-2009. However, the weekly prices contain one unit root and therefore are not stationary except for the period 2005-2009.The hypothesis of market efficiency is not rejected for the whole 10 years-period but we cannot strictly confirm this statement due to the inefficiency of certain sample sub-periods.

b) Futures prices

Next, the stationarity of futures prices should be examined in order to investigate the price development and infer some preliminary conclusions about market efficiency.

The ADF test is run on the different futures contracts[18] to detect the presence of unit roots. The appropriate number of lags to be added in order to minimize the information criteria for futures prices was always zero.

$$\Delta f_t = \mu + \lambda t + \psi f_{t-1} + \Sigma\alpha_i \Delta f_{t-i} + u_t$$

where $f_t = \ln F_t$

[18] For instance ‘contract week 3’ is the futures contract for delivery in 3 weeks. The sample period in each contract differ slightly every time. The test statistic for spot prices differs consequently.

Table 7.5 ADF test of futures contracts

Daily futures prices 2007-2009

5% CV= -2,86

contract	test statistic for futures price	contract	test statistic for futures price	contract	test statistic for futures price
week1	-2.216	month1	-1.964	quarter1	-1.798
week2	-1.976	month2	-1.869	quarter2	-1.276
week3	-1.884	month3	-1.740	quarter3	-1.201
week5	-1.787	month4	-1.446	quarter4	-1.492
week6	-1.852	month5	-1.224	quarter5	-1.450
		month6	-1.057	quarter7	-1.114
				quarter8	-1.534

Table 7.6 ADF test of daily spot prices 2007-2009

contract	test statistic spot	lags	contract	test statistic spot	lags	contract	test statistic spot	lags
week1	-2.734	1	month1	-2.564	1	quarter1	-2.564	1
week2	-2.582	1	month2	-2.564	1	quarter2	-2.564	1
week3	-2.715	1	month3	-2.564	1	quarter3	-2.564	1
week5	-2.257	1	month4	-2.426	1	quarter4	-2.562	1
week6	-2.340	1	month5	-2.420	1	quarter5	-2.566	1
			month6	-2.402	1	quarter7	-2.424	1
						quarter8	-2.550	1

The futures contracts contain a unit root and therefore are non stationary during the sample period.

Using the ADF test to examine the stationarity of futures and spot prices, one can infer some indications about market efficiency. The futures prices are non stationary which implies that the prices follow a random walk and arbitrage opportunities derived from predicting price differences are limited. The sample period used to test the stationarity of futures contracts is not very extensive but is focused on the futures prices with different maturities during the recent period. Futures prices have a zero lag length while spot prices during the same period studied have one lag length which could be explained by the intuition that prices move together since the series lag length are very close.

Our analysis will also be complemented with the cointegration technique to investigate this feature.

7.2.2 Cointergration test

In the attempt to test the cointegration between the spot and futures prices, our goal is to use this methodology to reveal the existence of a common trend and a long term equilibrium relationship. The cointegration method allows investigating long term relationship between non stationary series. For spot and futures prices, the cost of carry model explains the economical intuition of the long run equilibrium.

If the cointegration relationship is not rejected, this would reflect an efficiency in the market since shocks in the futures price would also affect the expected spot price and the two prices would converge avoiding arbitrage opportunities.

According to theory, in an efficient market, spot and futures prices are expected to be cointegrated since they are prices for the same asset at different points in time and will react similarly to new information. The cointegration reflects the absence of price differences and evidently the absence of arbitrage opportunities.

Following the Engle-Granger procedure, we start by using the ADF tests on the variables (log prices of spot and futures) to check for unit roots. Then, we estimate the cointegrating regression model:

$$s_{t+1} = \gamma_0 + \gamma_1 f_t + z_t$$

We proceed to test the stationarity of the residuals using the following regression:

$$\Delta z_t = \psi\, z_{t-1} + v_t$$

where v_t is an iid term

The null hypothesis H_0: $\psi = 0$ which means $z_t \sim I(1)$ and that there is no cointegration and no long run equilibrium relationship.

Alternative hypothesis H_1: $\psi < 0$ which means $z_t \sim I(0)$ and that there the variables are cointegrated.

We use the critical values tabulated by Engle and Yoo (1987) which are larger in absolute value than the DF or the ADF critical values generally used on raw values, while the residuals are constructed from a set of coefficient estimates. The estimation error in the coefficient will modify the distribution of the test statistics.

Table 7.7 ADF test of the residuals

5% CV= -2,86

contract	Test statistic for residual	lags	contract	Test statistic for residual	lags	contract	Test statistic for residual	lags
week1	-11.74	0	month1	-6.315	1	quarter1	-3.834	1
week2	-9.536	0	month2	-4.95	1	quarter2	-2.112	1
week3	-8.508	0	month3	-3.576	1	quarter3	-1.596	1
week5	-5.049	1	month4	-2.723	1	quarter4	-2.084	1
week6	-5.185	1	month5	-1.944	1	quarter5	-2.17	1
			month6	-1.52	1	quarter7	-1.469	0
						quarter8	-2.023	1

If the residuals are I(0), this means that they are stationary and the variables are cointegrated. We can proceed then to the next step;

As observed in table 7.7, the residuals are stationary for the week contracts, the three first month contracts and the first quarter contract. As the time to maturity is longer, we observe that the residuals tend to contain a unit root and therefore the cointegration hypothesis is rejected at a 95% confidence level. Consequently the market efficiency is rejected.

The second step is to build the ECM by using lagged value of the residual.

$\Delta \ln S_t = \beta_0 + \delta z_{t-1} + \beta_1 \Delta \ln S_{t-1} + \alpha_1 \Delta \ln F_{t-1} + v_t$

H_0: $\delta=-1$, $\alpha_1= 1$, $\beta_1= 0$

H_1: $\delta\neq-1$, $\alpha_1\neq 1$, $\beta_1\neq 0$

Table 7.8 ECM results

contract	α1	p-value	β1	p-value	δ	p-value	constant	p-value
week1	0.13	0.04	-0.08	0.05	-0.44	0.00	0.00	0.99
week2	0.16	0.04	-0.12	0.00	-0.30	0.00	0.00	0.97
week3	0.09	0.21	-0.15	0.00	-0.25	0.00	0.00	0.86
week5	0.15	0.06	-0.19	0.00	-0.19	0.00	0.00	0.90
week6	0.09	0.28	-	0.00	-	0.00	0.00	0.90

			0.18		0.19			
month1	0.11	0.14	-0.17	0.00	-0.23	0.00	0.00	0.97
month2	0.07	0.37	-0.19	0.00	-0.17	0.00	0.00	0.96
month3	-0.12	0.14	-0.22	0.00	-0.12	0.00	0.00	1.00
quarter1	-0.06	0.45	-0.21	0.00	-0.12	0.00	0.00	0.98

The statistical software used to perform the regressions is stata.
A p-value higher than 0.05 means that we reject the null hypothesis.

Out of the 18 different maturities of the contracts during the sample period, 9 were cointegrated according to table 7.7 which reflects the existence of a long term relationship between spot and futures prices and consequently the convergence of prices that would eliminate arbitrage opportunities. This long term relationship can be explained by the framework of the storage theory.

The ECM tests resulted in rejecting the null hypothesis for the remaining contracts except for the contracts with delivery in one and two weeks. The signs of the coefficients can be interpreted as follows:

α_1 is positive which means that the futures market is leading the spot market. β_1 is positive indicates a positive autocorrelation in spot returns. Positive δ means that the difference between spot and futures prices is negative and the spot price would increase to reach the equilibrium.

The coefficients are significant for contracts week 1 and week 2. The pricing of contracts is considered following the efficiency hypothesis for those contracts.

7.3 Limits

Regarding the ECM tests, we used the current futures price to predict future spot price. This methodology does not take into consideration the possibility that the current spot price can also be related to future movement of futures price. The VECM approach can be more comprehensive in terms of this aspect in order to describe the equilibrium relationship between spot and futures prices and the velocity of adjustment towards the equilibrium and judge whether the combination of lagged futures and spot price has predictability power.

Besides, the results of the econometric tests could be complemented with out of sample test.

7.4 Conclusions

The results of the ADF tests are not conclusive about the market efficiency in Nord Pool. According to the strong form of market efficiency, one would reject the efficiency hypothesis due to the presence of one or more periods of inefficiency where the predictability of spot prices is considered strong enough. Even with the presence of dominant indications of market efficiency observed in the non stationarity of the prices, the predictability of spot prices in certain periods lead us to estimate that the market seems to be inefficient.

The cointegration technique resulted in confirming this statement since half of the futures contracts analyzed are not cointegrated with the spot prices. We observe a tendency that the larger the time to maturity of the futures contract, the higher is the possibility that it is not cointegrated with the spot price and consequently would lead to market inefficiency.

The non cointegrated series would lead to market inefficiency since spot and futures price reaction to new information would not follow the same trend creating price differences, deviating from the cost of carry model and consequently lead to arbitrage opportunities.

8. Conclusions

In general, the electricity prices are extremely volatile relatively to other traded commodities like oil and gas. The Nordic power market is considered as the most mature established electricity market therefore many studies have approached the price dynamics in this market for different purposes.

The supply and demand are the determinants of electricity prices. It is important to mention the impact of climatic factors on supply and demand in addition to other factors that would result in the high volatility of power prices.

The Nordic power market has and would experience shortages in electricity supply due to these climatic factors and the strong dependence on hydropower.

Risks related to trading electricity in the Nordic market are evidently linked to the price volatility. Therefore the market participants give a careful attention to the hedging possibilities provided in the power exchange Nord Pool in order to cover or minimize their risks. In addition, the power exchange is the market place for speculative operations. The volatility analysis would give an indication about the risk in Nord Pool. With an empirical daily volatility close to 10%, the market is considered as relatively stable and very attractive to investors which would contribute to enhance the market efficiency by increasing the number of participants and the market liquidity.

In this thesis, we attempted to analyse the main factors that could contribute to the market efficiency such as the market structure and the determinants of power prices.

The Nordic market and in particular the Norwegian power market have settled efficient rules and regulations to run effectively the trading in a competitive way especially concerning the issues relative to probable market power . However, the high dependence on hydropower and the seasonality of the market can give some predictability to the electricity pricing.

To complement our analysis, an empirical study was conducted on the Nordic power exchange in order to investigate the market efficiency.

Descriptive statistics were used to better picture the data, then the ADF tests were performed on daily and weekly spot prices. Finally the Engle-Granger procedure was used to perform the cointegration technique.

The results of the tests seem to show that the market is interpreted as inefficient in certain periods. Therefore, the hypothesis of market efficiency according to its strong form would be rejected although we have observed signs of market efficiency in other periods.

However the inefficiency can be explained by other economical factors such as consumption and supply, weather, the market power and etc.

The contribution of this thesis is evidenced in empirically testing the efficiency of the Nordic Power exchange during the recent period using modern techniques such as the cointegration method and providing a thorough analysis of the various factors behind reaching a competitive and efficient power market such as its structure and stability. The previous studies on the efficiency of Nord Pool are limited and rather outdated. Gjølberg and Johnsen (2001) test results suggested the inefficiency of the market.

The pricing theory consisting of the cost of carry hypothesis used to explain the economic intuition behind our empirical analysis can be a controversial topic to price electricity futures. The storage theory is considered not applicable on electricity trading since it is a flow that is complex to store. However, the Nordic market relies mainly on hydropower which can be stored in the form of water in the reservoirs. It gives more flexibility to suppliers and none to the consumers in the arbitrage possibilities. Gas as a source of power generation can also be considered storable as many oil and gas producers are developing efficient storage possibilities for gas such as Statoil facility in Aldbrough in UK.

Further research can be explored on the asymmetry between arbitrage opportunities between consumers and producers in the Nordic market.

9. References

Benth, F. E. et el. (2008): Stochastic modelling of electricity and related markets. Advanced series on statistical science & applied probability vol. 11. Singapore: World Scientific.

Bergman, L. (2003), "European electricity market integration: the Nordic experiences", Research symposium European electricity markets, The Hague. <http://www.ecn.nl/fileadmin/ecn/units/bs/Symp_Electricity-markets/c1_2-paper.pdf> (Novembre 2009)

Brooks, C. (2008): Introductory econometrics for finance. Cambridge: Cambridge University Press.

Bye T. (2003): A Nordic Energy Market under stress: Economic Survey 4/2003, pp 26-37, Statistics Norway.

Bye T. and Hope E. (2006): Electricity Market Reform. The Norwegian Experience. In Lars Sørgard (ed.): 'Competition and Welfare: The Norwegian Experience', the Norwegian Competition Authority, Bergen, September 2006.

Cameron, L. and Cramton, P. (1999): The Role of the ISO in U.S. Electricity Markets: A Review of Restructuring in California and PJM, The Electricity Journal, Elsevier, vol. 12(3), pages 71-81, April.

Chow, Y., McAleer, M. and Sequeira, J. M. (2000): Pricing of Forward and Futures Contracts, Journal of Economic Surveys, Blackwell Publishing, vol. 14(2), pages 215-53, April.

Clewlow, L. and Strickland C. (2000): Energy Derivatives: Pricing and Risk Management, Lacima Publications, London.

D'Agostino, R. B., Belanger, A. J. and D'Agostino Jr R. B. (1990): A suggestion for using powerful and informative tests of normality. American Statistician 44: 316-321. Jarques ben test.

Deng, D. (2006): Three essays on electricity spot and financial derivative prices at the Nordic power exchange. Department of Economics, School of Economics and commercial law, Göteborg University. <http://gupea.ub.gu.se/bitstream/2077/2912/1/Deng_full.pdf> (November 2009)

Dickey, D.A. and Fuller, W.A. (1979): Distribution of the estimators of autoregressive time series with a unit root. Journal of the American Statistical Association, pp. 391–395.

Dickey, D.A. and Fuller, W.A. (1981): Likelihood ratio statistics for autoregressive time series with a unit root. Econometrica, 49, 1057-1071.

Engle, R. F. and Yoo B.S. (1986): Forecasting and Testing in Co-integrated Systems. Journal of econometrics, Vol. 35, No.1, p. 143-159.

Eydeland, A. and Geman, H. (1998): Pricing power derivatives. Risk, October 71-74.

Eydeland A. and Wolyniec K. (2003): Energy and Power Risk Management: New developments in Modeling, Pricing, and Hedging, Wiley, New Jersey.

Fama, E.F. (1970): Efficient capital markets: a review of theory and empirical work. Journal of Finance, pp. 383–417.

Fama, E.F. and French,K.R. (1987): Commodity futures prices: some evidence on forecast power, premiums and the theory of storage, *Journal of Business* (1987), pp. 55–73

Fløtre, E. (1996): Potensialet for futuresomsetning i kraftmarkedet. Master thesis, UiB, Berge.

Geman, Hélyette (2005): Commodities and commodity derivatives: modeling and pricing for agriculturals, metals and energy

Gjølberg, O. and Johnsen, T. (2001): Electricity futures: inventories and price relationships at Nord Pool, Discussion Paper #D-16/2001 (2001).

Gjølberg, O. and Johnsen, T. (2003): The Pricing of Electricity Futures: Empirical Tests for Market Efficiency at NordPool, Mimeo, Norwegian Agriculture University, Mars 2003.

Havn, K.H. (1995): Risikostyring I kraftmarkedet. Spesialfagsoppgave ved høyere avdelings studium i økonomisk-administrative fag, NHH, Bergen.

Hull, John C. (2009): Options, Futures, and Other Derivatives. Seventh Edition, Prentice-Hall series in finance.

James T. (2008): Energy markets: Price risk management and trading. Singapore: Wiley.

Jensen M. C. (1978): 'Some Anomalous Evidence Regarding Market Efficiency, Journal of Financial Economics, Vol. 6, Nos. 2/3.

Kaminski, V. (2004): Managing Energy Price Risk: the new challenges and solutions, 3rd Edition, London: Risk Books.

Konishi, S. and Kitagawa, G. (2008): Information Criteria and Statistical Modeling, New York, NY: Springer Science and Business Media.

Longstaff F.A. and Wang A.W. (2004): Electricity forward prices: a high-frequency analysis, *Journal of Finance,* pp. 1877–1900

Lucia, J.J. and Schwartz, E. (2000): Electricity prices and power derivatives: Evidence from the Nordic Power Exchange. UC Los Angeles: Anderson Graduate School of Management. <http://www.escholarship.org/uc/item/12w8v7jj> (December 2009)

Lundgren, J et al. (2008): "Multinational Electricity Market Integration and Electricity Price Dynamics, "HUI Working Papers 16, The Swedish Retail Institute (HUI).

Nakamura, M. et al. (2006): Electricity markets volatility: estimates, regularities and risk management applications, *Energy Policy*, pp. 1726–1749.

Pilipovic, D. and J. Wengler (1998):"Getting into the swing", Energy & Power

Risk Management, Vol. 2, No. 10, March 1998, pp. 22-24.

Pilipovic, D. (1998): Energy risk: valuing and managing energy derivatives. New York: McGraw-Hill.

Redl, C. Haas R., Huber C. (2007): Forward Markets and their Interactions with Spot Markets - An Empirical Analysis of the Liberalised European Electricity Market (27th USAEE/IAEE North American Conference, Houston, USA).

Redl C. et al. (2009): Price formation in electricity forward markets and the relevance of systematic forecast errors. Energy Economics, vol. 31, issue 3, pages 356-364.

Rud L. (2009): Essays on electricity markets. SNF-rapport. .

Rueda, I. E. A., Barrett, C. and Marathe, A. (2003): Assessing the efficiency of US electricity markets, Utilities Policy, 11, issue 2, p. 75-86. <http://econpapers.repec.org/RePEc:eee:juipol:v:11:y:2003:i:2:p:75-86> (December 2009)

Simonsen, I. et al. (2003): "Modeling highly volatile and seasonal markets: evidence from the Nord Pool electricity market". Econometrics 0303007, EconWPA.

Simonsen, I. (2005): Volatility of power markets. Physica A: Statistical Mechanics and its Applications, v. 355, iss. 1 [SPECIAL ISSUE], p. 10-20.

Thoresen, E. W. and Skinnes, B.I. (2006): The Nordic power market: market efficiency and technical trading systems. Thesis - Master of International Business - Norges handelshøyskole, fall 2006.

Wooldridge, J. M. (2009): Introductory econometrics: a modern approach. Mason, Ohio: South-Western Cengage Learning. 4th ed.

Yang, H. E al. (2009): Empirical Research on Efficiency of the Electricity Futures Market, International Journal of Emerging Electric Power Systems: Vol. 10 : Iss. 2, Article 6.

Internet sources:

Nord Pool ASA, <www.nordpool.no> (2009)

Nord Pool Spot AS, <www.nordpoolspot.no> (2009)

Statkraft AS, <www.statkraft.no> (2009)

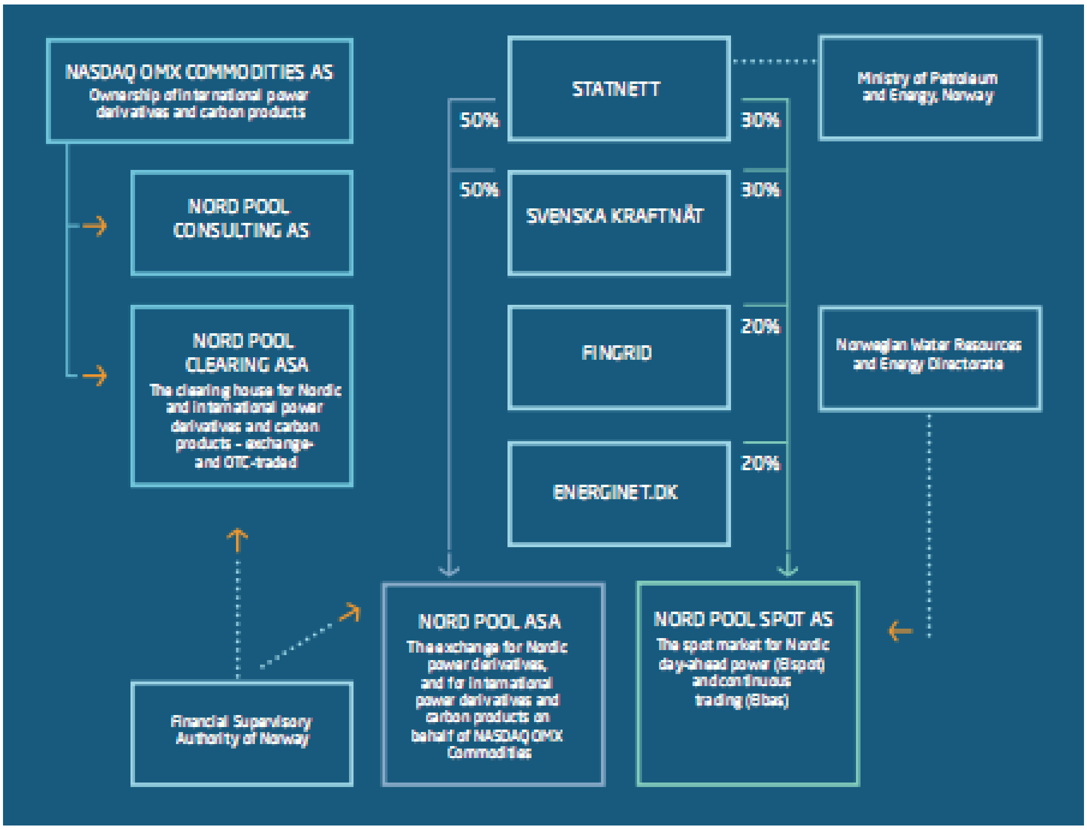
Statnett SF, <www.statnett.no> (2010)

Statistics Norway, <www.ssb.no>

Nordel annual statistics 2008, < http://www.entsoe.eu/index.php?id=65> (2010)

10. Appendices

Appendix 1: Organisation of Nord pool



Source: Nord Pool

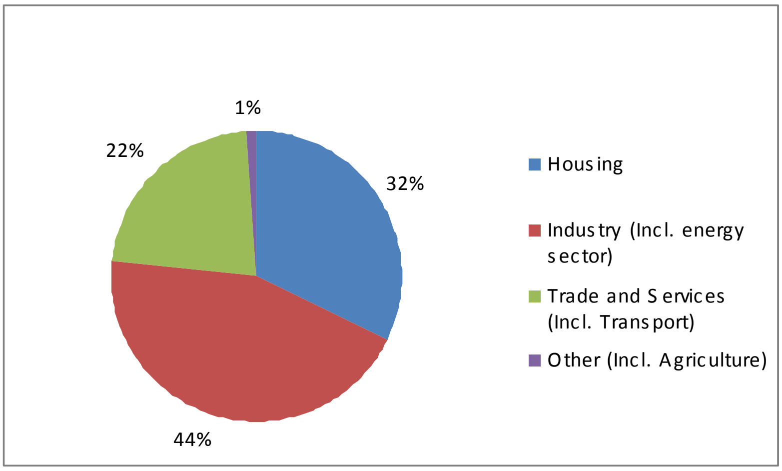
Appendix 2: key figures 2008 in the Nordics

	Nordic	Norway	Denmark	Finland	Iceland	Sweden
Population (Million)	25.2	4.8	5.5	5.3	0.3	9.3
Total consumption (TWh)	412.7	128.9	36.1	87	16.6	144.1
Maximum load[1] (GW)	61	18.4	6.1	12.5	1.7	22.2
Electricity generation (TWh)	414	142.7	34.6	74.1	16.5	146

Source: Annual statistics 2008 Nordel

[1] Measured 3rd Wednesday in January

Appendix 3: Estimated net[2] consumption of electricity 2008 by consumer category

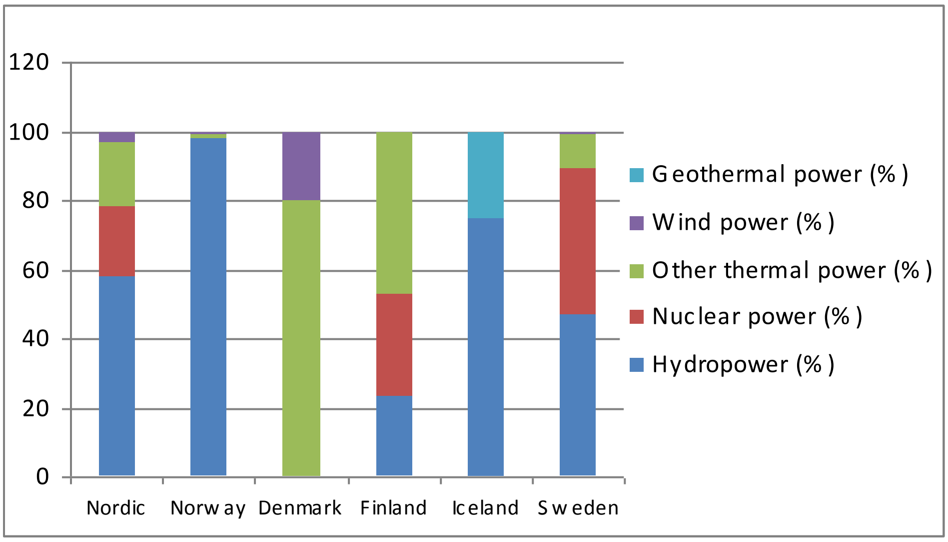


Source: Annual statistics 2008 Nordel

[2]Net consumption= The sum of the electricity delivered to the end users

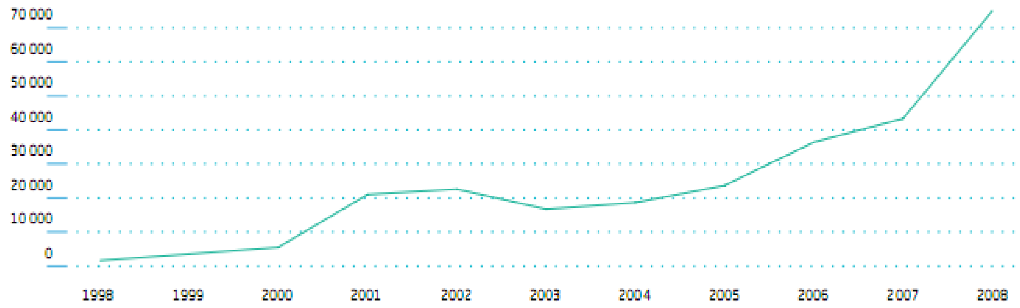
= Total consumption - Occasional power to electric boilers - (*Temperature correction*+ Grid losses+ Pumped storage power)

Appendix 4: Breakdown by electricity generation 2008 (%)



Source: Annual statistics 2008 Nordel

Appendix 5: Power volumes (EUR Million) 1996-2008



Source: Nord Pool ASA Annual report 2008

Appendix 6: HHI the Herfindahl-Hirschman Index

"HHI" means the Herfindahl-Hirschman Index, a commonly used measure of market concentration. It is calculated by squaring the market share of each firm competing in the market and then summing the resulting numbers. For example, for a market consisting of four firms with shares of thirty, thirty, twenty and twenty percent, the HHI is 2600 ($30^2 + 30^2 + 20^2 + 20^2 = 2600$). The HHI takes into account the relative size and distribution of the firms in a market and approaches zero when a market consists of a large number of firms of relatively equal size. The HHI increases both as the number of firms in the market decreases and as the disparity in size between those firms increases. Markets in which the HHI is between 1000 and 1800 points are considered to be moderately concentrated and those in which the HHI is in excess of 1800 points are considered to be concentrated.

Appendix 7: The Bera-Jarque normality test

Period	Prob>chi2 daily prices	Prob>chi2 weekly prices
1999-2009	0.0000	0.0010
2000-2004	0.0000	0.0000
2005-2009	0.0000	0.0003
1999-2001	0.0001	0.0493
2002-2004	0.0000	0.0000
2005-2007	0.0000	0.0025
2008-2009	0.0000	0.0005

We would reject the null hypothesis of normality when the p-value is lower than 0.05

Appendix 8: Stochastic processes

i. White noise:

It is a stochastic process characterized by uncorrelated data, constant mean and variance. It is a pure random process.

$E(y_t) = \mu$

$var\ (y_t) = \sigma^2$

$cov\ (y_t, y_{t-r}) = \sigma^2$ if $t=r$

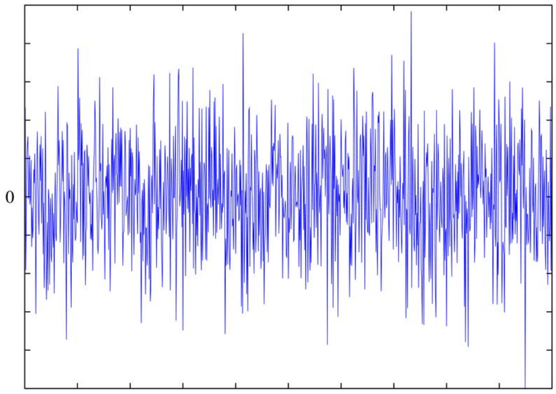
$= 0$ otherwise

When the mean is equal to zero, we have a zero mean white noise.

A commonly used notation for a white noise process is "independently and identically distributed" (iid) random variables.

Example of white noise process:

A plot of normally-distributed white noise (pure random process)



An example realization of a Gaussian white noise process.

ii. Random walk (RW)

A simple random walk process is defined such that the considered variable y take a current value that is dependent from its value during the previous period plus an error term assumed to be a white noise.

It is represented as follows: $y_t = y_{t-1} + \varepsilon_t$

The main characteristic of this process is that the change $y_t - y_{t-1}$ is completely unpredictable and random.

The mean of a random walk is constant while its variance increases with t which indicates that the process is not stationary and therefore OLS is not applicable and would give spurious results. On the other hand, differencing the model once would result in a stationary process.

A random walk with a drift is characterized by a trend

The model is written as follows: $y_t = a + y_{t-1} + \varepsilon_t$

If the drift (a) is positive, the process would exhibit an upward trend and vice versa.

The variable dynamics show that the mean value is crossed very rarely.

According to Brooks (2008) many financial and economic time series follow a random walk process either with a drift or without.

iii. Autoregressive process (AR)

In this type of model, the current value of the variable y is dependent on its value during the previous periods with the addition of an error term u_t that is a white noise disturbance term.

Using the lag operator, the model is written as follows:

$y_t = \mu + \Sigma\, \varphi_i\, L^i y_t + u_t$

or $\varphi(L)y_t = \mu + u_t$ where $\varphi(L) = (1 - \varphi_1 L - \varphi_2 L^2 - \ldots - \varphi_p L^p)$

To obtain valid results by applying the OLS method on an AR model, stationarity is an important property that has to be satisfied.

Appendix 9: Product calendar

Futures week contracts

Contract terms:

Spot Reference Price:	Nordic System Price
Quoted currency:	EUR
Settlements:	Daily Cash Settlement and Spot Reference Cash Settlement
Load:	Base load
Tick size in ETS:	0,01EUR/Mwh.
Contract Volume:	1 MW
Cascading:	No cascading
Settlement Date:	Every Clearing Day after an Opening Trade until end of the delivery period

Week contracts, base load, ENLBLWxx-xx

ENLBLW01-09 (product series)
First trading day: 01.12.08
Last trading day: 23.12.08
Start of delivery period: 29.12.08
End of delivery period: 04.01.09

Forward month contracts

Month contract, base load, ENOMmmm-yy

ENOMJAN-09 (product series)
First trading day: 01.07.08
Last trading day: 30.12.08
Start of deliver period: 01.01.09
End of delivery period: 31.01.09
Cascaded from: ENOQ1-09

Forward quarter contracts

Quarter contract, base load, ENOQx-yy

ENOQ1-09 (product series)
First trading day: 02.01.07
Last trading day: 30.12.08
Start of deliver period: 01.01.09
End of delivery period: 31.03.09
Cascaded from: ENOYR-09