NTNU
Norwegian University of
Science and Technology

Faculty of Social Science and
Technology Management
Department of Industrial Economics
and Technology Management

Aspects of Electricity Futures

Diploma Thesis

for

Audun Botterud

Trondheim
December 1997

Preface

This thesis is the final part of my “Sivilingeniør” degree at Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU). The work with the thesis was carried out during autumn 1997 in Trondheim.

Sincere acknowledgements go to my two supervisors at NTNU, Stein Erik Fleten and Prof. Dominicus van der Wijst, whose guidance and advice were invaluable in the preparations for this manuscript. I would also like to thank the Nordic Power Exchange, Nord Pool, which was very helpful and provided me with all the information and data I asked for.

Responsibility for the content and conclusions in this thesis rests solely with the author.

NTNU, Trondheim, 22.12.1997

Audun Botterud

Summary

The deregulation of the electricity market in Norway, and the following need for new risk management tools, among them futures contracts for electricity, is the background for this thesis. The thesis focuses on different aspects of electricity futures, with emphasise on the conditions in the Norwegian electricity market.

In the first part of the thesis I look at *general criteria for a well-functioning futures market*, to assess the sustainability of Nord-Pool's electricity futures market. I find that most of the criteria are fulfilled, but argue that market concentration, due to Statkraft's and Vattenfall's considerable market share in Norway and Sweden, probably represents the main obstacle to obtain a perfectly functioning futures market.

Pricing electricity futures contracts is the subject for the second part. The most common theory for commodities futures prices is based on the concepts of storage cost and convenience yield. I argue that there is no direct storage cost involved in storing electricity as water in reservoirs. For producers of electricity there could be a convenience yield concerned with storing water and hence being able to adjust the production to instant future price movements. The convenience yield is, however, very difficult to quantify and is probably not taken into consideration when pricing futures contracts for electricity today. No storage cost and convenience yield is consistent with the expectations hypothesis for futures prices, i.e. the futures contract price equals the expected future spot price. An empirical analysis of the historical prices in Nord Pool's futures market gave no significant evidence that could reject the expectations hypothesis for electricity futures.

There is another theory for futures contract prices which is based on the Capital Asset Pricing Model (CAPM). The theory claims that the element of systematic risk in the futures market, i.e. the part of the futures contracts' total risk which is related to moves in the overall market portfolio, can explain the returns on and thereby the prices of futures contracts. I argue that the element of systematic risk is probably not important for the main part of the participants in the electricity futures market, since they can not be considered as investors with well diversified portfolios of investments. Empirical analysis of electricity spot and futures prices did not give significant evidence for the CAPM's ability to explain the observed prices in electricity futures market the last two years. The theory is therefore rejected. The analysis I have carried out on electricity futures prices indicates in sum that the market price of an electricity futures contract is an unbiased estimator of the market's expected future spot price for electricity.

In the last part of the thesis I concentrate on *hedging strategies*. Basis risk, i.e. risk caused by the difference between the spot price and the futures price, is of major concern for hedgers in many futures markets. In the electricity futures market, however, basis risk is removed for the contractual volume because of the price securing settlement during the delivery week. The average difference between the futures price on the last day of trading and the average spot price in the following delivery week was more than 8% of the closing futures price, for the last two years in Nord Pool's futures market. The size of this difference clearly shows the risk reducing

effect of the price securing settlement. The price securing settlement also affect the traditional calculation of the optimal hedge ratio for futures contracts. I show that the optimal hedge ratio is one, assuming that the purchased futures contracts are held to delivery and that the contractual volume is traded in the spot market during delivery week. This ratio does, however, not take account for the uncertainty about the future exposure that the electricity companies are faced to.

Finally, I analyse the shape of the electricity forward curve, i.e. a curve showing the prices for electricity futures contracts with different times to delivery. Interpretation of historical data show that the prices of contracts with different maturities tend to move in the same direction, but the shifts are seldom parallel, and the contracts for the near future are considerably more connected to the spot price than for the far end of the curve. The electricity forward curve has much in common with the term structure of interest rates. Factor models similar to the ones used for describing the instantaneous changes in the short-term interest rate can therefore also be applied to predict electricity prices in the future. A good model could be very helpful in pricing of futures and options contracts, and would also be a tool for determining the risk exposure for different time periods in the future.

The reader of this thesis should always keep in mind that the amount of price data from the deregulated electricity market is very limited. Many of the conclusions must therefore be considered as preliminary.

Table of contents

List of figures

List of tables

1 Introduction

1.1 Background

The Norwegian market for electricity was deregulated in 1991. Norway was one of the first countries in the world to introduce competition in generation and supply of electricity, and England was the only European country deregulating the electricity market before Norway. Reorganisation of the electricity sector towards a market-based decentralised system is under consideration and even in progress in several countries. The Swedish electricity market was organised in a similar way to the Norwegian in 1996, while Finland followed in 1997. Today there is an extended cooperation between the Norwegian and Swedish electricity sectors and a common power exchange, Nord Pool, was established in 1996.

The deregulation has faced the participants in the electricity market to a new and demanding environment. The element of risk concerning the future price of electricity was considerably increased when the old regulated system was replaced. A rapid growth in the use of risk-sharing instruments, which allow consumers and producers to hedge their price-risk, has taken place. Futures and options are derivative instruments which are extensively used for risk management in other markets. The last years we have seen an introduction of these instruments also in the electricity market, and Nord Pool offers today an organised market place for trading of futures contracts for electricity.

1.2 Scope and limitations

In this thesis I try to illuminate different aspects of the electricity futures market. My aim is twofold. First I hope to present general theory about finance and futures trading which is relevant for the electricity market. Then I look at electricity futures in the light of the presented theory. A requirement in such an analysis is of course a fundamental understanding of the special conditions prevailing in the electricity market, and insight in how the spot and futures market for electricity is operated.

There are numerous questions to ask and approaches to take, when analysing the new electricity market. To limit the scope of the thesis I have emphasised the conditions prevailing in the Norwegian hydropower electricity market. The main part of the analysis focuses on Nord Pool's organised futures market, the bilateral market is only briefly discussed. I have further confined the thesis to include the following concepts, which I during my work found relevant and interesting:

1. The functions and sustainability of Nord Pool's new futures market for electricity.
2. Pricing models for futures contracts, and their validity for electricity futures.
3. Relevant hedging strategies in financial markets, and the degree to which these are transferable to the electricity market.

Most of the work is devoted to the last two parts. The discussion and conclusions in the thesis are based on theoretical considerations about the existing conditions in the electricity market in combination with an analysis of the historical price data for electricity spot and futures prices from Nord Pool's markets. Already in the introduction I would like to emphasise that the price material from the deregulated electricity market naturally is very limited. Many of the conclusions in the thesis must therefore be considered as preliminary.

The final version of this thesis might deviate a bit from the initial thesis outline. This is because the contents in it have evolved continuously as I obtained more insight and knowledge about the electricity market. During the work I chose to concentrate on the aspects of the market which I found most interesting.

1.3 Outline of the thesis

In chapter 2 I give a description of the electricity market. I present general facts about the market and outline the trading procedures in Nord Pool’s spot and futures market. I also take a brief look at the bilateral market, which comes in addition to Nord Pool’s organised market.

The remaining three chapters are devoted to the three subjects I described above. In the discussion I try first to present relevant theory from finance, and then connect this theory to the electricity market. At the end of each of these chapters I present a chapter summary, which contains the main results and conclusions from the chapter.

In the text I present several figures and tables which are the results from calculations based on historical price data from Nord Pool’s spot and futures market. The calculations include large amounts of data, and are inconvenient to present as printouts. A floppy containing Excel-files with the main calculations are therefore attached on the last page. An overview of the different files’ contents is given in *Appendix 2*.

2 The Electricity Market in Scandinavia

In this chapter I give a description of the electricity market in Scandinavia with emphasis on the situation after the deregulation of the electricity market in Norway and Sweden. An understanding of how the electricity market is operated is important for the analysis in the next chapters. The services provided by the official Scandinavian power exchange, Nord Pool, are first described. In addition to Nord Pool there is also an extended trade with bilateral contracts. These are either traded directly between two participants or through a broker firm. I present the bilateral market at the end of the chapter.

2.1 The power Exchange-Nord Pool[1]

As a result of the deregulation in the generation and supply of electricity in Norway and Sweden a common power exchange called Nord Pool has been established for the two countries. The power exchange was originally only operating in Norway under the name Statnett Marked, but in 1996 the world's first multinational power exchange was introduced when Sweden deregulated the market and took part in an extended co-operation with the Norwegian power sector. Today Nord Pool plays a crucial role for the price formation process in the Scandinavian electricity market.

More than 140 participants buy and sell power at Nord Pool's exchange. The participants are power producers and distributors, large industrial companies, brokers and traders. Most of the participants come from Norway and Sweden, but there are also a few from Denmark and Finland. Nord Pool offers two main markets for electricity trading, the spot market and the term market. While the spot market is a market place for physical delivery of electricity, the term market is a futures market with cash delivery (no physical delivery). There is also a controlling market for power, which basically is a tool to continuously keep the balance between supply and demand of electricity. I will give a description of the different markets below.

2.1.1 The spot market (Elspot)

The spot market is a contractual market where contracts for power delivery the following day are traded. Payment is done at the end of each week according to the agreed contracts and independent of the quantity of the real consumption. Statnett SF (the Norwegian grid company) is responsible for the trading system in Norway. The grid control is supposed to use market mechanisms in the spot market to adjust the power supply so that critical situations at bottlenecks in the transmission grid are avoided. Svenska Kraftnett has the same responsibility in Sweden. Statnett AF and Svenska Kraftnett are owners of Nord Pool with 50 % ownership each.

2.1.1.1 The pricing process in the spot market

The participants in the spot market submit sealed bids and offers for the following day to Nord Pool before 12.00. These orders are demand and supply schedules that specify the price-quantity combinations at which buyers and sellers are willing to trade for each single hour the following day (see Table 2.1). For Statnett to be able to operate the transmission system properly all participants in the power market have to notify

---

[1] The facts and figures in this section are, if not else stated, taken from information material published by Nord Pool in 1997(i.e. *Elspot, Eltermin and Annual Report*).

Nord Pool about all their plans for physical delivery or consumption of electricity the following day, including bilateral contracts. Figure 2.1 shows a typical bid/offer curve from a participant in the electricity market. The quantity bought or sold in the spot market depends on the spot price. Based on incoming orders, Nord Pool derives the aggregate supply and demand curves for each hour. The market-clearing prices and quantities are set so that supply equals demand of electricity (see Figure 2.2). This means that the equilibrium price and hence the auction are driven by the order flow. Resulting prices (called system prices) and quantities are revealed to the traders, but the market depth (i.e. orders that are not cleared) is hidden. Figure 2.3 shows system price in the Norwegian spot market since 1992.

Time	**Description**
-12.00	Bids and offers received from the participants by fax or an electronic standardised format.
12.00-14.00	Derivation of price and feedback to the participants about their trade. Specific price announcement to each trader.
14.00-14.30	½ hour complaint period. The participants control that their resulting trade coincidences with their bids and offers.
14.30-	Distribution of a general price announcement and other information to traders and other customers.

Table 2.1 The daily routines for trading in Nord Pool's spot market (Source: Nord Pool).

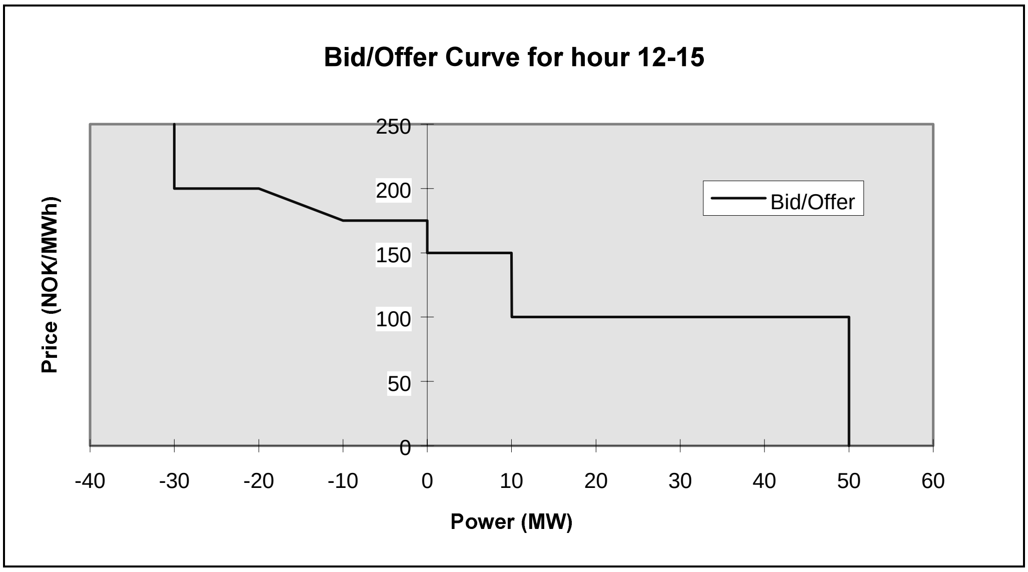


Figure 2.1 A typical bid/offer curve. The area to the right of the y-axis represents buying power, and the area to the left selling power in the spot market. All participants submit bids and orders like this to Nord Pool (Source: Nord Pool).

If the resulting quantity of power causes problems for the transmission capacity in some parts of the transmission network in Norway and Sweden, the two countries are divided into different price areas. The prices in each area are based on the original bids and offers, but a capacity fee, which reduces the demand in high demand areas and vice versa, is added or deducted to the system price to avoid bottlenecks. This explains why there sometimes are different prices for spot electricity in different areas. An explanation of how the capacity fee is calculated is given in *Nord Pool (Elspot)*.

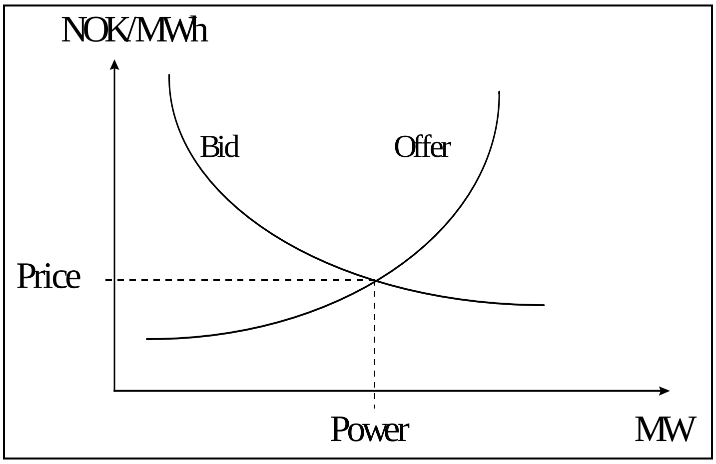


Figure 2.2 The aggregate bid and offer curve determines the price and quantity of power traded, as depicted in the figure (Source: Nord Pool).

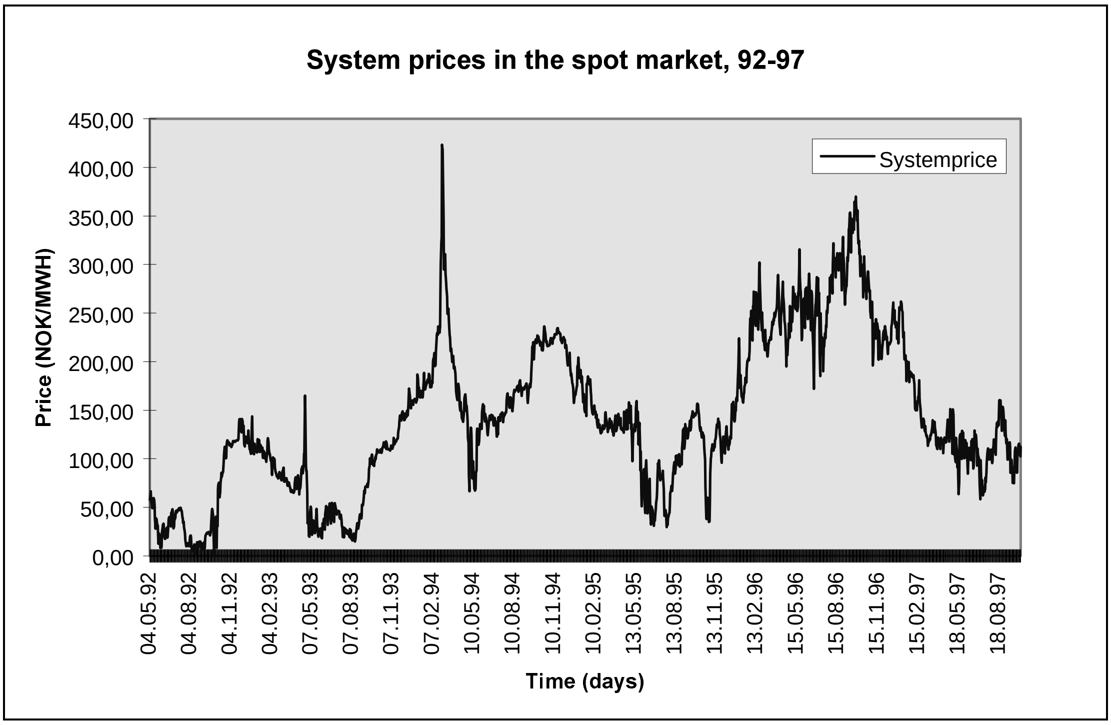


Figure 2.3 The daily system price in the spot market for electricity in Norway since 1992 (Source: Nord Pool).

2.1.2 The term market

The term market (Eltermin) is a futures market in which it is possible to secure the price of power supplies up to 3 years ahead. Standard term contracts for future delivery are traded. Trading in the market involves no physical delivery, since the entire settlement procedure is based on cash delivery. The system price in the spot market is the reference price during settlement of the contracts traded in the term market. Eltermin gives the participants an effective instrument for risk management. Changes in the value of a futures contract is daily settled between long and short position holders. The value of a participant's portfolio is calculated from the aggregate market value of his contracts. In this way the participants can easily realise losses and profits in their portfolio at the end of every trading day.

From 27. October 1997 it is also possible to buy and sell forward contracts at Nord Pool. The main difference between forward and futures contracts is that for forward contracts there is no market settlement in the trading period. This contributes to reduce margin and liquidity requirements in the period before delivery. Nord Pool hopes that this will make the long term market more liquid. Another difference is that while you can trade futures for weeks, blocks and seasons (see below), it is only possible to trade forwards for seasons at Nord Pool.

2.1.2.1 The products in the term market

A contract in Eltermin secures the price of a specified amount of power for a certain period of time. The contract secures a flat power schedule, i.e. the same amount of power throughout every hour of the delivery period. The time horizon in the market is for the time being three years. This means that contracts for delivery up to three years in the future are traded. The contracts are standardised into weeks, blocks and seasons as described below:

Season: The time periods for the seasons are:
Season 1 every year: Week 1-16
Season 2 every year: Week 17-40
Season 3 every year: Week 41-52/53

Blocks: The seasons are divided into blocks in week 1, 17 and 41. When a season is divided into blocks another one is added. Each block consists of 4 weeks.

Weeks: When less than 4 weeks remain to the delivery of a block, it is divided into single weeks. This means that in normal years with 52 weeks, 4-7 weeks are traded every day.

Historical data shows that the movements in prices of the weekly contracts and the most recent block contracts to a large extent have been connected to movements in the spot market price. For contracts with longer delivery periods, the prices are based on expectations of the fundamental conditions prevailing in the power market, according to Nord Pool. I will return to the development of futures prices and the shape of the so called electricity forward curve in Chapter 5.2.

2.1.2.2 Trading procedures with futures contracts

Term contracts are traded on the power exchange continuously between 11.30 and 15.00 all workdays - Monday to Friday. During this time period the participants can submit orders for the different contract types, or trade on the orders already submitted by other participants. Table 2.2 describes the trading procedures in Nord Pool's term market.

Time	**Description**
11.30-15.00.	The market is open for trading between 11.30 and 15.00 every weekday.
15.00-15.30	Closing prices are settled. Still possible to trade on request via help-desk until 15.30.
15.30-16.00	A written confirmation of today's trade is sent to all participants.
Next trading day	
-08.30	The participants receive clearing lists for yesterday's trade.
-11.00	Deadline for payment of margin requirement to deposit or margin account.

Table 2.2 The daily routines of trading in Nord Pool's futures market (Source: Nord Pool).

The market is operating electronically, i.e. all trading is carried out through an electronic system. The participants can trade directly in the market if they are connected to this system, but it is also possible to trade by telephone via an operated help-desk at Nord Pool. The electronic system makes continuously updated information available for the participants. The information system contains:

- The best buying and selling price and the depth in the market (i.e. prices of all the bids and offers submitted into the market). The last traded price and the highest and lowest prices traded during the day.
- The total quantity offered and demanded for each single price.
- A display showing the participant's own position in the market, i.e. bids and offers he has submitted together with the trades that already have been fulfilled during the trading day.

For participants not directly connected to the electronic system the same information is available by calling Nord Pool's help-desk. There are also other online information systems existing[1]. Internet and teletext can give sufficient information for participants which do not require continuously updating. In general, equal and simultaneous access to marketing information is a prerequisite for an efficient market and represents a fundamental pillar of the power exchange. Nord Pool has a special responsibility to ensure equal terms for all participants and to avoid imbalance in the market.

2.1.2.3 Settlement routines

Settlements for trading in the term market are carried out daily. All of them are cash settlements and no physical delivery is carried out. The settlement procedure includes:

- A *market settlement* based on the changes in the market value of the participants' portfolios of contracts. A contract's market value is the closing price of the contract on the trading day. If the market price has increased participants with long positions will receive an amount equal to the increase in price multiplied with the volume. Participants with short positions will have to pay a similar amount.

---

[1] At 01.01.97 the following companies supplied on-line service: Dow Jones, Falcon, First Electric, Montel and TDN.

- A *price securing settlement* for contracts in the delivery period based on the system price in the spot market. In the week of delivery the contract is daily settled according to the difference between the system price and the market price of the contract on the last day before delivery (the fixing price). If the system price is higher than the fixing price the long position will receive an amount equal to the difference between the two prices multiplied with the volume of the contract and vice versa. The other way around for the short position. The price securing settlement procedure secures that the participants end up with the agreed futures contract price as long as the contractual amount is traded in the spot market during the delivery week. Further consequences of the price securing settlement are discussed in the section about hedging strategies and basis risk (section 5.1.2).
- Calculation of the *margin requirements* which are supposed to equal the price risk that Nord Pool is exposed to because of the participant. The margin requirements are today between 3% and 10% of the contract value, depending on the type of the contract (season, block, week).

Figure 2.4 gives a description of the first two settlement procedures. The market settlement is dependent on the development of the futures prices towards expiry of the contract. The price securing settlement is applied to all contracts which are held to delivery and depends on the system price in the spot market during the delivery week.

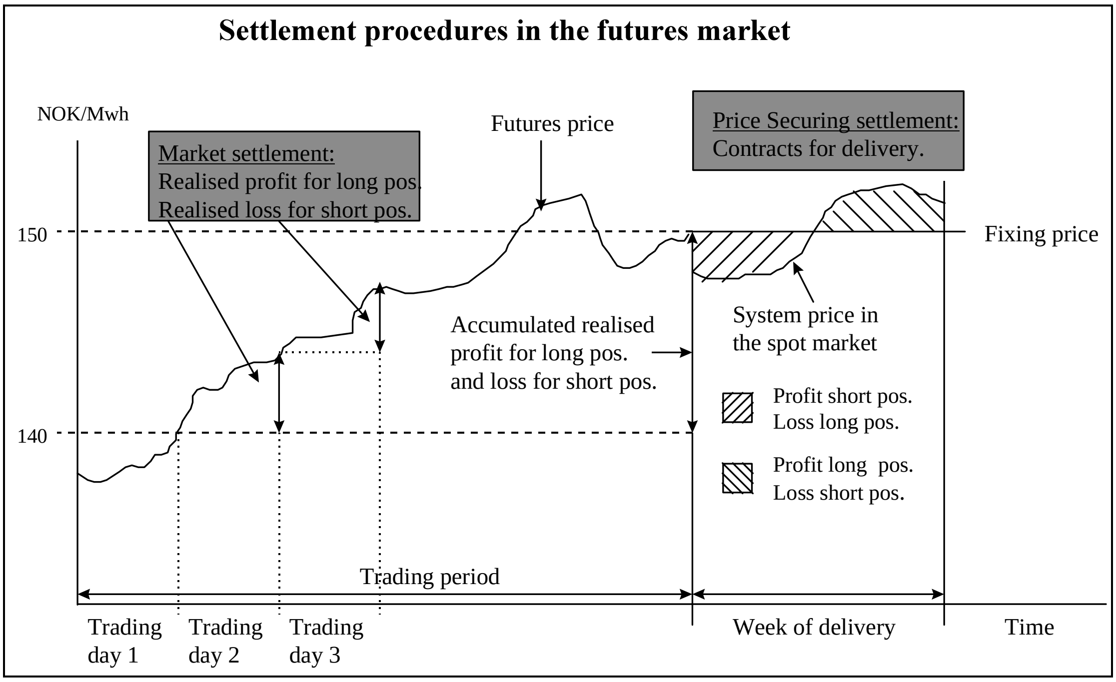


Figure 2.4 An example of the market and the price securing settlement in Nord Pool's futures market. In this example participants with long positions profit in the market settlement towards expiry because of increasing futures price. The price securing settlement is approximately neutral for long and short positions, since the average system price in the delivery week seems to be approx. equal to the fixing price (Source: Nord Pool).

2.1.3 The controlling power market

After the spot market is cleared, the delivery obligations of buyers and sellers are fixed for the following day. This follows from the spot contracts and the negotiated forward contracts (including bilateral agreements - see below). All delivery obligations are reported to the grid control. The electricity demand, however depends heavily on unforeseen factors such as temperature. At the same time the generation of energy may also depend on unforeseen factors such as technical defaults. As contracts state the obligation to take out or generate a specified amount of energy, natural load variations also necessitate adjustments. Thus, in the course of delivery, actual input to the grid may deviate from contracted input, and actual output may deviate from contracted output *(Knivsflå and Rud (1995))*. In the whole power grid system the aggregate supply has to be identical to the aggregate demand at every moment of time, and to adjust the power supply to the deviations from the contract quantities there exist a special market called the controlling power market. The administrative responsibility for the controlling power market was taken over by Statnett during the spring 1997, and this market is not a main topic in this report. For a good description of the way the controlling power market is operated, see *Knivsflå and Rud (1995).*

2.2 The bilateral market

Bilateral contracts are also utilised in the Norwegian power market, in addition to the contracts supplied by Nord Pool. A bilateral contract is traded over the counter (OTC) between two single participants in the market. More than 80% of bilateral contracts were traded through broker firms like e.g. Norsk Kraftmegling and Markedskraft the first four months of 1997, the remaining contracts were traded directly between the participants.

Organisation	Market share (TWh)	Market share (%)
Nord Pool	14	18
Norsk Kraftmegling	24	30
Markedskraft	11	14
Other broker firms	18	22
Direct trading*	13	16
SUM	80	100

*Table 2.3 The market share for futures contracts of electricity (without physical delivery) for different broker firms and Nord Pool between 01.01 and 01.05 1997. *Direct trading means trading directly between two participants without the help of intermediaries (Source: Rønningsbakk (1997)).*

As Table 2.1 shows, the bilateral market covers a larger quantity of power than Nord Pool's organised Eltermin market, and therefore makes a considerable impact on the whole term market. Especially for long-term contracts many of the participants use bilateral contracts instead of Nord Pool's official exchange. Nord Pool has even lost market share in the first months of 97, after having had a market share of about 25% of the futures market in 95 and 96. A common practice among participants in the market is to use Nord Pool for trading in week contracts and the nearest blocks, while bilateral contracts are preferred for larger contracts further ahead in the future *(Rønningsbakk (1997))*. The fact that long-term season contracts involve larger quantities of electricity, measured in TWh, than short-term week and block contracts explains some of the size of the broker firms' market share. The numbers presented above is consistent with volume data from Nord Pool, which shows that the liquidity in Nord Pool's Eltermin is very good for contracts with a short horizon, while it declines for long-term contracts.

Trading via broker firms is cheaper than using Nord Pool *(Rønningsbakk (1997))*. At the same time the participants in the electricity market were used to deal with bilateral contracts before the deregulation. This is probably the main reasons for the broker firms' high market share in long-term contracts. An advantage with bilateral contracts compared to the standardised contracts in Eltermin is that they can be tailored to fit the customers' needs. The flexibility in the contracts might include prices, duration, volume, price regulations, payment procedures etc. Still, a growing feature of the bilateral market is more standardised contracts. The standardised contracts do not differ very much from the contracts traded in Nord Pool's futures market (Eltermin). A standardisation of the contracts contributes to reduce the trading costs and at the same time improve the liquidity by making the contracts more tradable in secondary markets.

It is also possible to buy and sell other derivatives like options in the bilateral market. There is no official market place for electricity options, so that each option-contract has to be agreed between two specific participants. The bilateral options market is, however, not very liquid today, mainly due to the high risk involved in writing (selling) options. Buying options is very attractive because the only value you put at risk is the price you pay for the options. When writing options, however, you risk loosing much more than the option price, and for call options you can in theory loose infinitely. Options are basically a good tool for risk management, but it requires a liquid market with a sufficient number of participants. Low willingness to speculate in selling options makes the market for electricity options illiquid so far. A more liquid options market will probably emerge some time in the future when the electricity companies becomes more familiar with this instrument at same time as more speculators probably will enter the market. Options are not traded in Nord Pool's organised market.

The reason why I have chosen not to take a closer look at the bilateral market, despite its large market share, is that it is very hard to obtain historical price data from this market. The prices in the bilateral market and Nord Pool's market are, however, closely linked. The results I present in this thesis should therefore also be of interest for participants in the bilateral market.

3 The Functions and Sustainability of the new Electricity Futures Market

Trading in futures contracts emerged in the agricultural sector, and already in the 17th century it was possible to buy tulip bulbs on term contracts in Amsterdam. For many years futures markets were largely confined to the traditional agricultural products and especially grains. In the past three decades, however, there has been an explosion in the variety of products served by these markets. The first waves of expansion brought in new agricultural contracts (especially meats) and precious metals. The second stage, starting in the 1970s, saw the introduction of financial instruments, including currency, interest rate, and stock index contracts. A third phase brought in oil and a number of other industrial products. The fourth stage, which continues to evolve today, saw the introduction and rapid acceptance of options on futures contracts. In the 1990's we have seen the development of futures markets for electric power, with England and Norway as pioneer countries.

By looking at experiences from other and more established futures markets we can learn a lot about problems and pitfalls that might appear for the new electricity market. I will in this chapter first briefly describe the functions that futures markets traditionally serve. These functions are important to keep in mind when studying pricing of futures contracts and hedging strategies involving futures. By looking at general criteria for well-functioning markets I will comment upon the sustainability of the emerging futures market for electric power organised by Nord Pool.

3.1 The main functions of a futures market

Futures markets, i.e. spot markets for standardised forward contracts, basically serve three functions (*Treat(1990))*:

1. *Price Discovery, giving an instantaneous reading of marginal price movements.*
2. *Risk Management, allowing companies to hedge their price risks for limited periods of time. However, the hedging opportunity rarely extends more than six months forward as a result of market illiquidity in the more distant months.*
3. *Speculative Opportunity, attracting additional risk capital to the market from outside the original industry. Low margin requirements - lower than in equity markets - enhance the attraction of futures as a vehicle for speculation.*

The need for price discovery in the Norwegian electricity market is obvious. The deregulation of the market in 1991 has faced the electricity companies to completely new conditions. They are now faced with continuously changing spot prices due to the stochastic nature of supply and demand of electricity. This is in contrast to the old regime where long term bilateral contracts with fixed prices accounted for a larger part of the total power delivery, and the price environment in general was much more stable because of governmental regulations. A visible price discovery process, which the futures market represent, is therefore of major importance for the electricity companies in their overall planning strategies.

The increased risk that the companies in the electricity sector are exposed to give rise to an extended demand for risk management tools. The new electricity futures market represents in that sense a very important tool for reducing risk. Market illiquidity in the long term seems to be a problem also for Nord Pool’s term market, because the participants in the market tend to use bilateral contracts over long horizons. In the short term, however, the term market is very much used.

The number of pure speculators in the electricity market is very limited so far. The special conditions in the market over the last two years with extreme price fluctuations might have deterred speculators. The high volatility in the market and the cash settlement procedure should normally attract speculators. Several financial institutions are considering to enter the electricity market today. The speculative opportunity is also utilised by different electricity companies. The companies do not only use the term market for hedging risk. Many of them are also risk-takers and they speculate in the future development of the electricity price.

The functions of futures markets presented above are the necessary but not sufficient conditions for a successful futures contract. In reality, new futures contracts often fail. The reason is that the criteria for a successful futures contract are simply too stringent, with too few physical markets that can actually meet those criteria. I will now turn to looking at the criteria which normally are fulfilled for successful futures markets, and comment on the validity of these requirements in the electricity market.

3.2 Criteria for successful futures markets

John Elting Treat, a former director of the New York Mercantile Exchange (one of the world’s leading exchanges for futures trading), points out 9 criteria for successful futures markets. I will comment upon each criterion with the new term market for electricity in mind. The conditions in the Norwegian power market are emphasised in the discussion below. Treat claims that in assessing the suitability of any commodity/market for futures trading, the following conditions need to be analysed *(Treat(1989))*.

3.2.1.1 Price Volatility

Price volatility is perhaps the single most important criterion for it provides the basic economic justification for futures trading, which is to provide protection to the hedger against adverse price fluctuations. Price volatility is also necessary to attract risk capital from speculators and essential to ensure sufficient liquidity to maintain the market. Quantitative indicators: Variations of plus or minus 20% per annum are assumed to be the minimum necessary to sustain futures trading. In general, the greater the degree of volatility, the more likely a futures market will survive. Figure 2.3 shows the price development in the spot market for electricity, 1992-1997. The difference between the highest and the lowest average weekly price varies between 239 % and 1585% (!) for each year from 92 to 97. The seasonal trend can of course explain some of the variability. 65 % of the variation in observed prices in the spot market (or occasional market as it used to be named) between 1986 and 1990 can be explained by the influence of seasonal factors according to *Amundsen/Singh(1992)*. Even after removing the seasonal trend the criterion is fulfilled with a large margin, and the electricity market in Norway has no problems in fulfilling this requirement. The question is rather if the volatility is too high, deterring speculators from the market because of too high risk.

3.2.1.2 Uncertain supply and demand

Uncertain supply and demand are generally the causes of price volatility and therefore are generally present when price volatility is found. Quantitative indicators: In energy markets, which typically display a rather high inelasticity of price demand, variations of plus or minus 10% during a two-year period should be sufficient to sustain futures trading. While the long-time demand for electricity from year to year has shown a rather stable increase, the short-time demand is highly volatile because of the stochastic element in temperature and weather conditions which naturally affect the power demand. The supply side capacity is also variable, mainly because of uncertainty in future water reservoir levels and also restrictions and possible breakdowns in the national grid system. The inflow to the aggregate water reservoirs in Norway can vary from 90 TWh in a year with low inflow to 140 TWh in a year with high inflow *(Aasgaard (1996))*. There should be no doubt about the sufficiency of variations in demand and supply of electric power to maintain a futures market. These variations are of course also reflected in the very volatile spot prices.

3.2.1.3 Deliverable supplies

If there are not sufficient deliverable supplies of the commodity meeting the quality speculations, futures trading will fail. However, there must be some uncertainty about the sufficiency of supplies if the previous conditions are to be met. Quantitative indicators: Storage capacity equal to at least 30 days demand is highly desirable. Storage of electricity is in general not possible for consumers of electricity unless they have some kind of pumping storage facilities or very large batteries, which very rarely happens today. The consumers do not need storing facilities either, as long as they continuously are served with a sufficient quantity of power. The electricity market is in this way different from other commodity markets, where supply does not take place continuously. For suppliers with water reservoirs it is possible to store energy in form of water. The overall reservoir capacity in Norway is 80 TWh and this represents more than 2/3 of the average consumption the latest years (*Aasgaard (1996)*). The volume kept in the reservoirs is usually between 30 % and 100 %, depending on the time of the year, and is always well above the demand for the following month. Still, during winter when there is virtually no inflow to the reservoirs Norway might run into capacity problems. 1996 was a year with high import of power because of the extremely low inflow to the reservoirs. The prices were accordingly very high. The limited storage capacity does therefore also contribute to uncertainty about prices. The cash delivery procedure in the electricity futures market reduces in my opinion the need for sufficient deliverable supplies. Still, the requirement of a storage capacity for the suppliers equal to at least 30 days demand is fulfilled.

3.2.1.4 Product homogeneity

Product homogeneity is another prerequisite. Futures contracts are traded on the premise that product taken on a delivery will meet certain quality specifications. The commodity must therefore have certain key characteristics that are quantifiable, allowing the clear differentiation of the product from other grades. Quantitative indicators: The quality of the product must be capable of being described by objective, quantifiable standards. This should not be a problem in the electricity market, since the quality of the electricity that different consumers receive is in general both homogenous and high. There is always a small probability for faults in the transmission network, interrupting the delivery, but the probability for disruption in the Scandinavian grid system is in general low. This is more to consider as a problem for the national grid companies (Statnett and Svenska Kraftnett) and the local transmission companies which are independent of the electricity supply companies. The term contracts should also give sufficient specifications about delivery, as described in the previous section.

3.2.1.5 Product perishability

Product perishability can be a deterrent to trading. In general a product should have a shelf life sufficiently long enough to permit storage and delivery as called for under the contract. In addition, the maintenance of stocks of the commodity will both facilitate deliveries and provide a ready pool of potential hedgers. Quantitative indicators: Products should have a minimum shelf or stock life of 6-12 months. Electricity is indeed a perishable good. As mentioned above, most consumers have no storage facilities, and the supply of electricity equals consumption continuously. The only participants that the notion stock life makes sense for in a hydropower system is therefore producers with reservoir capacity. Power kept as water in reservoirs has in that sense an infinite stock life. Storing power today for future physical delivery is only possible for producers with reservoirs. Other participants can not buy power in the market today, store it, and sell the power in the future, which is possible for most other commodities. This does, however, not prevent them from shorting futures contracts. Producers without reservoirs (river plants) can hedge their expected future production. Participants without production at all can speculate in shorting futures if they expect a price decrease, without worrying about physical delivery. They can either close out their positions before delivery or even hold the contracts to expiry, because of the cash delivery process. A shortage of participants willing to short futures contracts would lead to futures prices above the expected future spot price. I will come back to this question in the section 4.2. Based on the discussion above my conclusion so far is that the perishability of electricity should not be a major deterrent to trading.

3.2.1.6 Market concentration

Market concentration is a difficult factor to quantify. A successful futures market is a highly competitive market, marked by a large number of buyers and sellers. No one market participant, or plausible combination of market participants, should possess sufficient market power to exert unilateral control either in the short or medium term. Quantitative indicators: In general, the market share of the top five firms should be less than 50%, and the top ten firms should have less than 80%. The reason for this requirement is that if one single company (or a constellation of companies) actively influences the price development in the spot and/or futures market to its own advantage, this would be unfair for other participants in the market and reduce their profit opportunities. A price setting and dominant producer may have both an incentive and the ability to suppress the market *(Amundsen and Singh (1992)*). The figure on the next side shows the market concentration in the Norwegian power supply market, in terms of middle production for the 20 largest production companies in the period from 1982 to 1991.

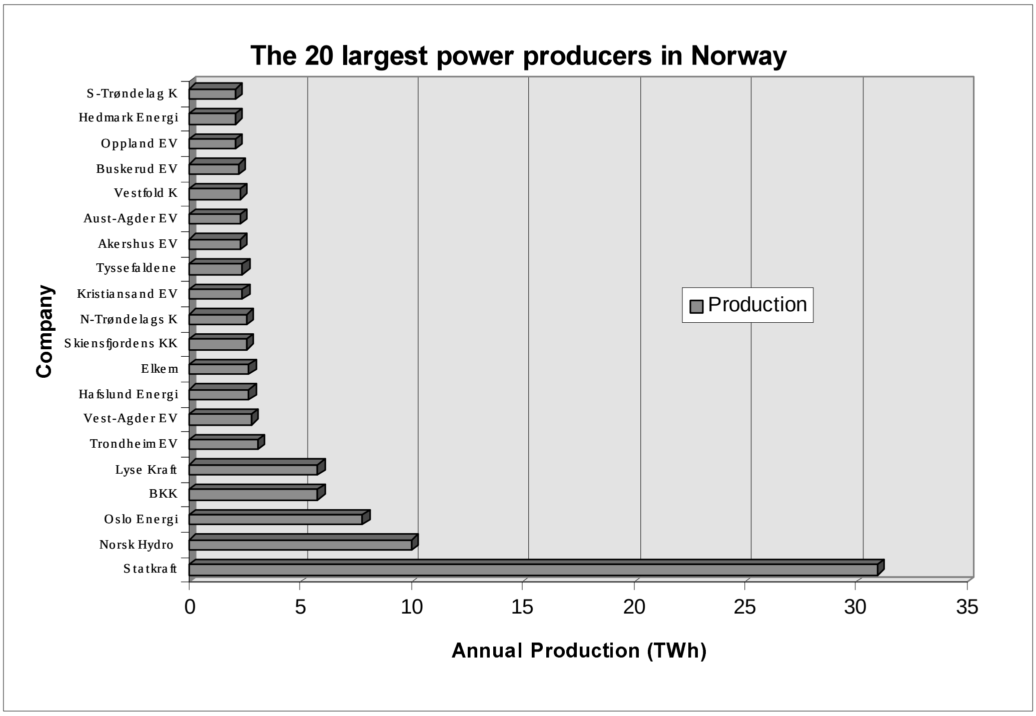


Figure 3.1 Annual middle production for the 20 largest producers of electric power in Norway, in the period 1982-1991. The average overall annual production capacity in the Norwegian power system is 112 TWh (Source: Aasgaard (1996)).

Figure 3.1 shows that Statkraft has a production of more than 30 TWh each year. The remaining production is rather smoothly distributed between smaller companies. The 5 largest companies have approx. 50 % and the 20 largest companies have 80 % of the overall production, indicting that the suggested criteria is fulfilled, but with only a small margin. Statkraft's influence on the prices, with 31 % of the production capacity, is a very much discussed subject in the power industry. Taking into consideration that they also control as much as 37 % of the reservoir capacity, it becomes clear that they certainly have the possibility to influence the prices. The open trading procedure in the futures market, where the participants all the time can see the prices of the bids and offers submitted into the market, reduces the possibility for Statkraft to take advantage of its market power directly. In the spot market, however, where the bids and offers are hidden to the participants, it is easier to make unexpected moves and influence the spot price. The futures prices are in turn influenced by the spot prices. When trading in bilateral contracts, the information is also hidden to others than the two involved participants. The degree to which Statkraft deliberately exploits its market power would be an interesting study on its own, but is left for future work. I conclude by emphasising the element of risk concerned with Statkraft's possibility to exert market power, and the adverse consequences this might induce for the electricity futures market.

Norway and Sweden is, as mentioned in the previous chapter, operated as one common power market. It should therefore be mentioned that in Sweden the major electricity company, Vattenfall, controls 50 % of the overall production while Sydkraft AB controls 20 % *(Aasgaard(1996)).* The market conditions in Sweden contributes to increase the problems concerned with market concentration, also in the Norwegian market, as the links between the two countries electricity markets become closer. The electricity market is attracting new participants all the time, and the smaller participants become more professional when their experience increases. Problems due to market concentration will hopefully diminish when the deregulated market completely settles.

3.2.1.7 Price information

Readily available price information is critical to market success. A sufficiently broad base of price information to permit evaluation of spot prices and their relationship to futures prices is of major importance. Convergence between these two prices as the delivery period approaches is essential. Quantitative indicators: Daily cash market prices should be available from at least two independent sources. As explained in the previous chapter Nord Pool has a comprehensive information system for their customers, and there are also additional suppliers of information. Many of the broker firms quote bid/ask prices for futures contracts continuously. The system price in the spot market, which serves as the reference price for the futures market, is published as soon as it is determined each trading day. Due to the restrictions in the transmission system, which requires an operating and controlling system embracing the whole network, it is only possible with one market place for spot electricity, and therefore only one spot price. The frequency of auctions in the spot market could be a source of inefficiency in the electricity market. *Knivsflå and Rud (1995)* states that the informational and allocational efficiency of the Norwegian spot market could improve by increasing the frequency of electricity auctions. They further suggests to increase the number of auctions per day from one to two, and then perhaps to several auctions or continuous auctions and also integrate the controlling market into the spot market. This would eventually be more to consider as a structural change in the trading system, in my opinion. The price information system on its own should be sufficient to serve the electricity futures market. I will come back to the question of convergence between futures and spot price in section 5.1.2 about basis risk.

3.2.1.8 Unique trading opportunity

Unique trading opportunity is another key factor. If an existing market for a commodity has reasonable liquidity and is serving its customers well, it is extremely difficult to launch a copycat contract. Quantitative indicators: The ideal candidate would be a commodity that is not currently traded on any futures exchange in the world and has not been the subject of a failed attempt in the previous five years. Nord Pool’s electricity futures market is the only official power exchange in Norway and Sweden. It is the second official exchange for electricity in the world, after England, and extensive competition from other foreign exchanges is unlikely because of the natural monopoly in the transmission network system, and the extended co-operation between Nord Pool and the two national grid companies (Statnett and Kraftnett). There is also a market place for futures and forward contracts in the bilateral market, but this should not be a deterrent to trading in the organised market as long as the transaction costs are held at a reasonable level for Nord Pool’s products. Nord Pool’s futures market and the bilateral market seem to supplement each other, with Nord Pool’s market being popular for short-term contracts, while the bilateral market is more used for long-term contracts and special agreements. The criteria of unique trading opportunity should therefore not be an obstacle for a well functioning electricity futures market.

3.2.1.9 Market timing

Market timing (and blind luck) are often critical to the success or failure of a contract. However, they are often impossible to forecast. Ideally, contracts should be introduced to coincide with periods of high volatility and high levels of cash market activity. Quantitative indicators: Contracts should be introduced to coincide with high levels of cash market activity, to the extent these are predictable. The introduction of the common Norwegian and Swedish power exchange 01.01.1996 has turned out to be both prudent and lucky timing. The winter is of course the period of the year with highest electricity demand and thus highest activity in the spot market. Additionally, 1996 was a very special year with high volatility and unpredictably high prices in the electricity market. The extreme conditions in the first year of operation, causing that many of the smaller electricity companies made losses on their contracts, has helped to emphasise the need of good risk management procedures in the electricity market. The obvious need for a fundamental understanding of the new conditions in the deregulated electricity market has probably helped to speed up the development of Nord Pool's futures market into a mature market.

3.3 Summary

First in this chapter I briefly described the functions of futures markets in general. Three functions are basically served, price discovery, risk management and speculative opportunity. There should be a need for all of these functions in the electricity market. I then turned to looking at general criteria for well-functioning futures markets, defined by John E. Treat, a previous director of New York Mercantile Exchange. By studying the Norwegian electricity market I find that most of the criteria are fulfilled for Nord Pool's futures market. I argue that the fact that electricity is perishable and in general not possible to store for consumers, should not prevent a well functioning electricity market. Market concentration is perhaps the biggest obstacle to obtain a perfectly operating futures market, since the state owned production company Statkraft controls about 27 % of the overall production and 37 % of the reservoir capacity. By using their market power Statkraft can influence the prices both in the spot and futures market. The problem also applies to Sweden, where Vattenfall controls 50 % of the production capacity.

Amundsen and Singh (1992) emphasise that in addition to fulfilment of the general criteria for well functioning futures markets, success of an electricity futures market will be crucially dependent on the structure of competition and regulation which applies to the deregulated spot market. Statkraft's market power is also in that sense an important factor, at the same time as the smaller participants in the market have to adjust to the new conditions. The development is of course also dependent on the consistency in the governmental deregulation process. The degree of free competition in the spot market is not extensively discussed here, but my impression is that the electricity market is beginning to fit into its new environment, after a rather sluggish start. The fact that several foreign countries regularly visit Norway and Sweden to see how a deregulated power market is functioning, indicates that we are about to obtain full fledged spot and futures markets for electricity in Scandinavia.

4 Pricing Futures Contracts

In this chapter I look at the price formation process in the electricity futures market. In the first part general pricing theory for commodities futures contracts is presented. In the second part I look specifically at the electricity market and discuss if any of the existing pricing theories apply. I also analyse the limited amount of historical price data that exist for Nord Pool's electricity futures market. I search for significant trends in the futures contracts prices and try to explain these trends using the presented theory.

4.1 Pricing commodities futures contracts

There is a difference in the pricing theory for futures contracts on financial assets (bonds, shares etc.) and futures contracts on commodities. I consider electric power more as a commodity than a financial asset, so below I will outline general theory about pricing commodities futures contracts. Compared to pricing of financial futures contracts, which is based on pure arbitrage arguments, the pricing of commodities futures contracts is complicated by the fact that storage is costly and that spot markets may be non existent or too thin for arbitrage. Only for less than 3% of commodities futures contracts traded today is physical delivery of the good actually carried out. As we already know, the futures market at Nord pool is organised only with cash delivery. When looking at the pricing of futures contracts, however, delivery or not make no difference in the price formation process. In the literature I have found two general approaches for explaining prices of commodities futures, one based on convenience yields and storage costs, and the other on risk premium such as the Capital Asset Pricing Model (CAPM) beta.

4.1.1 Futures Prices and storage

4.1.1.1 Initial assumptions

Before deriving the pricing formula in this section it is important to be aware of the required assumptions for the formulas to be valid *(Hull(1997))*:

1. *There are no transaction costs.*
2. *All trading profits (net of trading losses) are subject to the same tax rate.*
3. *The market participants can borrow money at the same risk-free rate of interest as they can lend money.*
4. *The market participants take advantage of arbitrage opportunities as they occur.*

Note that it is not required that these assumptions are true for all market participants. All that is needed is that they be true for a subset of all market participants. The fact that these market participants are prepared to take advantage of arbitrage opportunities as they occur means that in practice arbitrage opportunities disappear almost as soon as they arise. An implication of the assumptions is therefore that market prices are such that there are no arbitrage opportunities.

The first three assumptions are obviously not perfectly valid in the electricity market. The degree of validity should, however, not be less than in other commodity markets where this pricing theory is utilised. Adjustments can also be made to adjust the model to "the real world". The main requirement is the arbitrage assumption, and it is highly discussible if assumption 4 is valid in the electricity market. The market is young and consists of very few participants compared to other markets. At the same time the volatility is extremely high which makes it difficult to forecast future prices. It is with no doubt a demanding task for the inexperienced participants to interpret and trade in the market in such a way that the arbitrage opportunities disappear as soon as they occur. Anyway, I will give an outline of the model below.

4.1.1.2 Storage cost and convenience yield

The traditional view explains the current futures price as the expected spot price, plus the cost of storage (e.g. interest foregone, warehousing, shrinkage etc.), and minus a convenience yield. The convenience yield is much like a liquidity premium, usually being described as the convenience of holding stocks because many commodities are inputs in the production process or as the convenience of having stocks to meet unexpected demand. The theory of storage predicts low convenience yields when stocks are plentiful and vice versa *(Copeland/Weston(1992))*.

According to the storage theory which again is based on traditional arbitrage pricing, the futures price, F, of a T-period contract observed at time t is given by:

$$F = S_t e^{r(T-t)} + U - Y \qquad (4.1)$$

where

$S_t e^{r(T-t)}$ is the current spot price compounded by the interest rate, r, between the current time, t, and the delivery time, T.
U is the storage cost between now and delivery.
Y is the convenience yield (measured in money) for the same period.

If expressing the storage cost as a proportion, u, of the spot price and the convenience yield as a compounding factor, y, the futures price is:

$$F = S_t e^{(r+u-y)(T-t)} \qquad (4.2)$$

4.1.1.3 Futures prices and the expected future spot price

If storage costs and convenience yields are very low, then you for some commodities predict that prior to delivery the futures price is below the expected future spot price *(Copeland/Weston (1992))*:

$$F < E\left(S_T\right) = S_t e^{r(T-t)} \qquad (4.3)$$

This relationship is called normal backwardation, and was proposed by John Maynard Keynes. The origin of the idea is that producers (e.g. farmers) normally wish to hedge their risk by shorting the commodity. Since there are risks associated with being long, Keynes hypothesised that hedgers would have to entice the speculators by making the expected return from a long position greater than the riskless interest rate. The futures price will rise (on average) through time until, at delivery, the futures price equals the spot price.

A contrary hypothesis holds that, if hedgers need to go long, or if the convenience yield is negative owing to oversupply, then the hedgers must pay a premium for futures contracts in order to induce speculators to go short. This requires the futures price to be greater than the expected spot price *(Copeland/Weston (1992))*:

$$F > E\left(S_T\right) = S_t e^{r(T-t)} \tag{4.4}$$

Thus, a speculator who short sold a futures contract at a price of F would expect to be able to buy it back on (or near) the delivery date at a lower price, $E(S_t)$. This relationship has been referred to as normal contango. Figure 4.1 shows the expected price development for a futures contract under the normal backwardation and the normal contango hypothesis.

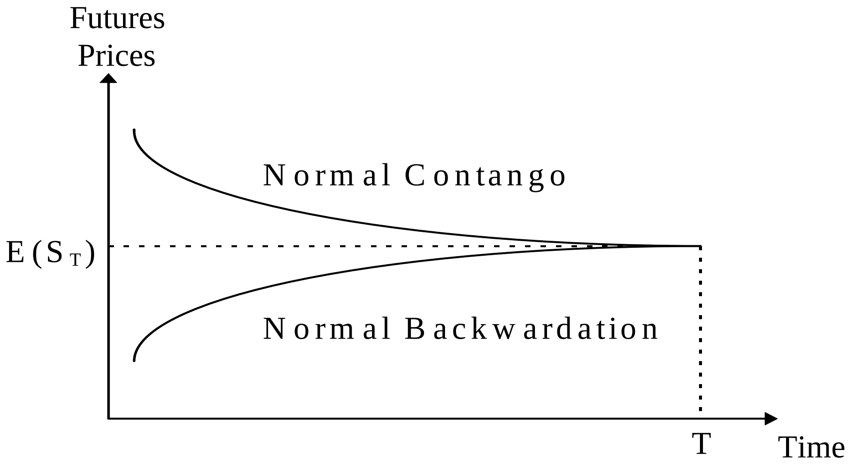


Figure 4.1 The expected price development for futures contracts under the normal backwardation and the normal contango hypotheses for futures prices (Source: Copeland/Weston (1992)).

I now turn to consider the factors determining normal backwardation and contango from the point of view of the trade-offs between risk and return in capital markets.

4.1.1.4 Risk and Return

In general, the higher the risk of an investment, the higher the expected return demanded by an investor. The capital asset pricing model (CAPM) leads to the conclusion that there are two types of risk in the economy: systematic and nonsystematic. Nonsystematic risk should not be important to an investor. This is because it can be almost completely eliminated by holding a well-diversified portfolio. An investor should not therefore require a higher expected return for bearing nonsystematic risk. Systematic risk, by contrast, cannot be diversified away. It arises from a correlation between returns from investments and returns from the stock market as a whole. An investor in general requires a higher expected return than the risk-free interest rate for bearing positive amounts of systematic risk. Also, an investor is prepared to accept a lower expected return than the risk-free interest rate when the systematic risk in an investment is negative *(Hull(1997))*.

4.1.1.5 The risk in a Futures Position

Consider a speculator who takes a long futures position in the hope that the price of the asset will be above the futures price at maturity. I assume that the speculator puts the present value of the futures price into a risk-free investment at time *t* while simultaneously taking a long futures position. The proceeds of the risk-free investment are used to buy the asset on the delivery date, at time *T*. The asset is then immediately sold for its market price. This means that the cash flows to the speculator are:

Time t: $-Fe^{-r(T-t)}$

Time T: $+S_T$

where S_T is the price of the asset at time *T*.

The present value of this investment is

$$-Fe^{-r(T-t)} + E(S_T)e^{-k(T-t)}$$

where *k* is the discount rate appropriate for the investment, i.e. the expected return required by investors on the investment. Assuming that all investment opportunities in securities markets have zero net present value gives *(Hull(1997))*:

$$F = E(S_T)e^{(r-k)(T-t)} \tag{4.5}$$

The value of *k* depends on the systematic risk of the investment. If S_T is uncorrelated with the level of the stock market, the investment has zero systematic risk. In this case, $k = r$ and Eq. (4.5) shows that $F = E(S_T)$. If S_T is positively correlated with the level of the stock market, the investment has positive systematic risk. In this case, $k > r$ and Eq. (4.5) shows that $F < E(S_T)$. Finally, if S_T is negatively correlated with the level of the stock market, the investment has negative systematic risk. In this case, $k < r$ and Eq. (4.5) shows that $F > E(S_T)$. The systematic risk can in this way be utilised to explain normal contango or backwardation. This outline about risk and return concerning futures positions leads us naturally over to the second pricing method for futures contracts, which uses the CAPM to quantify the systematic risk.

4.1.2 Futures prices and the CAPM[1]

A second way of explaining commodity futures prices posits that the futures price can be divided into the expected future spot price plus an expected risk premium based on the capital asset pricing model. The CAPM states that:

$$E(R_i) = R_f + \left[E(R_m) - R_f\right]\frac{COV(R_i, R_m)}{\sigma^2(R_m)} \tag{4.6}$$

where

$E(R_i)$	= the expected return of the *i*th asset.
R_f	= the risk-free rate, assumed to be constant over the life of the futures contract.
$\sigma^2(R_m)$	= the variance of return on a (single factor) market index portfolio.

---

[1] The general theory and equations presented in this section are, if not else stated, based on *Copeland/Weston (1992)*.

$COV(R_i, R_m)$ = the expected covariance of returns between the *i*th asset and the market index portfolio.

The equation for a one-period rate of return for an investor who holds the risky commodity is given by:

$$E(R_i) = \frac{E(S_{iT}) - S_{i0}}{S_{i0}} \tag{4.7}$$

where

S_{i0} = the current spot price of the *i*th commodity.
$E(S_{iT})$ = the expected spot price at the time of delivery, T.

Combining the CAPM, Eq. (4.6), with Eq. (4.7) we have a certainty equivalent model for the spot price of the commodity:

$$S_{i0} = \frac{E(S_{iT}) - \left[E(R_m) - R_f\right]S_{i0}\beta_i}{1 + R_f} \tag{4.8}$$

where

$\beta_i = \dfrac{COV(R_i, R_m)}{\sigma^2(R_m)}$ = the systematic risk of the *i*th commodity.

Finally, a futures contract allows an investor to purchase an asset now but to defer payment for one period; therefore the current price of the futures contract, F_{iT}, must be the current spot price multiplied by the future value factor. From Eq. (4.8) we have:

$$F_{iT} = S_{i0}(1 + R_f) = E(S_{iT}) - \left[E(R_m) - R_f\right]S_{i0}\beta_i \tag{4.9}$$

The futures price, F_{iT}, equals the expected spot price minus a risk premium based on the systematic risk of the commodity. The systematic risk is that part of a security's total risk which is related to moves in the market portfolio and, hence, cannot be diversified away (see above).

The CAPM approach, Eq. (4.9), argues that systematic risk should be important in the pricing of futures contracts but leaves out storage costs and convenience yields. On the other hand, the first approach, Eq. (4.1) and Eq. (4.2), ignores the possibility that systematic risk may affect the equilibrium prices of commodity futures contracts.

4.1.2.1 Empirical evidence

Bodie and Rosansky (1980) studied risk and return in commodities futures for all major commodities traded in the United States between 1950 and 1976. They found that the mean rate of return on a portfolio consisting of their selected commodity futures contracts in the 27 years period was well in excess of the average risk free rate. Their findings lend support to the normal backwardation hypothesis. On the other hand, the relation between the rates of return on the commodity portfolio and the corresponding beta coefficients appeared to be inconsistent with the conventional form of the CAPM. The validity of Eq. (4.9) is therefore rejected. *Chang (1985)* also finds evidence of normal backwardation for wheat, corn, and soybeans over the time interval from 1951 to 1980. *Fama and French (1987)* find marginal evidence of normal backwardation when commodities are combined into portfolios but conclude that the evidence is not strong enough to resolve the existence of a nonzero risk premium. In sum, the empirical research carried out on commodities futures prices finds weak evidence to support normal backwardation, but the risk premium may be time varying and is not related to a CAPM beta. Later in this chapter I will try to find out if the returns in the electricity futures market can be explained by the CAPM beta.

4.2 Pricing theories and the electricity futures market

I now turn to looking at the electricity market. By discussing the special features of the electricity futures market and using the available price data from Nord Pool, I will try to see if any of the pricing theories presented above make sense for this market.

4.2.1 Storage cost and convenience yield in the electricity market

As already mentioned in chapter 3 it is not possible to store electricity like you can store other commodities. The only realistic way of storing electricity in a hydropower system today is in water reservoirs. This possibility is only available for producers of electricity, the consumers have in general no such possibility. For electricity companies with water reservoirs it is therefore possible to store water today in hope of higher prices in the future (or the other way around). The expected marginal future value of the water stored in the reservoir, called the water value, is used for planning the production in the hydropower plants to maximise expected profit[1]. The water value implies a cost of using the water. It is not a real cost, but reflects the expected future profit from keeping the water now and use it at a later stage. The use of water values in the production planning is a risk management tool which comes in addition to using instruments like forwards, futures, options and so on for reducing risk.

Electricity companies with power plants downstream in rivers may not have any reservoir capacity at all, and they have to produce according to the instant flow of water in the river. For these companies the possibility of storing electricity are non-existent and storage cost becomes a meaningless notion. Even for the companies with water reservoirs there are no direct costs of storing the electricity in the existing reservoirs. The cost of building the reservoirs, and the following repayment and interest of the borrowed money is indeed a direct cost for the production company. This cost is, however, not in any sense connected to the water level kept in the reservoirs. The payments are the same with full or empty reservoirs, and also the minor costs of maintaining the reservoirs are not necessarily connected to the level of water stored in them. The investment costs can therefore in my opinion not be considered as storage costs in the sense used in traditional commodities futures pricing.

There is also a possible cost of storing the water if the prices in the future fall. Storing water today for future delivery gives an expected reduction in profit if the spot price is

---

[1] A very much used production planning program called Vansimtap uses water values in the decision process. Power producers controlling more than 80% of the hydropower production in Scandinavia use Vansimtap in their production planning. *Faanes (1996)* gives a description of water values and their use in Vansimtap.

higher than the water value. This should be considered before taking positions in the futures market. Selling futures contracts in the term market does, however, not under any circumstances mean that physical delivery has to take place. This is because of the cash settlement procedure. Even participants without production can sell futures contracts and let them go to delivery. This would actually be a very attractive investment opportunity if a storage cost was calculated into the futures price. Increased supply of futures contracts from pure speculators would therefore probably remove the eventual storage cost element from the futures price, assuming that the market is efficient. Anyway, I doubt that the risk and eventual loss (due to falling prices) from storing water can be considered as a storage cost. As far as I can see the risk concerned with this indirect cost is more to be considered as a factor in the risk management and production planning process and it does probably not affect the pricing formation of futures contracts. Intuitively I therefore would assume that the storage costs of electricity in a hydropower based system like the Norwegian is equal to zero.

The concept of convenience yield does also only make sense for producers with water reservoirs. There probably is something like a convenience yield concerned with having the flexibility to adjust the quantity of power delivered immediately to adjust to the continuous changing demand in the market. Especially on days with high demand it is favourable to be able to produce the maximum quantity of power during the peak hours of the day with high prices. During the night, when the demand and prices are low, you can close down the production and maintain the water level in the reservoirs, and buy cheap electricity in the spot market to fulfil your delivery obligations. *Knivsflå and Rud (1995)* points out that there is a possibility of speculating in the controlling market by holding back volume from the spot market and trading in the controlling market instead. The possibility of trading and profiting in the controlling market can also be considered as a form of convenience yield as long as we have separate spot and controlling markets. The reason for this is that this eventual profit is not possible to obtain unless you are a producer of electricity with storage capacity, which is required to take part in the controlling market. The possible convenience yield concerned with storing water would be hard to quantify. I do not think it is taken account for when pricing futures contracts for electricity.

After having spoken to two participants in the electricity market[1] my impression is that today the futures prices are mainly determined from the markets' expectations about the future spot price. Eventual storage cost and convenience yield are only vague or non-existing notions and are not considered when the participants calculate and assess the futures prices. Power producers want to hedge future delivery while many of the pure distribution companies and large consumers want to hedge future purchase of power. Hedgers among both buyers and sellers create an equilibrium in the market, and should mean that there is no need for neither a discount nor a risk premium to attract speculators for creating liquidity in the market. The speculators should be attracted anyway, because of the high volatility in the market. My initial assumption (or null hypothesis), before looking at the price data, is therefore that the price of a futures contract equals the expected spot price at delivery. This is in the

---

[1] Statkraft and Hydro Energy.

literature called the expectations hypothesis of futures prices *(Alexander and Sharpe (1989))*, and is consistent with no storage cost or convenience yield.

4.2.2 Expectations hypothesis, Backwardation or Contango - Empirical results

I now start to look at the historical price data from Nord Pool's Eltermin. There are three possible hypothesis concerning the futures price and the expected future spot price (see Figure 4.1). If $F=E(S_t)$, the futures price will drift up or down only if the market changes its views about the expected future spot price. Over a long period of time, you can reasonably assume that the market revises its expectations about future spot prices upwards as often as it does so downwards. The average profit from holding futures contracts over a long period of time should under the *expectations hypothesis* be zero. This is my initial assumption, as explained above. In the case of *normal backwardation* $(F<E(S_t))$, a futures price should on average drift up and a trader should over a long period of time make positive profits from consistently holding long futures positions. Similarly, the normal contango $(F>E(S_t))$ situation implies that a trader should over a long period of time make profits from consistently holding short futures contracts *(Hull(1997))*. Below I look at price data from the electricity futures market to see if there is significant indication of any of the three hypotheses. I have taken two approaches to the problem. First I look at the return on single contracts over different time periods, then I look at the return on constructed benchmark portfolios consisting of multiples of futures contracts.

4.2.2.1 The data

The data I have studied consist of weekly closing prices in Nord Pool's futures market (Eltermin) and is from Sept.-95 (week 39-95) to Oct.-97 (week 41-97), which is the period that Eltermin has been operating. In the analysis of the data I have assumed that the contracts are closed out on the last day of trading, so that eventual profit or loss from the price securing settlement during the delivery week is not taken into consideration. Throughout the analysis I consistently look at returns from the point of view of a participant with long positions. Profits on long positions indicate a similar loss on the corresponding short positions, and vice versa. Continuous compounding is applied when calculating the nominal returns. The risk-free rate of return on the margin account is omitted in the calculations. The returns on futures contracts presented below are therefore in reality returns in excess of the risk free return. In *Appendix 1* different ways of calculating the returns on futures contracts are discussed. All returns are converted to weekly returns to make comparisons possible. The reason for looking at weekly data is to obtain a satisfactory amount of data despite the short period that the futures market has been operating. No transaction costs are taken into consideration in the results below.

A problem with the data from the power market is, as already mentioned, the limited amount of data that actually exist, only two years to be exact. We also know that especially 1996 was an extreme year with very high prices in the spot and futures market due to the so called "power crisis", with very low inflow to the water reservoirs in Norway. The impact of the "power crisis" on the spot market can be realised by looking back at Figure 2.3, which shows the system price in the spot market from 1992 to 1997, and noting the very high prices throughout 1996 compared to the rest of the period. Bearing these facts in mind makes it impossible to draw strong conclusions. The results presented in this thesis, based on the limited historical price data, should therefore be read and interpreted with a high degree of caution. Uncritical interpolation of the results into the future might lead to fatal mistakes.

4.2.2.2 The returns on single contracts

Five different holding periods are utilised when analysing the return on single contracts. The five periods are the return over the whole contract life, from issue to expiry, and the return on the last 4, 3, 2 and 1 week(s) of trading respectively. A distinct feature of Nord Pool's electricity term market is that the liquidity for long term contracts is low, while it improves when expiry approaches. This might influence the average return holding the contract from issue to expiry versus holding the contract only the last week(s) before expiry.

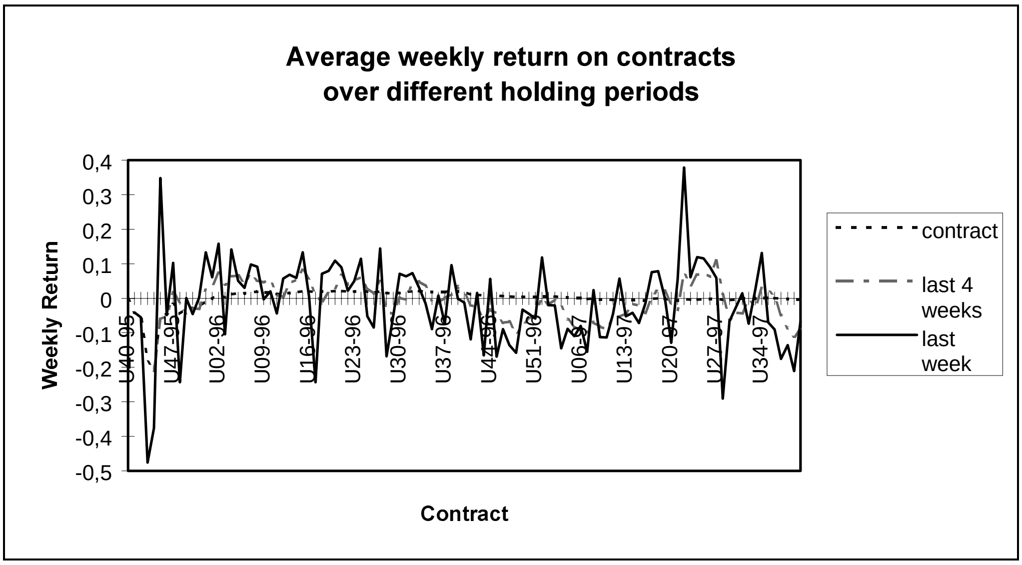


Figure 4.2 Average weekly returns on the expired week contracts for holding the contract the whole trading period (contract), the last 4 weeks and the last 1 week. The last 2 and 3 weeks' returns are omitted to avoid confusion when studying the plot. U means week, e.g. U06-96 is week 6 in 1996.

Returns	contract	last 4 weeks	last 3 weeks	last 2 weeks	last week
2 years	-0,00068	-0,00651	-0,00922	-0,01171	-0,01500
1. year	-0,00121	0,01711	0,01284	0,01051	0,00668
2. year	-0,00015	-0,02876	-0,03044	-0,03351	-0,03668

Table 4.1 Average weekly returns on single contracts. Notice the difference between the 1. and 2. year.

The average weekly returns for all holding periods show a negative value, indicating that participants holding long contracts on average make a loss (Table 4.1). It is worth noting for the four shortest holding periods that there is a large difference in returns for the 1. year with positive mean, compared to the 2. year where the returns are negative. This trend can also be seen from Figure 4.2 and Table 4.2. The overall reason for the difference is probably the prices in the spot market, with an increasing trend more or less continuously from the launch of the futures market until Sept. 96, and the following period with a decreasing trend which lasted almost until today (Figure 2.3). The reason for the negative average return holding the contract the whole period is mainly two outliers in the data for Week 43 and Week 44 in 1995. Extreme results for the first contracts influence this result because of the short period of trading for these contracts. Removing the two outliers give positive return on average both for the 1. year and for 2 years holding the contract the whole period.

nr. of +/- contracts	**whole period**	**last 4 weeks**	**last 3 weeks**	**last 2 weeks**	**last week**
neg (-)	44	51	55	54	54
pos (+)	60	50	47	49	50
1.year (-)	13	14	18	18	21
1.year (+)	40	36	33	34	32
2.year (-)	31	37	37	36	33
2.year (+)	20	14	14	15	18

Table 4.2 The number of positive and negative returns on single futures contracts for the different holding periods. Notice the difference between the first and second year.

Standard deviation	**contract**	**last 4 weeks**	**last 3 weeks**	**last 2 weeks**	**last week**
2 years	0,03171	0,05457	0,06707	0,08625	0,12333
1.year	0,04461	0,04846	0,06469	0,08906	0,13171
2.year	0,00446	0,05050	0,06231	0,07744	0,11015

Table 4.3 Standard deviation for the average weekly returns on single futures contracts for different holding periods.

The standard deviations for the returns on the single contracts are shown in Table 4.3. An interpretation of the results is that the standard deviations or volatility in the market was approximately at the same level for both one-year periods. The exception is the whole contract holding period, with much higher volatility the first year. The reason for this is again the two already mentioned outliers. The decreasing standard deviation for longer holding periods is natural because the averaging process to weekly returns diminishes the effect of extreme results over long periods.

Autocorrel-ation coeff.	contract	last 4 weeks	last 3 weeks	last 2 weeks	last week
1. lag	0,7762	0,7684	0,6891	0,5373	0,1653
2. lag	0,5367	0,5951	0,4169	0,0797	0,0766
3. lag	0,4907	0,4099	0,1764	0,0755	-0,0080
4. lag	0,7006	0,3074	0,2225	0,1504	0,0846

Table 4.4 Autocorrelation coefficients for lag 1 to 4 (i.e. 1 to 4 weeks) for the weekly returns on futures contracts.

I also looked at autocorrelations for up to four time lags for the weekly returns (Table 4.4). The most interesting feature here is that there are no clear correlations between following weeks' contracts when looking at the returns for the last week holding period. The consequence of this is that a profit on this week's contract is no indication of a profit on holding a similar contract the next week. The same can be realised for 2, 3 and 4 weeks holding periods. When the number of lags in the autocorrelation coefficient extends the length of the holding period, so that the there is no overlap in the general market movements for the compared contracts, the correlations turn out to be rather low (see the numbers in bold in Table 4.4). The reason for the high correlation coefficient for all lags for the whole contract holding period is that the contracts here to a large degree overlap in time and therefore are faced to the same market movements.

Finally, I tested the hypothesis that the expected value of weekly returns from holding long positions are negative over the two years period, using my initial assumption that weekly returns equal to zero as the null hypothesis. Negative returns would indicate normal contango according to the theory presented above. I used a standard z-test procedure. The significance values (p-values) for the different holding periods are shown in Table 4.5. None of them validates the hypothesis with a significance level, α, of 0,05 or lower. The p-values of the 2 and 3 weeks holding period are lower than 0,10, but with the limited data available and the large differences in the mean for the 1. and 2. years I will not draw any conclusions unless the significance level is very low.

z-test	contract	last 4 weeks	last 3 weeks	last 2 weeks	last week
p-value	0,4138	0,1166	0,0835	0,0851	0,1085

Table 4.5 p-values when testing the hypothesis of negative weekly returns (r<0) for the different holding periods, using weekly returns equal zero (r=0) as null hypothesis.

The conclusion so far is therefore that the price development observed in Eltermin does not indicate average weekly returns different from zero with sufficient significance. This means that there is no apparent trend of neither normal backwardation nor contango in Nord Pool's electricity futures market. The most plausible hypothesis based on the observed price data is therefore the expectations hypothesis, i.e. $F_T = E(S_T)$. This is consistent with my initial assumption of no storage cost or convenience yield in the electricity futures market.

4.2.2.3 4.2.2.3 Normality of the data - single contracts

When using many statistical tools like for example the hypothesis test (z-test) one of the assumptions made is normality of the sample data. The two plots in Figure 4.3 show the distributions for the returns on contracts with 1 week and the 2 weeks holding periods compared to the normal distribution. As seen from the figures the normality assumption is apparently not seriously violated for the two shortest periods. Table 4.6 shows skewness and kurtosis for the data. Skewness is a measure for the symmetry of a distribution. A negative, positive or zero skewness means that distribution has a longer tail to the left, to the right or is symmetrical, respectively. Kurtosis is a measure for the peakedness of a distribution. A negative, positive or zero kurtosis means that the distribution is less peaked (platykurtic), more peaked (leptokurtic) or have the same degree of peakedness (mesokurtic) as the normal

	2 weeks	1 week
Skewness	-0,92	-0,38
Kurtosis	2,68	2,47

Table 4.6 Skewness and kurtosis for the distribution of returns on contracts with 1 week and 2 weeks holding period. The corresponding values for the normal distribution are both zero.

distribution *(Dougherty (1990))*. Table 4.6 shows that the distributions for the two shortest holding periods are skewed slightly to the left, and they are also leptokurtic. A leptokurtic distribution has a sharper peak, but also fatter tails than the normal distribution. From Figure 4.3 we can see the fat tails in the number of outliers or extreme data, which is a bit higher than the normal distribution suggests for both holding periods. The problem of fat tails is very common in statistics, and it also occurs for example in data for returns on stock markets. The daily changes in electricity spot prices (system prices), measured both as differences and as the logarithm of the price relatives, also have leptokurtic distributions in the period from 93 to 97 *(Johansson (1997))*. Assessing normality of the returns from the power market is an interesting topic on its own. A further study of the normality condition is, however, beyond the scope of this thesis.

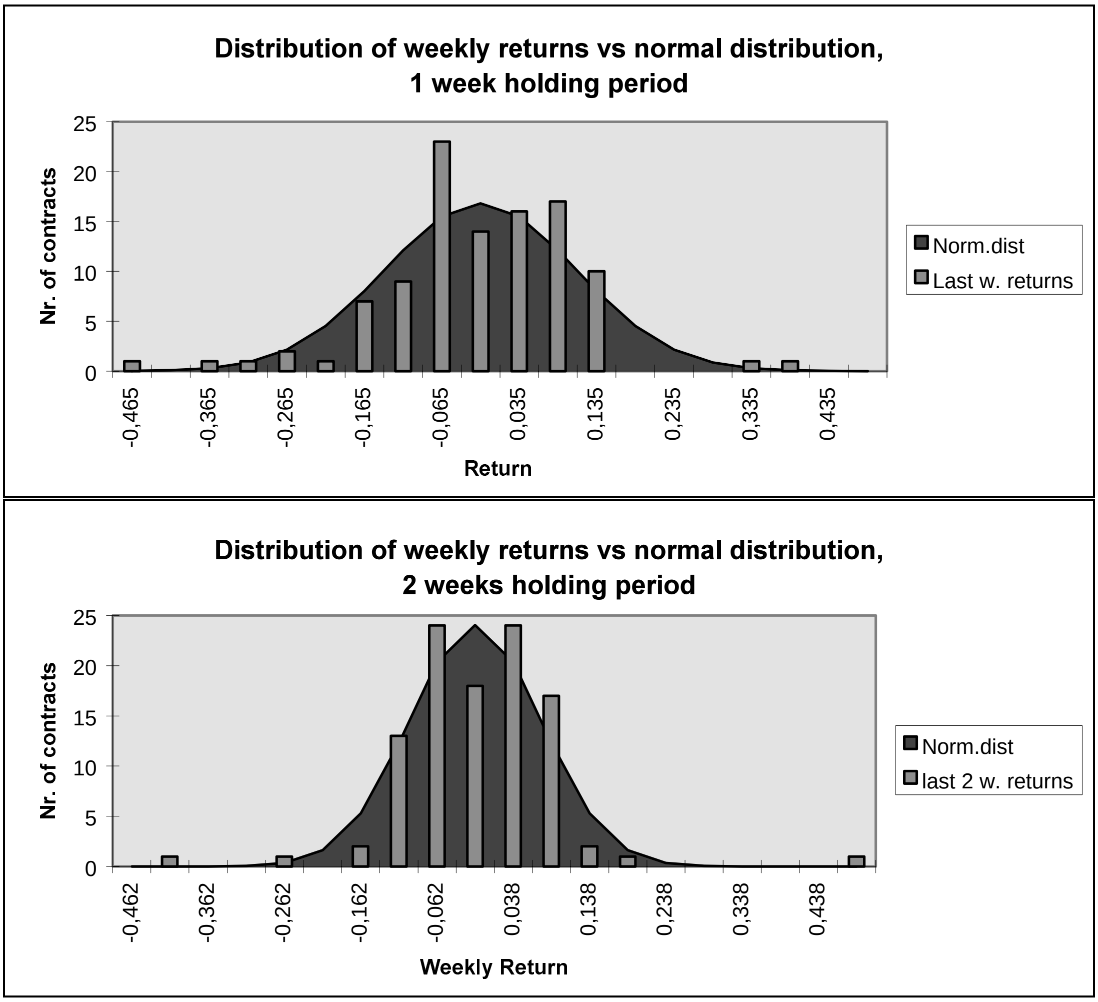


Figure 4.3 A comparison of the observed distribution of returns from one and two weeks holding periods with their respective normal distributions.

4.2.2.4 Returns on portfolios of futures contracts

I constructed three different dynamic benchmark portfolios of futures contracts to study the returns from holding a multiple of contracts. The first portfolio consist of an equal amount of all contracts available on the market, measured in number of contracts (not in money). The portfolio includes the contracts that go to delivery in the future (i.e. in 1998 and 1999). The return and value of the portfolio are calculated at the end of each week, and I have constructed an electricity index (called ELEX-w) like the stock market indices to see the development in the value of the benchmark portfolio. The second portfolio is calculated as the first, but consists of only the four contracts with shortest time to delivery. The index for this portfolio is called ELEX-4. The third portfolio is no real portfolio. It consists of only the contract that is to be delivered the following week, i.e. there is only one contract in the “portfolio” at each point of time. The return will therefore be the same as for the single contract with one week holding period. This index for the single contract is called ELEX-1.

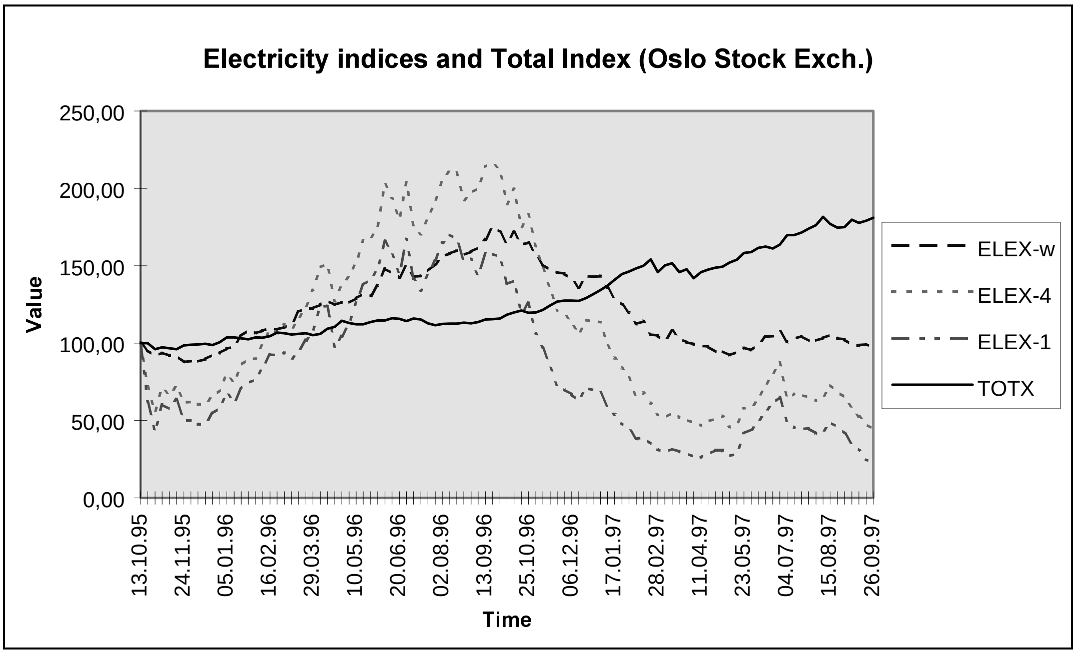


Figure 4.4 The constructed electricity indices over the two years period and the total index on Oslo Stock Exchange, TOTX (adjusted). The comparison with the stock market is commented in the next section.

Figure 4.4 shows the development of the electricity portfolios over time. ELEX-4 and ELEX-1 have a very similar shape with large variations over the two-years period. ELEX-w has a smoother shape and is not as volatile as the smaller portfolios. The trend for all three curves is an increase in the value (after a decrease in the first few weeks) until September-96, followed by a steep decrease towards 1997. The shapes of the curves reflects the already mentioned “power crisis”. During 1997, as the conditions in the power market return back to more normal conditions, the curves seem to flatten out.

	Weekly returns for the periods			**St. deviations for weekly returns**		
Period	*2 years*	*1. year*	*2. year*	*2 years*	*1. year*	*2. year*
ELEX-w	-0,0002	0,0097	-0,0102	0,0321	0,0292	0,0318
ELEX-4	-0,0079	0,0126	-0,0284	0,0985	0,1017	0,0905
ELEX-1	-0,0144	0,0064	-0,0351	0,1244	0,1337	0,1102
TOTX	0,0050	0,0025	0,0075	0,0159	0,0132	0,0178

Table 4.7 The average weekly returns on portfolios of futures contracts for the whole 2 years period, the 1. year and the 2. year respectively. Standard deviations for the weekly returns over the respective periods. For TOTX the weekly return in excess of the risk-free rate is shown.

Table 4.7 confirms the periodical trend in the data, with the large average profits the 1. year and corresponding losses the next. Over the whole two years period the portfolio with all available contracts shows the best performance of the four electricity portfolios, even though also this portfolio on average makes a small loss. The losses on the two other futures portfolios are considerable, and the index falls from 100 to 44,44 and 23,12 for ELEX-4 and ELEX-1 respectively. Extremely large losses in the first three weeks of trading partly explain the bad performance for these portfolios. The stock market (TOTX) is obviously a much better place to speculate over the whole two years period, but during the first year all the electricity indices outperform the total index from Oslo Stock Exchange. The standard deviations decrease with the size of the portfolio, which is natural due to lower weekly volatility in long term contracts compared to contracts with short time to expiry. The volatility is at the same level for the 1. and 2. year. Note also that the volatility of the weekly returns on the portfolio of all futures contracts is about twice the volatility of the returns on the stock market index.

autocorrelation coeff.	1 lag	2 lags	4 lags	**p-value, z-test**
ELEX-w	0,07636	0,18888	0,15500	0,4733
ELEX-4	0,06641	0,09656	0,08276	0,2094
ELEX-1	0,16442	0,06593	0,09675	0,1231
TOTX	-0,06059	0,00936	-0,06024	0,9993

Table 4.8 Autocorrelation coefficients for the weekly returns on the portfolios of 1, 2 and 4 lags. The z-test tests the hypothesis that the weekly returns are less than 0, and p is the significance level for this test. The null hypothesis is that the weekly returns equals zero.

I also looked at autocorrelation coefficients for the weekly returns on the portfolios. Table 4.8 shows that there are no significant correlations between returns with 1, 2 or 4 weeks difference in time. The last weeks' return is therefore no indicator for the following week's return on the portfolios. Finally, I did a similar hypothesis test as for the returns on single contracts. The results (Table 4.8) shows, not surprisingly, that there are no significant proof of negative average weekly returns on the electricity portfolios. The portfolio approach does therefore also reject the hypothesis of normal contango, and I end up with the expectations hypothesis as the most plausible hypothesis for futures contract prices. For the stock market index, however, the z-test shows that the mean of the weekly excess returns is positive with a significance as low as (1-0,9993)=0,0007(!) for the two years period.

The initial assumption of no storage cost or convenience yield in the electricity market is therefore still not rejected after having studied both returns on single futures contracts and returns on portfolios of contracts. I will now try to apply the futures pricing model based on the capital asset pricing model (CAPM) on the electricity futures market.

4.2.3 Pricing using CAPM and systematic risk

In the pricing model that utilises the CAPM it is assumed that the investors in the futures market price futures contracts according to the degree of systematic risk involved in the investment. Intuitively, I would not expect the participants in the electricity futures market to care to much about the systematic risk when buying and selling futures. The number of pure speculators in the market is very limited, and I do not think that their investment in the futures market is closely connected to their investment in other assets. Using the electricity market to diversify the portfolio of investments is probably not very common today, but may be more interesting for investors in the future when the electricity futures market becomes more mature. I would therefore be surprised if the returns and prices in the electricity market for the last two years can be explained by the systematic risk connected to the development of electricity futures prices.

The systematic risk in the electricity futures market is connected to the degree of correlation between the return on the futures contracts and the return on all available investment assets (see section 4.1.1.4). The stock market is usually used as a proxy for the overall market. I would not expect the return on the electricity futures market to be show close relations to the returns on the stock market. The electricity futures prices are very closely connected to the electricity spot price, which again is a function of the demand and supply of electricity. One possible connection between the electricity price and the level of the spot market is that when the level of the stock market is increasing this is usually caused by higher general demand for goods in the society. Higher demand of goods leads to higher demand for electricity, and the electricity price will naturally increase. However, the demand for electricity is also closely linked to other factors like the weather and temperature. These factors strongly influence the supply and demand for electricity, and therefore also the electricity price. I would therefore assume that systematic risk in the electricity market is rather low.

Below I will try to quantify the systematic risk in the electricity futures market by looking at historical futures and spot prices for electricity. I will also comment on how good the CAPM can explain returns in the electricity futures market for the past two years.

4.2.3.1 Interpretation of historical data

To examine the possibility of systematic risk connected to the electricity futures market I first compare the constructed electricity benchmark portfolios with the indices on Oslo Stock Exchange. When comparing returns on futures and on the stock market, I have used returns in excess of the risk-free rate (assumed to be 4% p.a.) for the stock market as recommended by *Bodie and Rosansky (1980)*. This is because the payment in the futures market occurs at the end of the holding period, except for the margin requirement. See *Appendix 1* for a discussion about the calculation of returns.

Table 4.9 shows that the excess returns on all the stock indices exceeds the returns on the electricity portfolios over the whole 2 years period. The table also confirms the already mentioned difference between the first and second year for the electricity futures returns. The stock indices show positive returns with the second year more profitable than the first year. This is due to the high momentum in the Norwegian economy the last year. The shipping sector has apparently been the most profitable sector over the two-years period. To try to quantify the degree of systematic risk in the electricity futures market I have calculated a correlation matrix for the returns on the benchmark portfolios and the excess returns on the stock indices. Table 4.10 shows that the correlations are close to zero for all the possible combinations of the returns on the electricity portfolios and the returns on the stock market indices.

Returns	2 years	1.year	2.year	Av. annual
ELEX-w	-0,022	0,496	-0,518	-0,011
ELEX-4	-0,809	0,641	-1,450	-0,404
ELEX-1	-1,464	0,324	-1,788	-0,732
TOTX	0,513	0,129	0,384	0,257
FINX	0,600	0,157	0,443	0,300
INDX	0,460	0,101	0,359	0,230
SKIX	0,697	0,208	0,489	0,349
SMBX	0,393	-0,050	0,442	0,196
OBX	0,453	0,106	0,347	0,227

Table 4.9 Returns on the constructed electricity indices and returns in excess of the risk-free rate on different indices on Oslo Stock Exchange over three time periods. TOTX is the total index, FINX is the finance index, SKIX is the index for the shipping sector, SMB for small and medium sized companies and OBX is the Oslo Stock Exchange index.

Corrlation matrix	ELEX-w	ELEX-4	ELEX-1	TOTX	FINX	INDX	SKIX	SMB	OBX
ELEX-w	1,000	0,781	0,681	-0,144	-0,034	-0,151	0,002	-0,119	-0,123
ELEX-4		1,000	0,960	-0,045	-0,018	-0,069	0,109	-0,137	-0,041
ELEX-1			1,000	-0,007	-0,017	-0,033	0,146	-0,089	-0,014
TOTX				1,000	0,402	0,978	0,786	0,473	0,969
FINX					1,000	0,334	0,221	0,225	0,480
INDX						1,000	0,671	0,466	0,946
SKIX							1,000	0,323	0,721
SMB								1,000	0,406
OBX									1,000

Table 4.10 Correlation coefficients between the return on electricity benchmark portfolios and the excess return on the indices on Oslo Stock Exchange for the period between week 42/95 to week 40/97.

Low correlation to the return on the stock market should mean a corresponding low systematic risk. If I use the total index at Oslo Stock Exchange as a proxy for the overall market I can calculate beta values, and the corresponding expected returns on the benchmark portfolios based on the CAPM (Eq.(4.6)). The results for the whole two years period is shown in Table 4.11. It turns out that the CAPM predicts the right signs of the observed average weekly return, as both the calculated and observed returns are negative for the three indices. The fit to the observed data is, however, far from perfect. While CAPM predicts that the weekly returns should be increasing with the size of the portfolio, the observed values show the opposite development. When calculating beta values it is recommended to use observations from a period with "normal" conditions in the market. This is not yet possible in the electricity market, so eventual conclusions based on observed betas in the market so far are only preliminary. My initial doubt about the CAPM's ability to predict futures prices and returns in the electricity market can therefore not be rejected. The fact that the fit is as good as it is might only be a pure coincidence, bearing in mind the limited amount of data and the special conditions prevailing in the electricity market in the 2 years period.

	Beta-value	Calculated Return	Observed Return
ELEX-w	-0,29025	-0,00124	-0,00021
ELEX-4	-0,27864	-0,00119	-0,00793
ELEX-1	-0,05099	-0,00022	-0,01436

Table 4.11 Beta values, calculated value for weekly returns on futures portfolios in excess of the risk-free rate based on CAPM, and the corresponding observed values over the two years period.

Another way of searching for systematic risk in the electricity market is to compare the spot price in the electricity market with the level of the total index on the stock market. When the futures price equals the expected future spot price, which I claim earlier in this chapter, correlations between the electricity spot price and the stock market should indicate the degree of systematic risk. For electricity spot prices I have data back to 1992. Table 4.12 shows the correlation coefficients between the electricity spot price and the total index on Oslo Stock Exchange for six different time periods. The results are not consistent for the different intervals. For the last two years (Oct. 95-Sept. 97), which is the same period as I have studied futures prices, the correlation is negative (-0,5016). Negative correlation indicate negative systematic risk, which I also found when directly comparing the returns on electricity futures and returns on the stock market (Table 4.11). The correlations for the two last one year periods are, however, showing completely different values. In the period (Oct. 95-Sept. 96) the correlation is close to +1, while it is close to -1 for the period (Oct. 96-Sept. 97). The special situation in the electricity spot market due to the "power crisis" during the first period explains this development. The spot prices rose together with the level of the stock market from Oct-95. When the situation in the spot market

May92-Sep97	May92-Sep95	May92-Des96	Oct95-Sept97	Oct95-Sep96	Oct96-Sep97
0,3589	0,5286	0,7241	-0,5016	0,8390	-0,8419

Table 4.12 Correlation coefficients between the electricity spot price and the total index at Oslo Stock Exchange for 6 different time periods.

returned to normal conditions with falling prices in 1997 the stock market continued climbing and the correlation for the second year is therefore negative. It is tempting to use these results to explain the returns in the electricity futures market for the same period. Positive systematic risk the first year gives corresponding high returns on futures, and vice versa for the second year. This implication is however wrong. If investors base their investments on the systematic risk connected to the investment, they probably determine the degree of systematic risk by looking at historical data over a long period of time. Before Oct. 1995 the most reliable estimate of the systematic risk is therefore the correlation coefficient for period from May 92 to Sept 95, which indicates a positive systematic risk. The correlation is even more positive from May 92 to Sept. 96 so that investors could still expect positive returns in the futures market for the next year (unless they by other means predicted the decreasing electricity prices that were to follow). During the last year, however the observed returns on futures have been far below zero (Table 4.9). It is therefore not possible to explain the return pattern in the electricity futures market for the last two years based on correlation between the electricity spot price and the level of the stock market. When looking at the correlation for the whole period from 92 to 97 the correlation coefficient is 0,3589, indicating a positive systematic risk. If the CAPM model was right we could therefore expect the return in the electricity futures market in the future to be above the risk-free rate. However, I can not find any significant evidence for the CAPM's ability to predict prices and returns in the electricity futures market from the results above. I therefore still have more confidence in the expectations hypothesis for electricity futures prices, which states that the expected return in the electricity futures market equals the risk free rate of return.

To summarise and conclude this section, I have tried to see if CAPM can be utilised to predict futures prices and returns in the electricity futures market. When directly applied to the returns in the futures market for the last two years, CAPM predicts correct signs of the returns, but the match is not very close to the observed values. A comparison of electricity spot prices and the total index on the stock market shows weak evidence of positive systematic risk over the period from 92 to 97. Positive systematic risk should lead to a higher rate of return on holding long futures contracts than the risk-free rate, according to CAPM. This is, however, not reflected in the futures prices and returns from 95-97. I conclude that the CAPM can probably not explain futures prices and returns in the electricity futures market. This is consistent with what I initially expected.

4.2.3.2 Comment on normality - benchmark portfolios

To get an impression concerning the degree of normality of the data for the returns on the futures and stock market indices I have plotted the distribution of the returns on the ELEX-w portfolio and on the TOTX together with their respective normal distributions. The two plots are shown in Figure 4.5. None of the plots do perfectly fit the normal distribution, but apparently the returns on ELEX-w deviate a bit more from the normal distribution than what is the case for the returns on TOTX. When looking at the skewness and kurtosis for these

	ELEX-w	**TOTX**
Skewness	0,030	-0,95
Kurtosis	-0,290	2,10

Table 4.13 Skewness and kurtosis for the distribution of returns on ELEX-w and TOTX. The corresponding values for the normal distribution are both zero.

distributions (Table 4.13), however, it turns out that the values for the return on ELEX-w are closer to the normal distribution than the values for the return on TOTX. The distribution of returns on TOTX is slightly skewed to the left and is leptokurtic (i.e. has a positive kurtosis and fat tails). The skewness and kurtosis for the distributions of returns on ELEX-w do not differ much from zero. These observations indicate that assuming normality for the returns on the benchmark portfolios of futures contracts is probably not more wrong than doing the same assumption for the returns on the stock market index.

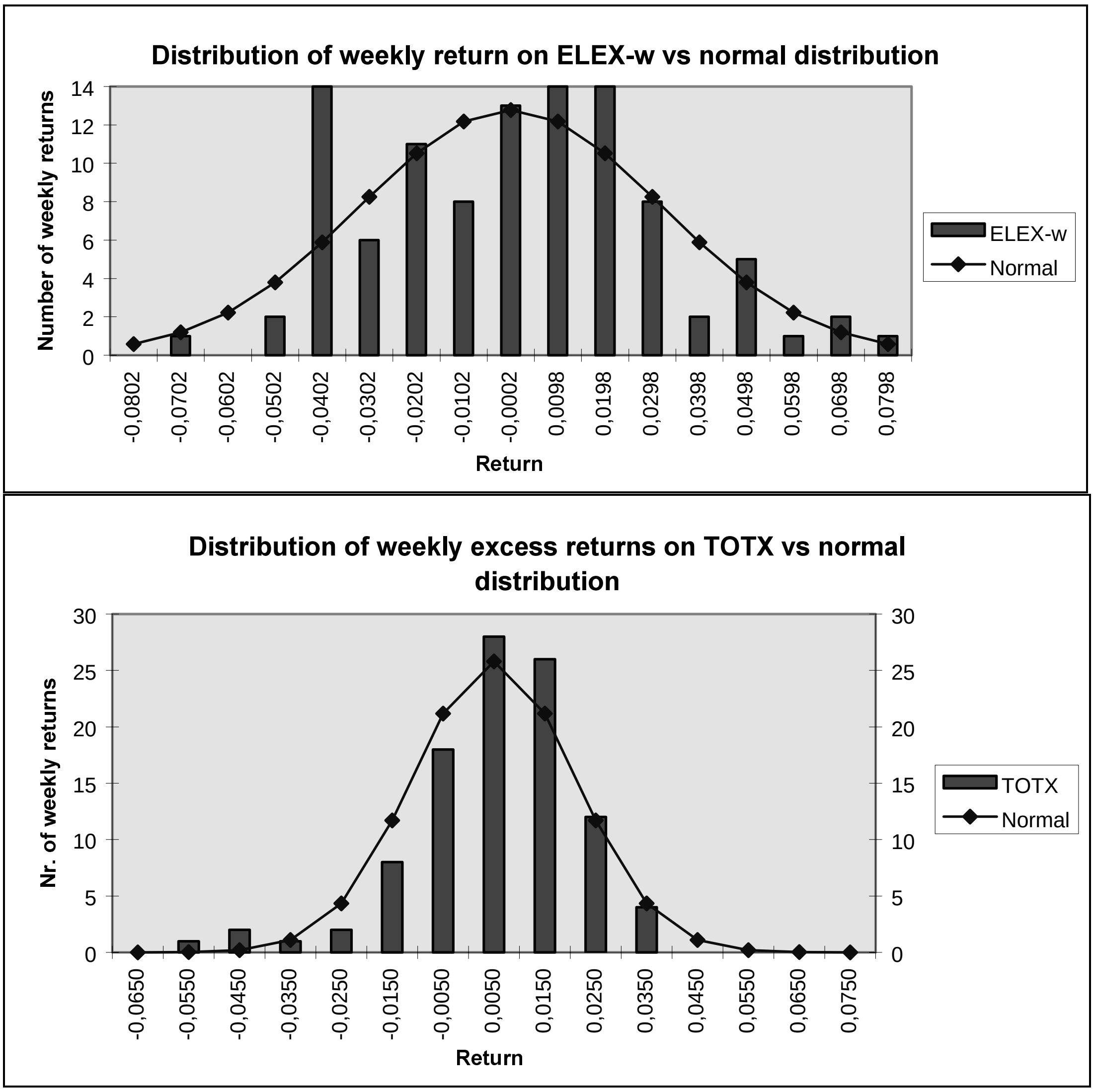


Figure 4.5 The distribution of the returns on the ELEX-w index and the total index compared to their respective normal distributions.

4.3 Summary

In the first part of this chapter I outlined general theory for pricing of commodities futures contracts. Two models for futures pricing are presented, one based on storage cost and convenience yield, the other one based on systematic risk and the capital asset pricing model (CAPM). I also described three different hypotheses for the development of a futures contract price towards expiry of the contract, namely normal backwardation, normal contango and the expectations hypothesis. Under the first pricing model these hypotheses can be explained by storage cost and convenience yield. Under the second model by the degree of systematic risk involved in the futures market.

Before looking at historical data from the electricity futures market, I argue that storage cost and convenience yield only make sense for producers of electricity with reservoir capacity in a hydropower system like the Norwegian. I claim that there is no direct cost concerned with keeping water in the reservoirs. The storage cost should therefore be considered as zero when calculating futures prices. There could be a convenience yield concerned with storing water and thereby being able to adjust the production to instant future price movements. Calculating the convenience yield would, however be a very complex task, and it is probably not taken into consideration when calculating and assessing futures prices in the electricity market. I also doubt that systematic risk should play any significant role for the participants in the electricity market, since most of them are electricity companies and only a very few are pure investors with well diversified portfolios of investments.

In the analysis of the historical data of futures prices I first looked at returns on single futures contracts with five different holding periods, from only the last week of trading, to the entire contract life. The average returns in the period from Oct. 95 to Oct. 97 are slightly negative for all holding periods. I find, however, no significant evidence of weekly average profit or loss holding single electricity futures contracts. The calculations show positive returns on holding long futures contracts the first year, and losses the second year. This was explained by the “power crisis” in 1996 with increasing electricity spot prices, and the return to normal conditions in 1997, with falling spot prices. I further looked at returns on three constructed benchmark portfolios of futures contracts. The returns on the benchmark portfolios show similar results as the returns on single contracts. I therefore concluded that the most plausible hypothesis for the futures price of electricity, based on the analysis of the two years period that Nord Pool’s term market has been operating, is the expectations hypothesis. This hypothesis is consistent with the initial assumption that no storage cost or convenience yield is taken account for in the pricing of electricity futures.

I further tried to apply the CAPM model to the returns on the electricity futures contracts, by calculating correlations to the return on the stock market and the corresponding beta values. The results for the two years period show that CAPM correctly predicted negative average weekly returns over the period. The fit to the observed returns is, however, far from perfect. When comparing electricity spot prices and TOTX from May 92 to Oct 97 I find weak evidence of positive systematic risk connected to the expected spot price. This is, however, not reflected in the observed returns in the electricity futures market for the last two years, which on average are negative. Based on these results I could therefore not reject my initial assumption that CAPM can probably not explain electricity futures prices and returns.

It is important to emphasise that the validity of the empirical results is seriously hampered by the very limited amount of available price data for electricity futures contracts.

5 Hedging Strategies

In this chapter I look at some of the common hedging strategies used in commodities and financial markets. I try to transfer the same strategies into the electricity market, too see if the strategies are tractable in this market. In the first part I look at common hedging strategies involving futures contracts. The concept of basis risk is presented and analysed specially for the electricity futures market. I show how basis risk traditionally is applied to determine optimal hedge ratios, and describe how the special features of the electricity market influence this process. In the second part I take a closer look at the electricity forward curve, i.e. the term structure of electricity futures prices. I further look at how the electricity sector can learn from the management of interest rate risk and movements in the term structure of interest rates.

5.1 Hedging in futures contracts

A company that knows that it is due to sell an asset at a particular time in the future can hedge by taking a short futures position. If the price of the asset goes down, the company makes a loss on the sale of the asset but makes a gain on the short futures position. If the price of the asset goes up, the company takes a loss on the futures position. Similarly, a company that knows that it is due to buy an asset in the future can hedge by taking a long futures position. It is important to recognise that futures hedging does not necessarily improve the overall financial outcome. What a futures hedge does do is to reduce risk by making the outcome more certain.

There are a number of reasons why hedging using futures contracts works less than perfectly in practice (*Hull(1997)*):

1. *The asset whose price is to be hedged may not be exactly the same as the asset underlying the futures contract.* This is not a problem in the power market unless you try to hedge your position using other futures than electricity futures, which is not very common.
2. *The hedger may be uncertain as to the exact date when the asset will be bought or sold.* Most electricity companies deliver power continuously and not on a specific date. They can, however, not know the exact future demand schedule for power resulting from their customers needs.
3. *The hedge may require the futures contract to be closed out well before its expiration date.* This could have been a large problem when trading in electricity futures, since the contracts are settled on the last trading day before the delivery week, and the price within the delivery week might very well vary unfavourably for the hedger. The price securing settlement (see section 0 and Figure 2.4) during the delivery week reduces the problems and risk connected to this, as we will se below.

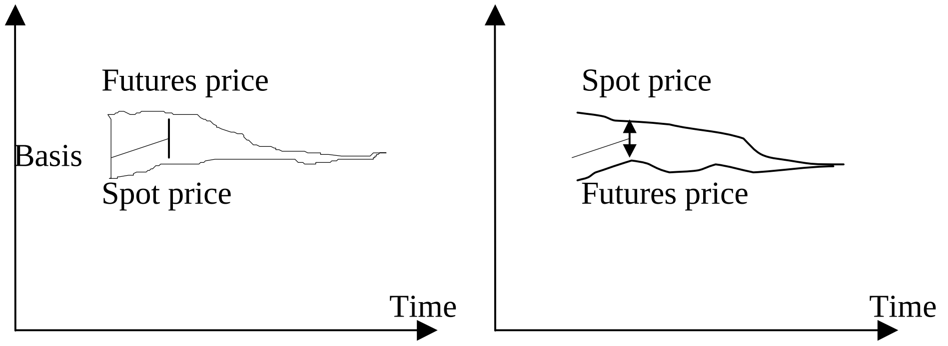
These problems give rise to what is termed as *basis risk*. Below I give a definition of basis risk, and comment upon the consequences that this risk incurs for the electricity market. Later I look at the problem of calculating optimal hedge ratios when using futures for hedging in the electricity market compared to in more “normal” commodities markets.

5.1.1 Basis risk[1]

The basis in a hedging situation is defined as follows:

basis = spot price of asset to be hedged - futures price of contract used

If the asset to be hedged and the asset underlying the futures contract are the same, the basis should normally be zero at the expiration of the futures contract. Prior to expiration the basis may be positive or negative. The figures below illustrate typical relationships between spot and futures prices for traditional commodities (like oil, sugar, wheat etc.) and electricity.



a) Futures price above spot price. b)Futures price below spot price.

Figure 5.1 Relationship between futures price and spot price as the delivery month is approached for "traditional" assets (Source: Hull (1997)).

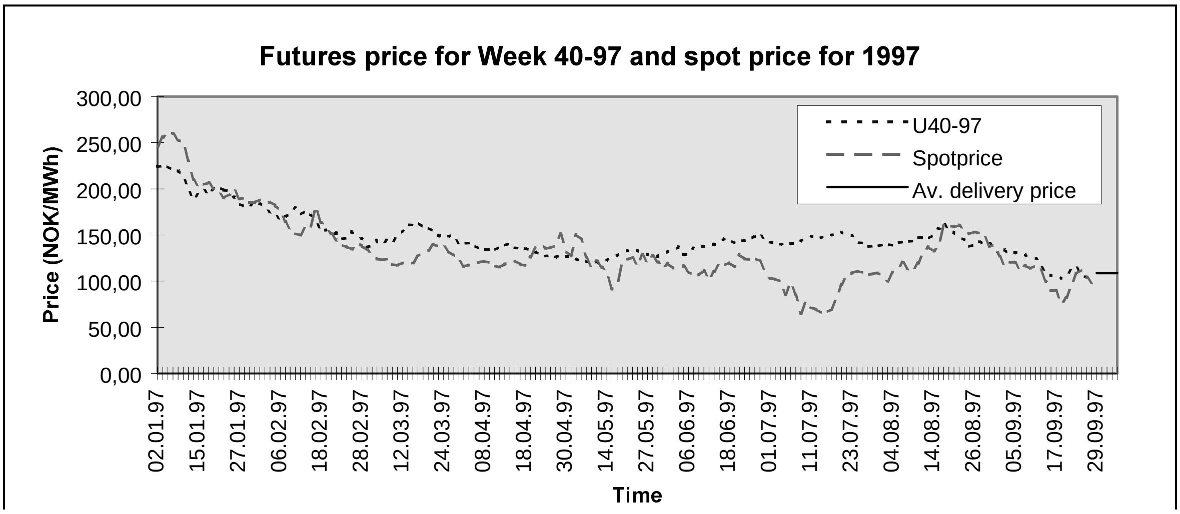


Figure 5.2 Futures price for week 40-97 (closing day for trading 26.09.97), spot price and average spot price during delivery week. Notice the difference between the average delivery price and the closing futures price. The difference between the spot price and the futures price is the basis. The correlation coefficient between futures and spot price is 0.82.

Consider the situation of a hedger who knows that the asset will be sold at time t_2 and takes a short futures position at time t_1. This might be an electricity company with contracts of physical delivery at spot price some time in the future. The price realised

---

[1] The general financial theory presented in this section is based on *Hull (1997).*

for the asset is S_2 and the profit of the futures position is F_1-F_2 if the futures position is closed out at time t_2. The effective price that is obtained for the asset with hedging is therefore:

$$S_2 + F_1 - F_2 = F_1 + b_2 \tag{5.1}$$

where S is spot price, F is futures price and b is basis. The value of F_1 is known at time t_1. If the closing basis, b_2, were also known at this time, a perfect hedge (i.e. a hedge eliminating all uncertainty about the price obtained for the contractual volume) would result. The hedging risk is the uncertainty associated with *b2*. This is known as *basis risk.*

Now consider a situation where a company knows that it will buy the asset at time t_2, e.g. an electricity company having agreed to deliver more power than its own production capacity at some time in the future. The company initiates a long hedge at time t_1. The price paid for the asset is S_2 and the loss on the futures position is F_1-F_2 if the position is closed out at time t_2. The effective price that is paid with hedging is therefore the same as for the short hedge, Eq.(5.1). The value of F_1 is known at time t_1 and the closing basis, b_2, represents basis risk. The difference between the long and the short hedge is that for the short hedger it is favourable with an increase of the basis, while the long hedger profits on a decrease of the basis.

For investment assets such as currencies, stock indices, gold and silver, the basis risk tends to be fairly small. This is because arbitrage arguments lead to a well-defined relationship between the futures price and the spot price of an investment asset. The basis risk for an investment asset arises mainly from uncertainty as to the level of the risk-free interest rate and the asset’s yield in the future. In the case of a commodity such as oil, corn or copper, imbalances between supply and demand and the difficulties sometimes associated with storing the commodity can lead to large variations in the basis and therefore a much higher basis risk. Electricity has got more in common with pure commodities than financial assets.

5.1.2 Basis risk and electricity futures

There is not necessarily a convergence between the spot price and the futures price as the futures contract expires, because of the time gap between the last trading day of the futures contract and the delivery week (Figure 5.2). The price securing settlement provides a solution to this problem. I will first describe the impact of the price securing settlement on basis risk for electricity futures. Then I will analyse the need for such an additional settlement procedure, by looking at the differences between closing futures price and the spot price in the delivery week.

5.1.2.1 The impact of the price securing settlement procedure on basis risk

There is a special feature of the electricity futures market which makes it possible to avoid the basis risk despite the lack of convergence between spot price and futures price when expiration is approached. By letting the futures contract go to delivery, the basis risk is removed because of the price securing settlement. In the price securing settlement the value of the closing basis, which appears during the delivery week, is transferred between participants with short and long positions according to the movements in the system price (the reference price in the spot market). The hedger knows that the difference between the closing futures price and the system price in the spot market is eliminated by the price securing settlement. (For a closer description of the settlement procedure, see section 0 and Figure 2.4) The closing basis, b_2, from Eq. (5.1) is fixed and equal to zero, and the participant is certain to end up with the initially agreed futures price (F_1) for the contractual volume. The requirement for the perfect price hedge is that the exact contractual volume is also traded in the spot market at system price during delivery week. Volume risk, or risk connected to the uncertain volume (quantity) of the delivery, is not removed since the futures contract only hedges the contractual volume. Also note that the futures contract does not hedge an eventual capacity-fee caused by excess demand in the participant's area (which, in fact, occurs rather frequently). With a capacity-fee the perfect hedge disappears.

The price securing settlement removes the basis risk. Risk-averse hedgers should therefore normally let their futures contracts go to delivery and in that way diminish the price risk for the contractual volume. Still, if a risk-averse participant finds out that he probably is long or short in too many contracts due to alterations in the demand schedule for the delivery period, he should consider to close out some of the contracts. The problem of matching the number of futures contracts to expected demand/supply in the future is very complex in the electricity market. This is because of the very high uncertainty connected to future demand, and for electricity producers also the uncertainty about own future production capacity. The problem of volume risk requires a dynamic approach, and in the search for an optimal solution the participant can not forget about the basis and the basis risk when considering to close out contracts before delivery.

Anyway, the existence of a price securing settlement reduces risk for the electricity companies as long as the difference between the closing futures price and the system price during the following delivery week is of a considerable size. To assess the need of the price securing settlement I will now briefly look at the magnitudes of the differences that have appeared in Nord Pool's term market for the last two years.

5.1.2.2 Closing basis and the need for a price securing settlement

By closing basis for electricity futures I mean the difference between the average system price in the spot market during the delivery week and the price of the futures contract on the last day of trading. If this difference consistently was very small the need of the price securing settlement would not be present. The hedgers could then close out the contracts just before the delivery week and save the costs concerned with the price securing settlement. Closing out contracts before delivery is the common way of trading in other futures markets. Below I analyse historical data to see if the closing basis concerned with electricity futures contracts is of a considerable size. The analysis should not be of interest only from a hedger's point of view. Any observed trend of positive or negative closing basis could indicate profitable investment opportunities for speculating in the price securing settlement.

Figure 5.3 shows the closing basis for the futures contracts traded at Nord Pool's Eltermin market[1] from Oct. 95 to Sept. 97. The closing basis seems to be of considerable size, but it is not easy to spot any particular trend in the closing basis

---

[1] The prices of similar bilateral contracts usually follow the price movements in Eltermin and should therefore also involve approx. the same amount of closing basis.

from the figure. If there was no price securing settlement the participants in the market would obviously be exposed to a risk when closing out the contracts on the last trading day. Another interesting interpretation of the figure is that the market's ability to predict next week's spot price, which is reflected in the size of the closing basis, is not too impressive. In fact, the correlation between the closing futures price and the spot price of the same week is higher than between the closing futures price and the average weekly spot price in the following delivery week (0,983 vs. 0,968). This indicates that a common forecast for next week's system-price is a "no-change from this week" forecast.

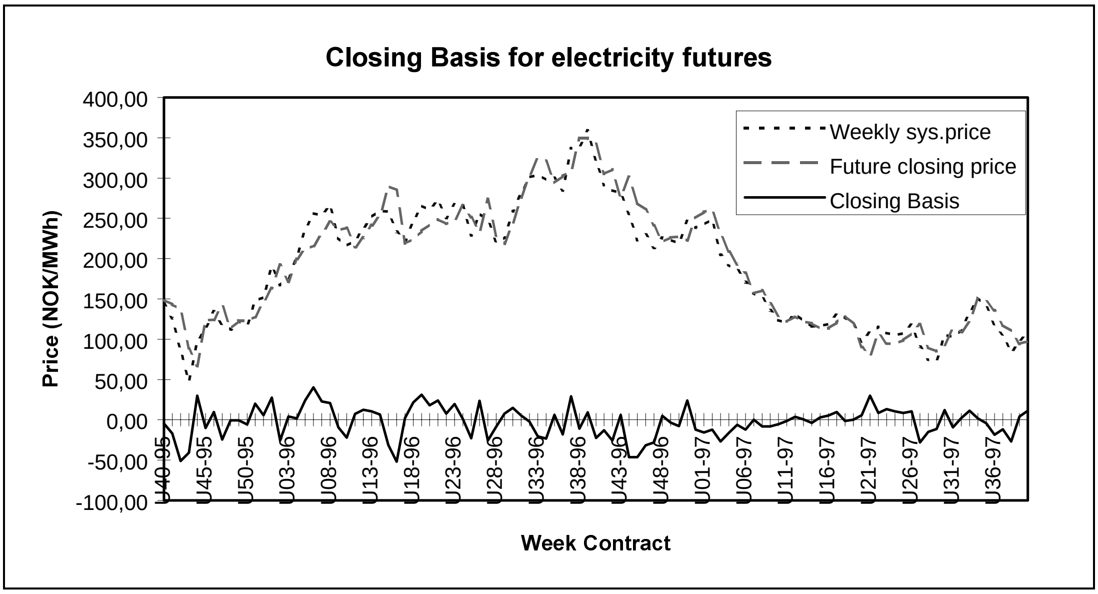


Figure 5.3 Closing futures prices, average weekly system prices and closing basis in Nord Pool's Eltermin futures market.

Table 5.1 and Figure 5.4 clearly show the risk element that the closing basis would have exposed the participants to without the price securing settlement. The average absolute value of the closing basis over the 2 years period turns out to be more than 8% of the closing futures price. The numbers of positive and negative closing basis values are the same over the whole period, but the mean is -2,41 NOK/MWh indicating that on average participants with short positions have profited on the price securing settlement. However, by looking at the 1. year and 2. year separately the mean is 0,73 and -5,49 respectively, so there is no clear overall trend. The positive closing basis the first year corresponds to increasing spot prices (the "power crisis), while in the second year the spot prices generally decreased. The observed difference between the closing basis the first and the second year is therefore somehow as expected. The separate statistics also show that the variability of the closing basis has decreased for the 2. year (this can also be realised by looking at Figure 5.3). The standard deviation has declined from 21,35 to 15,75 and the average absolute value of the closing basis has been reduced from 9,17% to 8,12% of the closing futures price. The reason for this might be the improved liquidity in the futures market in the sense that the futures market's influence on the price discovery process has become more important. Another plausible explanation is the extreme conditions in the power market during 1996, with very high prices and also a high degree of uncertainty in the market, leading to difficulties in predicting future spot prices.

	Weekly Spot price	**Closing Futures price**	**Closing Basis**
Week 40-95->40-97			
Mean	189,41	191,82	-2,41
Std.dev.	74,52	75,51	18,91
1st quartile	117,96	121,92	-13,15
3rd quartile	252,11	246,92	9,75
Week 40-95->39-96			
Mean	220,38	219,65	0,73
Std.dev.	71,50	68,66	21,35
1st quartile	163,15	159,61	-12,41
3rd quartile	265,69	256,22	18,59
Week 40-96->40-97			
Mean	159,03	164,52	-5,49
Std.dev.	64,76	72,43	15,75
1st quartile	108,87	110,46	-13,15
3rd quartile	219,25	226,43	5,42

Table 5.1 Mean, variance, standard deviation, 1st quartile and 3rd quartile for the average weekly system price, futures price on last day of trading and the closing basis.

Table 5.1 and Figure 5.4 further show that there are large values to win (or loose) if interpreting and predicting the value of the closing basis correctly (or incorrectly). If e.g. a speculator thinks that the futures price on the last day of trading is higher than what will appear the following week he can sell futures contracts and profit on the price securing cash delivery, if he is right. The eventual profit depends of course also on the transaction costs involved. Speculating in basis risk can obviously be carried out during the whole life of the futures contract, but if buying or selling futures contracts before the last day of trading you also speculate in the behaviour of the futures prices before the delivery week, and not only in closing basis. One of the factors that makes the financial electricity futures market attractive to pure speculators, without production or consumption of power, is the fact that they can hold the contracts to expiration without taking part in any physical delivery.

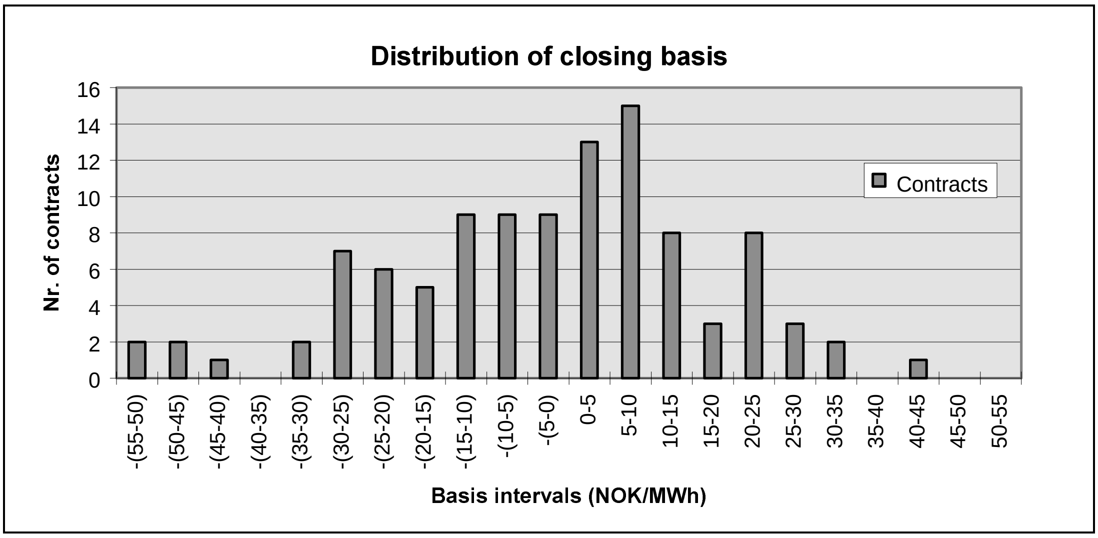


Figure 5.4 The distribution of the closing basis in intervals of 5 NOK/ MWh.

The conclusion of the analysis in this section is that the size of the closing basis that has occurred in the electricity futures market so far validates the need of a price securing settlement. Without, the hedgers in the market would be exposed to a basis risk of such a size that it could be a deterrent to using the futures market for risk management. The considerable closing basis could be used for speculating.

Speculating in the price securing settlement would involve high risk, and the data does not give strong indications of which position, long or short, is most profitable to take.

5.1.3 Optimal hedge ratio

The hedge ratio is the ratio of the size of the position in futures contracts to the size of the exposure. The traditional derivation of the hedge ratio is presented below *(Hull(1997))*:
Define:

ΔS = change in spot price, S, during a period of time equal to the life of the hedge.
ΔF = change in futures price, F, during a period of time equal to the life of the hedge.
σ_s = standard deviation of ΔS.
σ_F = standard deviation of ΔF.
ρ = coefficient of correlation between ΔS and ΔF.
h = hedge ratio.

When the hedger knows he is going to sell the asset in the future and therefore short futures contracts, the change in the value of the hedger's position during the life of the hedge, v_s, is:

$$v_s = \Delta S - h\Delta F \tag{5.2}$$

When hedging a future purchase of the asset (a long hedge), the change in the value, v_l, is:

$$v_l = h\Delta F - \Delta S \tag{5.3}$$

In either case the variance of the change in value of the hedged position is given by:

$$\sigma_{v_l}^2 = \sigma_{v_s}^2 = \sigma_v^2 = \sigma_S^2 + h^2\sigma_F^2 - 2h\rho\sigma_S\sigma_F \tag{5.4}$$

so that the first derivative of the variance is:

$$\frac{d\sigma_v^2}{dh} = 2h\sigma_F^2 - 2p\sigma_S\sigma_F \tag{5.5}$$

Setting this equal to zero, and noting that the 2. derivative is positive, we see that the value of h that minimises the variance is:

$$h = \rho\frac{\sigma_S}{\sigma_F} \tag{5.6}$$

The optimal hedge ratio is therefore the product of the coefficient of correlation between ΔS and ΔF, ρ, and the ratio of the standard deviation of ΔS, σ_S, to the standard deviation of ΔF, σ_F, assuming that the aim is to minimise the variance and hence the risk connected to the hedging position.

5.1.3.1 Optimal hedging ratio in the electricity market

As described above it is possible to carry out a perfect hedge of the price risk of a specific volume in the electricity market by letting the contracts go to delivery. In the price securing settlement the basis risk is removed, and you are guaranteed that the spot price you end up with in the delivery week matches the closing futures price 100% (as long as the spot price in your area equals the system price). This fact involves consequences for the outline of the optimal hedge ratio. Consider an electricity company that wants to hedge a future delivery by shorting futures contracts. The expression for the change in the value of the company's position is the same as above (Eq. (5.2)), written out it is:

$$v_s = \Delta S - h\Delta F = (S_d - S_p) - h(F_d - F_p) \tag{5.7}$$

where the subscript *d* and *p* refers to the time of delivery and purchase. A risk-adverse company will normally let the contract go to delivery as explained above. When doing this the hedger knows that:

$$S_d = F_d \tag{5.8}$$

Combining Eq. (5.7) with Eq. (5.8) gives:

$$\begin{gathered} v_s = (F_d - S_p) - h(F_d - F_p) \\ \Downarrow \\ v_s = (1-h)F_d + hF_p - S_P \\ \Downarrow \\ v_s = (1-h)(F_d - F_p) + (F_p - S_P) \end{gathered} \tag{5.9}$$

Noting that $(F_p\text{-}S_s)$ is a constant the expression for the variance of v_s is now:

$$\sigma_{v_s} = (1-h)^2\sigma_F^2 \tag{5.10}$$

so that:

$$\frac{d\sigma_{v_s}}{dh} = 2(h-1)\sigma_F \tag{5.11}$$

Setting this equal to zero, and noting that the 2. derivative is positive, we see that σ_F disappears and the value of *h* that minimises the variance is:

$$h = 1 \tag{5.12}$$

The optimal hedge ratio is therefore always equal to one when the intention is to hold the futures contracts all the way to delivery. When h = 1 the variance becomes zero. The same conclusion holds for a long hedge. In practice, this means that the electricity company should buy the number of futures contracts that equals the expected exposure in the delivery period. The remaining problem is to predict the company's net future exposure.

If, however, the hedger intends to close out the futures contracts before delivery (he might e.g. use contracts that expire at a later stage than the exposure he is hedging) the first conclusion (Eq. (5.6)) applies for the optimal hedge ratio. The problem now is that the hedger does probably not know at what time he wants to close out the contracts. He will wait for a profitable situation in the market. It is therefore difficult to calculate historical standard deviations and correlations for the right time interval, since the length of the interval is unknown. There are also other factors that hampers the use of this method in the electricity market. The high degree of seasonality for the prices is one factor, and the lack of historical data to obtain plausible estimates for the standard deviations and correlation another one.

Fleten (1995) proposes another optimal hedge ratio for electricity producers. He takes into account the uncertainty about the quantity of the future exposure, and the correlation between the spot price and this uncertain quantity. The correlation can be estimated using historical data, and tends to be negative since low inflow and production results in high prices and vice versa. The negative correlation contributes to smooth out differences in profit from year to year for electricity producing companies. Fleten claims that in order to minimise risk, electricity companies should find a hedge ratio that is equal to the slope of the change in profit (spot price times the quantity of delivery) to the change in futures price. The resulting hedge ratio is:

$$h = \rho_{sq,q} \frac{\sigma_{sq}}{\sigma_s} \tag{5.13}$$

where subscript q refers to the uncertain quantity and sq to the joint distribution of the spot price and the uncertain quantity. It would be interesting to compare the three presented hedge ratios (Eq. (5.6), Eq. (5.12), and Eq. (5.13)) to see which one gives the best historical results for different participants. I would expect the results to be different for a producer and a pure distributor of electricity. The latter will not experience the same smoothing effect on the profit from the negative correlation between price and quantity, since he has to buy the electricity before he can sell it. This analysis is, however, beyond the scope of this thesis (I have no data about the quantity, q) but is a relevant topic for future work.

5.2 The electricity forward curve

The expected prices for electricity at different time periods in the future is often called the electricity forward curve. As stated in section 4.2, the prices of electricity futures contracts should be an unbiased estimate of the expected future spot price. I therefore consider the prices for futures contracts as the market’s perception of the electricity forward curve. A good estimate of the electricity forward curve and knowledge of its movements is of good use for the participants in the electricity market, both for production planning, hedging and speculating. If a participant has a better estimate of the future spot price or the movement in the forward curve than the estimates prevailing in the market he can in the long run profit from this.

Figure 5.5 shows an example of the electricity forward curve. The term structure of the curve is striking, with high prices during the winter and low prices in the summer. Interest rate management is a field of finance where the term structure of interest rates has been a subject of interest for many years. Different models have been developed to capture the movements in the yield-curve[1]. There also exist a comprehensive theory

---

[1] The *yield-curve* is a graph that shows the yields-to-maturity for treasury securities of various maturities. This provides an estimate of the current *term structure* of interest rates, and will change daily as yields-to-maturity change. The term structure of interest rates is the set of yields-to-maturity across bonds that possess different terms-to-maturity, but are similar with respect to other attributes (coupon rate, call provisions, tax status, marketability and likelihood of default) *(Alexander/Sharpe (1989))*.

about different hedging strategies applied to avoid the risk connected to movements in the yield-curve, and many of these strategies have been tested and used for several years. I will in this section first take a look at the electricity forward curve for the period that Eltermin has been operating (95-97), to look for typical patterns of movements in the curve. Afterwards I will give a short description of some of the models and tools used in interest rate risk management and comment upon the degree to which these can be applied in the electricity market.

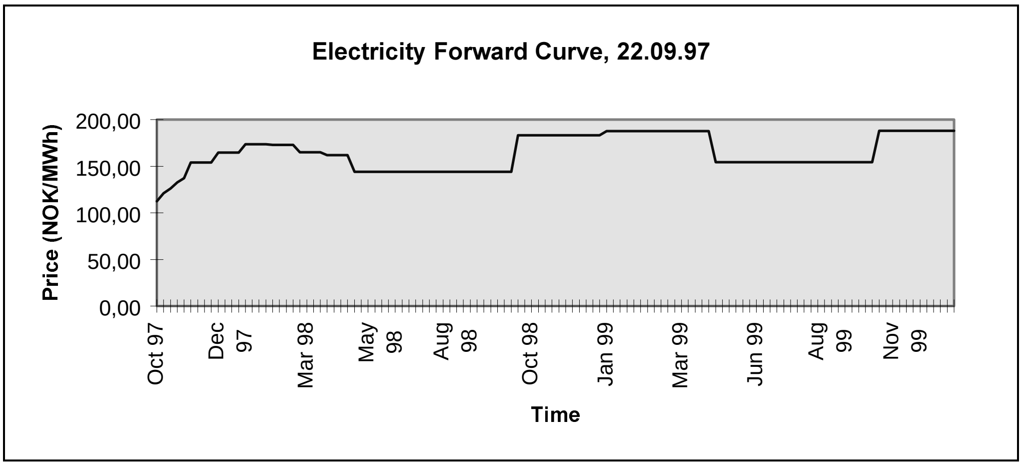


Figure 5.5 The prices in the futures market, i.e. the electricity forward curve, as at 22.09.97. The sharp edges in the plot represents changes in block or season contracts.

5.2.1 The structure of the electricity forward curve

An interesting feature of the electricity forward curve is the degree to which moves in the curve at different times in the future are connected. I would expect the contract prices in the nearest end of the curve to be very dependent on the moves in the spot price, because the spot price of this week often is a good estimate for the spot price the following week(s). The link to the spot price is less intuitive for the far end of the forward curve, where historical prices for the same period should be a better estimate of the future spot price. I have used data from Nord Pool’s term market to study the development of the forward curve for the last two years. I have looked at futures prices for contracts with 5 different times to maturity (1 week, 5 weeks, 17 weeks, 1 year and 2 years). The figures and tables on the next pages show the main results.

Figure 5.6 shows the development of futures contract prices with different time to maturity (or delivery) compared to the spot price. I have used futures contract closing prices for the first trading day of each week. On the first day of trading participants in the market know the average system price for the last week, and can use this as a forecast for the next week (they do not necessarily do this). Therefore I have compared the futures prices to the average spot price of the previous week. The figure shows that the futures price for the next week (Fut.p.1 w.) matches the spot price for the previous week good. Actually, the correlation coefficients between the two curves is as high as 0,965 (Table 5.2). Also for the futures contracts with 5 weeks and 17 weeks to delivery the fit to the spot price is pretty good, with correlation coefficients of 0,902 and 0,814 respectively (Table 5.2). The curves for the futures prices one year and two years ahead (only the one year curve is presented in Figure 5.6) are rather similar and do not have the same wide fluctuations as the curves for the shorter contracts. For the

1 year curve it is possible to see the seasonal trend, and the changes between the three different season contracts represent naturally the largest weekly changes in the futures prices. Still, the prices tend to move in the same direction as the spot price, and the correlations to previous week's spot price are as high as 0,799 for the 1 year contract and 0,511 for the 2 years contract (Table 5.2). Apparently, the one year contract price is more sensitive to spot price movements than the two years contract price. A reason for this might be less liquidity for contracts with two years to delivery in Eltermin.

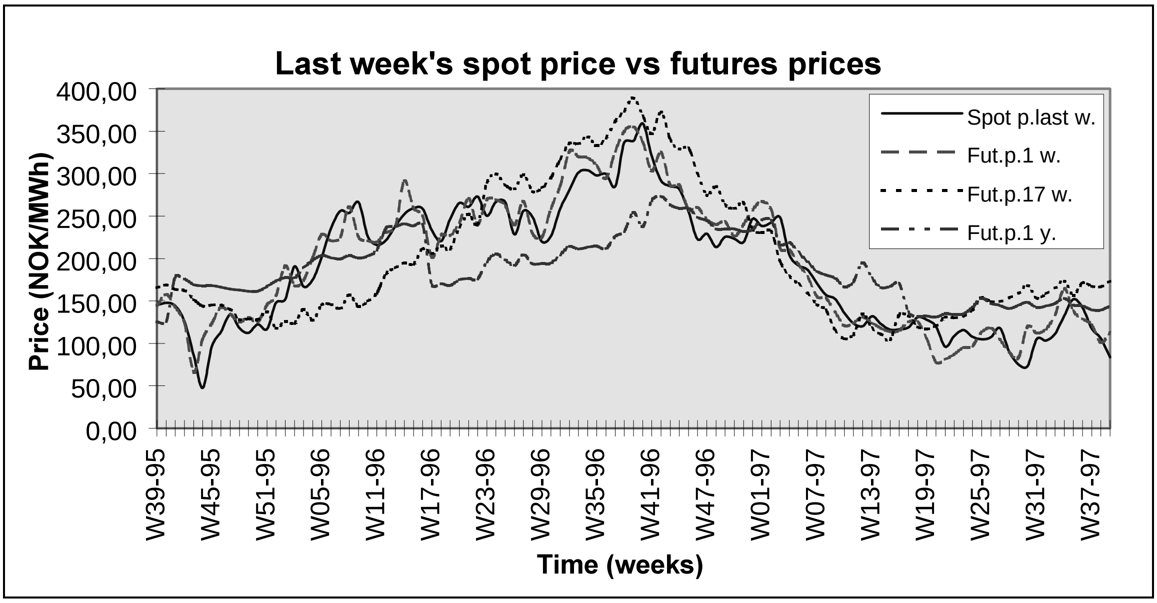


Figure 5.6 The development of futures prices for contracts with 1 week, 17 weeks and 1 year to delivery compared to the average system price in the spot market the previous week. Contracts with 5 weeks and 2 years to delivery are omitted to avoid confusion.

Autocorr.	Spot price	1 week	5 weeks	17 weeks	1 year	2 years
Spot price	1,000	0,965	0,902	0,814	0,799	0,511
1 week		1,000	0,956	0,859	0,836	0,547
5 weeks			1,000	0,929	0,836	0,568
17 weeks				1,000	0,693	0,368
1 year					1,000	0,883
2 years						1,000

Table 5.2 Autocorrelation matrix for spot prices (previous week) and futures contract prices with different times to delivery.

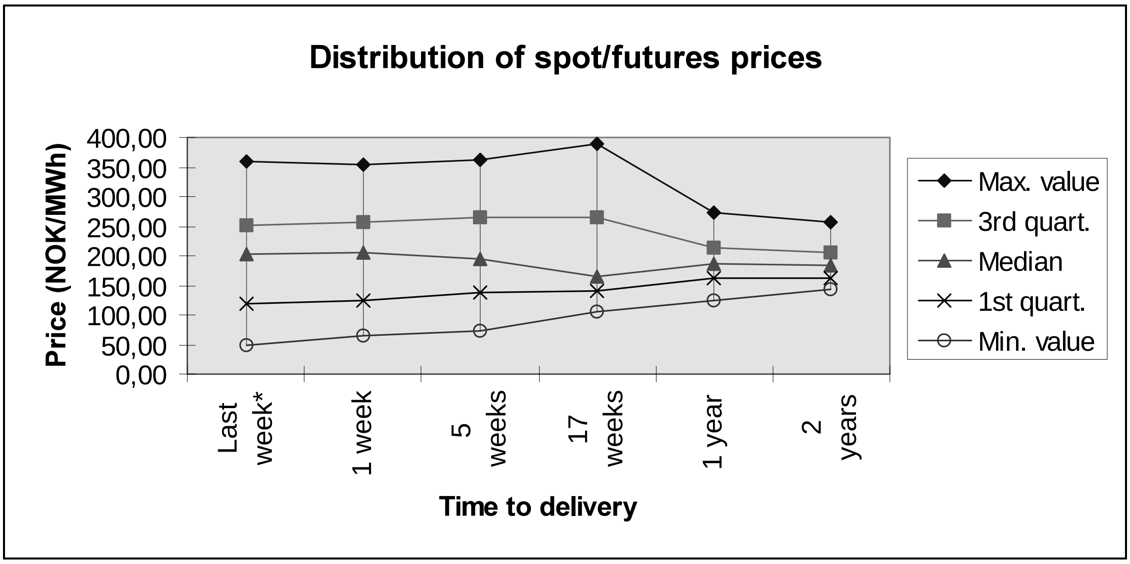


*Figure 5.7 Max., min., median, 1. and 3. quartile for the spot price and futures contracts with 1 week, 5 weeks, 17 weeks, 1 year and 2 years to delivery. Note that the spread between max. and min. value for the last two years are much less than for the other futures contracts and the spot price. *Last week means the average spot price of the previous trading week.*

Figure 5.7 confirms the indications from Figure 5.6, namely that the variability of the prices of contracts with short time to delivery (1, 5 and 17 weeks) is larger than for contracts with longer time to delivery (1 and 2 years). The prices for contracts with 1 and 2 years to delivery fluctuate in a shorter price interval. Calculation of standard deviations for prices show that the volatility is at the same level for the spot price and the three shortest futures contracts, while it is much smaller for the contracts with 1 and 2 years to delivery (Table 5.3). The special situation in the spot market, due to the "power crisis", explains the relatively high volatility that the futures prices exhibit over the two years period. When looking at the weekly changes the standard deviation is slightly higher for the 1 week futures contract than for the spot price, while the 5 and 17 weeks contracts show a lower deviation. Also note that the volatility of the weekly change in the 1 year contract is about twice the size of what occurs for the 2 years contract (Table 5.3).

Std. Dev.	Spot price	1 week	5 weeks	17 weeks	1 year	2 years
Prices	73,80	75,79	77,17	79,58	38,26	32,38
Δ Prices	19,72	21,27	15,77	14,49	9,43	4,70

Table 5.3 Standard deviations for prices and weekly changes in prices (Δ Prices) for the spot price and futures prices with different time to delivery. The spot price is the average system price for the last week. For the 1 year and 2 years contracts I have removed the data for changes between different season contracts.

To study the relative movement in the electricity forward curve for different maturities I have calculated an autocorrelation matrix for weekly changes in futures prices over the whole two-years period. The result is shown in Table 5.4. All the correlations are positive with a significant margin. The trend is that the degree of correlation is decreasing with increasing length between the maturities. The exception is the 2 years contract, which is more correlated to the shorter contracts than is the 1 year contract. I can not find any plausible explanation to this, and it is surprising since the 1 year contract is considerably more correlated to the spot price than the 2 years contract (Table 5.2). Anyway, the correlation coefficient between the two contracts with the longest time horizons shows the highest value (0,811). This is natural because the 1 and 2 years contracts relate to the same period of the year for two following years. There should as far as I can see not be any big difference between the expected future spot price one and two years into the future, under the conditions that have been prevailing in the Norwegian/Swedish power market the last two years.

Autocorrel.	1 week	5 weeks	17 weeks	1 year	2 years
1 week	1,000	0,756	0,540	0,425	0,621
5 weeks		1,000	0,688	0,502	0,607
17 weeks			1,000	0,579	0,623
1 year				1,000	0,811
2 years					1,000

Table 5.4 Autocorrelation matrix for weekly changes in futures contract prices with different time to delivery. For the 1 year and 2 years contracts I have removed the data for changes between different season contracts.

The results presented above and a further study of the electricity forward curve over the two years period indicate that the prices of the futures contracts are closely connected to the spot price, especially for the contracts with short time to delivery. The prices of contracts with different maturities tend to move in the same direction, but the shifts are in general not parallel. Shifts, twist and rotations have frequently occurred for the electricity forward curve over the period. The prices of contracts with short time to delivery have been much more volatile than the prices for contracts with longer maturities.

Now I turn to briefly looking at what consequences the behaviour of the electricity forward curve result in for the risk management in the electricity sector. By comparing the electricity forward curve to the term structure of interest rates I will try to find out if some of the concepts from the management of interest rate risk can be utilised in the electricity sector.

5.2.2 A comparison of the electricity forward curve and the yield curve

The management of electricity risks has a great deal in common with the management of interest rate risk. In both cases the problem is that prices at different future dates have both an element of functional relationship to each other and also a great deal of flexibility (Johansson (1997)).

5.2.2.1 The term structure of interest rates and the electricity forward curve

To be able to manage risk connected to interest rates or the futures prices of electricity, it is important to have models that capture the respective moves in the yield curve and the forward electricity curve. When developing models for the term structure of interest rates a common approach is to use a generalised Wiener process, also called an Ito process, to describe the movements in the short term risk free interest rate, r, over small periods of time. When looking at infinitesimal short periods an Ito process is expressed as (*Hull (1997)*):

$$dr = a(r,t)dt + b(r,t)dz \tag{5.14}$$

where *dz* represents a simple Wiener process, i.e.

$$dz = \varepsilon\sqrt{dt}\,, \quad \varepsilon \text{ is } N(0,1) \tag{5.15}$$

a(r,t) is the expected drift rate and *b(r,t)* is the variance rate, both of which are in general liable to change over time. After having chosen a and b in the interest rate dynamics model it is possible to obtain the term structure of interest rates at any given time in the future from the value of *r* at that time. When the possible outcomes of the shape of the yield curve is found you can explore what the process implies for bond prices and option prices. As an example, *Cox, Ingersoll and Ross (1978)* look at anticipations, risk aversion, investment alternatives and preferences about the timing of consumption to determine the term structure. By deriving an equilibrium model with all these factors they find the interest rate dynamics to be:

$$dr = \kappa(\theta - r)dt + \sigma\sqrt{r}\,dz \tag{5.16}$$

where κ; θ and σ are constants. Notice that the process is mean reverting at a rate κ.

A similar approach can also be applied for the electricity forward curve. If a correct price dynamics is found, this could be used to calculate forward and futures prices. A mean-reverting model is also required for the electricity prices, because of the behaviour of the electricity price which tends to return to its mean over a period of time. Due to the seasonal structure of the prices, the mean value function has to be dependent on time. *Johansson (1997)* suggests the following price dynamics for the electricity spot price, S:

$$dS = \left[\frac{d\mu_S(t)}{dt} + \kappa(\mu_S(t) - S)\right]dt + \sigma dz \tag{5.17}$$

where $\mu_s(t)$ is the seasonal mean value function and κ and σ are constants. The process is clearly mean reverting and the term $d\mu_s(t)/dt$ introduces a seasonal trend. Johansson also derives an expression for futures prices based on the price dynamics. He uses the following mean value function in Eq. (5.17) to calculate futures prices:

$$\mu_S(t) = \overline{\mu} + \alpha\sin\left[2\pi t + \phi\right] \tag{5.18}$$

By comparing results from the model to Nord Pool’s market prices he finds that the model is not very good at capturing the market prices at the very short end of the curve. With a longer horizon the fit becomes better. Taking into account that the model is only a pure fledgling, I find the results encouraging. When more work is done to fit the model to reality it can be of good use for participants in the electricity market. There is for example room for improvement in the mean value function, because I do not think a simple sine wave is a sufficiently good estimate of the mean value over the year. Estimates for κ and σ will probably also become better when more effort is put into the problem and more data is available. One possibility is to let σ depend on time. There is also a vast number of other models which can be applied for the price dynamics. Both one-factor and several factor models must be considered in the search for the optimal solution. In this search results from similar work with interest rates can be of good help. One difference from the term structure of interest rates is that while as much as 85-90 % of the shifts in the yield curve are explained by parallel movements (*Meade (1997)*), the results above indicate that this number is probably much lower for the electricity forward curve. Developing models which also capture twists and rotations in a sufficient way will therefore be a challenge for the electricity market. It is, however, beyond the scope of this thesis to take a further look at these problems.

5.2.2.2 Mark-to-market and mark-to-cost models

Pilipovic (1997) calls the family of models presented above for mark-to-market models. Mark-to-market techniques attempt to capture supply and demand as they converge in actual market prices. There is another family of forward price models called mark-to-cost models. These models attempt to understand electricity prices as a direct function of cost. This is the traditional way of forecasting the forward curve (before deregulation of the market), and in a hydropower system this is a complex task involving the calculation of water values (see section 4.2.1). The only relationship between the two families is that the mark-to-cost models may give a lower boundary for the price ranges of the mark-to-market models. Pilipovic further claims that mark-to-cost models are primarily relevant only to participants with price arbitrage strategies, i.e. mainly energy producers. The arbitrage lies in the spread between the internal cost forecast (the mark-to-cost curve) and the external mark-to-market forward price curve. Other participants in the market, like speculators, market makers and hedgers must base their strategies on the expected future spot price, which is best modelled by mark-to-market models. This underlines the importance of developing and improving price dynamics models like the one presented above.

5.2.2.3 Applications of a good model

There is a multiple of applications for a good mark-to-market model. *Johansson (1997)* suggests some of them. With a model in which you have confidence you can try to find relative pricing errors for futures prices. For instance if a futures contract for a particular month seems cheap relative to the adjoining months you could buy that month and sell the adjoining. This is known as a barbell trade in bond markets. Another obvious application is to use the model to price non-standard contracts, e.g. for a period that is not traded in the standardised market (Nord Pool). The sensitivity of the model prices to changes in the parameters of the model can be used to compute hedge ratios. If futures contracts are bought and sold according to the hedge ratios, and of course if the model is a good approximation to reality, you can immunise your portfolio from the change. A good model can also be applied for option pricing and developing hedging strategies involving options. A good model of the electricity forward curve would play a fundamental role in the overall risk management strategy for participants in the electricity market.

5.2.2.4 Duration

Duration is a very much used measure in the management of interest rate risk. The concept of duration was introduced by Frederick Macaulay (1938) and it is a measure of the effective maturity of a bond, defined as the weighted average of the times until each payment, with weights proportional to the present value of the payment (*Meade (1997)*). Duration shows the proportionate change in the value of a bond for a small change in the yield to maturity. If the average duration of a company's portfolio of assets is equal to the average duration of its portfolio of liabilities then its present value is immune to small, parallel shifts in the yield curve. Matching interest rate sensitivity of assets and liabilities is known as duration matching or portfolio immunisation.

Keeping in mind the similarities between the yield curve and the electricity forward curve, it is tempting to try to derive some sort of duration measure for the electricity market. This is however not a straight forward task, because interest rates and futures prices are two completely different quantities. Changes in interest rates do directly affect the present value of the future cash flow of a company, because the compounding factor is altered. The consequence of a change in the futures price of electricity is a corresponding change in the margin account for the participants holding the contract. The aggregate cash flow connected to the futures contract is still not changed if the participant keeps the contract to expiry and trades the volume of the contract in the spot market. The value of the contract for a company that consequently uses the term market for price fixing is therefore not altered by a change in the futures price. For speculators with no corresponding transactions in the spot market the situation is different. They realise profits or losses because of the changes in the prices of their futures contract portfolio. To derive a general measure for the proportionate change in the value of a futures portfolio for a small change in the futures prices is therefore not possible. It would depend on the situation for the specific participant (speculator, hedger or something in between). Duration matching would be of limited use in the electricity market even if an expression for the duration was derived, because this strategy only immunises against parallel and small shifts in the forward curve. As shown above the shifts in the electricity forward curve tend to be neither small nor parallel.

5.2.2.5 Cash flow matching

Another common strategy for hedging interest rate exposure is to divide the yield curve into segments and ensuring that you are hedged against a movement in each segment. The hedger can examine the effect of a small increase in the yield curve for each time segment, holding the rest of the yield curve constant. If the exposure is unacceptable, further trades would be undertaken from the range of possible instruments to reduce the exposure. The extreme case is complete cash flow matching. This means that the company invests in bonds that provide total cash flows in each period that exactly matches its payment obligations. Once the cash flows are matched the interest rate risk is eliminated, once and for all. Exact cash flow matching is, of course, difficult to achieve in practice, because of a limited selection of feasible bonds and uncertainty connected to future payment obligations.

The method of dividing the forward curve into different time segments should also be tractable in the electricity market. If an electricity company knows whether it is net long or net short within each time segment it can calculate the degree of risk exposure. The risk can be calculated as the financial loss when each time segment is subject to a shock in the wrong direction (*Johansson (1997)*). These shocks can be modelled by shifts or twistings in the forward curve for the specific period. Another approach is to represent the shocks by significant changes in the parameters of the chosen forward curve model. The probabilities for the shocks to appear in reality are also important to take in to account when assessing the risk exposure for each time segment. If the risk manager in the electricity company finds that the exposure in any of the time segments exceeds the limits chosen by the company, he has to change the company's portfolio of contracts for that period. This can be done by selling or buying futures and/or options, or eventually by changing the physical delivery obligations for the period. When trying to immunise the time segments as described above a dynamic risk management strategy is required to obtain the best possible result. New conditions emerging in the market have to be taken into account. The result is that calculations of the degree of risk exposure in each time segment and re-balancing of the contract portfolio has to be carried out continuously.

5.2.2.6 Volume risk and options

The problem for most suppliers and distributors of power is the substantial uncertainty connected to the quantity (or volume) of the future delivery obligations. Due to the volume risk it is impossible to obtain a complete immunisation to changes in the forward curve, as opposed to asset and liability management where exact cash flow matching in theory removes all interest rate risk. Futures contracts do in general not diminish volume risk, even if a dynamic re-balancing strategy can help to diminish the problem. Options are, in contrast, derivatives which lowers the volume risk. Options can be considered as an insurance for the electricity companies, because when holding an option you have the possibility, but not the obligation, to buy or sell electricity for a specific price. For this insurance the company pays a limited premium, the option price. Since electricity options are not extensively traded today, and the price material therefore is very limited, I have chosen not to take a closer look at electricity options in this thesis.

5.3 Summary

In this chapter I first presented the concept of basis risk. In the electricity futures market the problem of basis risk is diminished by the price securing settlement. This settlement procedure removes the risk concerned with the price for the contractual volume, except for the eventual capacity fee element. The volume risk is, however, not removed by the price securing settlement. By comparing average spot prices in the delivery week and futures prices on last day of trading, I found that the absolute value of the closing basis in the electricity term market on average was more than 8 % of the closing futures price over the last two years. The large size of the closing basis shows that there is a need for a price securing settlement to reduce the risk exposure for hedgers in the electricity futures market. It is also possible to speculate in the price securing settlement, since no physical delivery is involved by letting the futures contracts go to delivery.

I further looked at hedge ratios when hedging in futures contracts. I show that for a fixed quantity of electricity the optimal hedge ratio becomes one, as long as the purchased futures contracts go to delivery and a corresponding quantity is traded in the spot market. This is because of the price securing settlement. If volume risk is taken into account, or if contracts are closed out before delivery, the optimal hedge ratio will probably be different.

The historical weekly movements of the electricity forward curve over the last two years were studied. The analysis show that the prices of futures contracts are closely connected to the spot price, especially for contracts with short time to expiry. The prices of different contracts tend to move in the same direction, but the shifts are seldom parallel. The futures prices are much more volatile for the end of the curve that is close in time compared to the far end. The electricity forward curve has much in common with the term structure of interest rates, even if the movements in the yield curve tend to be more regular. Factor models similar to the ones used for describing the instantaneous changes in the short-term interest rate can also be applied for the electricity spot price dynamics. More work has to be put into this subject to obtain satisfactory models. A good model would have many applications for the different participants in electricity market, both for hedging, speculating and production planning. Finally, I argue that the very much used strategy of duration based hedging from the management of interest rate risk, can not be transformed and utilised to hedge against movements in the electricity forward curve. The concept of dividing the yield curve, or the electricity forward curve, into time segments and considering the risk exposure in each segment, should on the other hand be tractable also for participants in the electricity market.

Appendix 1 Returns on Futures Contracts and Stock Indices

In studies of rates of return on common shares or bonds, the continuously compounded rate of return is normally calculated as:

$$R_t = \ln\left(\frac{P_{t+1} + D_t}{P_t}\right) \qquad \text{(A1.1)}$$

where P_t and P_{t+1} are the starting and ending market prices of the security and D_t is the cash dividend to the investor during the period. For stock market indices the dividend payment is usually calculated into the index, so that the natural way of calculating continuous compounded returns on the index is therefore:

$$R_i = \ln\left(\frac{I_{t+1}}{I_t}\right) \qquad \text{(A1.2)}$$

where I_{t+1} and I_t is the value of the index at the start and end of the period. Here it is assumed that the investor holds a portfolio equal to the index during the period. R_t and R_i equal the return to a hypothetical investor who purchased the security or portfolio with his own funds.

Commodity futures contracts present the investor with a somewhat different situation. When an investor takes a long position in a futures contract, he promises to pay the current futures price at the end of the investment period. No payment is done at the time the contract is agreed except for the margin requirement (between 3% and 10 % for the contracts in Eltermin). Knowing that none of the contracts in Eltermin involves physical delivery of electricity, one possibility is to use the amount paid into the margin account during the holding period as the initial investment when calculating the rate of return. The balance on the margin account changes daily according to the price movements for the futures contract, and this approach would lead to very high absolute values of returns. This is because the margin requirement is only a small part of the futures price. If the margin requirement is 10%, a 10% increase in the futures price would lead to a 100% rate of return on the margin account for a long position. This way of calculating rates of return will apply for a pure speculator in the market as long as he never buys or sells corresponding power in the spot market. The number of pure speculators in the electricity futures market is, however, very low and most participants do also regularly trade in the spot market.

Participants who use the term market as a price securing instrument must be able to pay the price for power in the spot market at delivery. This means that they must have an amount equal to the futures price deposited in some way. If not they will run into liquidity problems. When calculating rates of return on futures contracts (or portfolios of futures contracts), R_C, I have used the following formula:

$$R_C = \ln\left(\frac{P_{t+1}}{P_t}\right) \qquad \text{(A.1.3)}$$

where P_t and P_{t+1} is the futures price (or value of the futures portfolio) at time t and $t+1$. In this equation I assume that the investor or hedger posits a 100% margin and earns no interest on it. A rational investor would, however, invest the margin at the risk free rate of return. *Bodie and Rosansky (1980)* shows that an approximation to the rate of return on a futures contract, R_{C2}, when depositing the 100% margin at the risk free rate, R_f, is:

$$R_{C2} \approx R_C + R_f \qquad \text{(A.1.4)}$$

The returns on futures contracts that I present in this thesis, R_c, is therefore approximately equal to the rate of return in excess of the risk free rate. When doing comparisons with the stock market indices I have therefore calculated the excess return on the indices, R_i' (in the calculations I have assumed that the risk-free rate with continuous compounding is 4% p.a.):

$$R_i' = \ln\left(\frac{I_{t+1}}{I_t}\right) - R_f \qquad \text{(A.1.5)}$$

I could of course also have compared the rate of return of futures contracts including the risk free rate (Eq. A.1.4) with the rate of return on the stock indices as conventionally measured (Eq. A.1.2). This would lead to the same conclusions. *Bodie and Rosansky (1980)* use both approaches in their analysis of commodity futures returns. I find it sufficient to use only one of the methods.

Appendix 2 Attached Data Files

The attached floppy disk contains Excel data-files with the spreadsheets for the main calculations in this thesis. The table below lists the files in the floppy disk and which part of the thesis they correspond to.

Filename	**Contents**	**Chapter**
Chapter42.xls	Prices, returns and calculations with single futures contracts, portfolios of futures contracts and Stock Exchange indices.	4.2 Pricing theories and the electricity futures market
Table412.xls	Correlation between electricity spot price and TOTX	4.2.3.1 Interpretation of historical data
Figure52.xls	Development of electricity futures price for week 40-97 vs electricity spot price	5.1.1 Basis risk
Chapter512.xls	Calculations concerning closing basis	5.1.2 Basis risk and electricity futures
Chapter521.xls	Calculations of movements in the electricity forward curve	5.2.1 The structure of the electricity forward curve

References

Aasgaard, Ketil Reed: “Elkraftmarkedet 1996” (“The electricity market 1996”), *Coopers & Lybrand and Fondspartner*, 1996.

Alexander, Gordon J. and Sharpe William F.: “Fundamentals of investments”, *Prentice-Hall International*, 1989.

Amundsen, Eirik S. and Singh, Balbir: “Developing Markets for Electricity in Europe”, *The Energy Journal*, Vol. 13, No. 3, p. 95-112, 1992.

Bodie Zvi and Rosansky, Victor I..: “Risk and Return in Commodity Futures”, *Financial Analysts Journal*, p. 27-39, May-June 1980.

Chang, E.: “Returns to Speculators and the Theory of Normal Backwardation”, *Journal of Finance*, p. 193-208, 1985.

Copeland, Thomas E. and Weston, Fred J.: “Financial Theory and Corporate Policy”, 3rd ed., *Addison-Wesley Publishing Company*, 1992.

Cox, J.C., Ingersoll, J.E., Ross, S.A.: “A theory of the term structure of interest rates”, *Econometrica* (53), p. 385-407, 1985.

Djuskås, Ole Tom: “Kraftmarkedsundersøkelse pr 1.2.1996” (“Survey of the power market at 1.2.1996”), Publication nr. 10/1996, *Norges Vassdrags og Energiverk (NVE)*, 1996.

Dougherty, Edward R.: “Probability and Statistics for the engineering, computing, and physical sciences”, *Prentice-Hall*, 1990.

Elting Treat, John: “Energy Futures”, *Pennywell Publishing Company*, Tulsa, Oklahoma, 1990.

Faanes, Hans H.: “Optimalisering av Energisystemer - Driftsplanlegging” (“Optimisation of power systems - production planning”), Lecture Notes, Course 41261 Energiøkonomi (Energy Economics), *Norwegian University of Science and Technology*, Trondheim, 1996.

Fama, E. and French, K.: “Commodity Futures Prices: Some Evidence on the Forecast Power, Premiums, and the Theory of Storage”, *Journal of Business*, p. 55-73, 1987.

Fleten, Stein-Erik: “Portfolio Management in the Electricity Industry”, Thesis, *The Norwegian Institute of Technology*, Trondheim, 1995.

Godager, Grønli, Holtan, Heggheim, Landaas, Mo, Ottesen: “Risikohåndtering i kraftmarkedet - erfaringer fra andre markeder” (“Risk management in the power market - experiences from other markets”), Technical Report TR A4370, *Norwegian Electric Power Research Institute (EFI)*, 1996.

Hansen, M. I., Johansen, T.A., Oftedal, J.Q.: “Det norske kraftmarkedet til år 2020” (“The Norwegian power market to year 2020”), Report 96/16, *Statistisk Sentralbyrå (Stastistics Norway)*, 1996.

Holtan, Jon Anders and Mo, Birger.: “Risikohåndtering i kraftmarkedet” (“Risk management in the power market”), Technical Report TR A4311, *Norwegian Electric Power Research Institute (EFI)*, 1995.

Hull, John C.: “Options, Futures and other Derivatives”, 3rd ed., *Prentice Hall International*, 1997.

Johansen, Tor Arnt and Larsen, Bodil M.: "Kraftmarkedsmodell med energi- og effektdimensjon", ("A model of the power market with energy and power dimension") Report 95/33, *Statistisk Sentralbyrå (Stastistics Norway)*, 1995.

Johansson, Svante: "Pricing Electricity Derivatives", Lecture Notes, *D.Carnegie AB*, 1997-07-30.

Knivsflå, Kjell H. and Rud, Linda: "Markets for electricity: Structure, pricing and performance", Publication no.: 71-1995, *The Norwegian electricity Federation ENFO*, 1995.

Lunde, Rolf. J. and Rogde, Arild: "Bruk av derivater i kraftmarkedet" ("The use of derivatives in the power market"), Thesis, *Norges Handelshøyskole (The Norwegian School of Economics and Business Administation)* Bergen, 1996.

Mageli, Bård and Undebakke, Arvid: "Kraftbørsen og kratmarkedets oppbygning" ("The Power Exchange and the construction of the power market"), Thesis, *Norges Handelshøyskole Bergen (The Norwegian School of Economics and Business Administation)*, 1997.

Meade, Nigel: "Asset and Liability Management", Lecture notes, *Imperial College of Science and Technology*, London, 1996.

Moore, David S.: "The basic practices of Statistics", *W.H. Freeman and Company*, 1994.

Nord Pool: "Elspot", "Eltermin", "Annual Report 1996" and other information material, including internet-homepage: http://www.nordpool.no.

Norsk Kraftmegling: "Annual Report 1996".

Norwegian Electric Power Research Institute (EFI): "Programpakken Vansimtap" ("The program Vansimtap") and "Vannverdier" ("Water values"), instruction papers.

Pilipovic, Dragana: "Electricity forward curves - Mark to reality", *Energy & Power Risk Management*, p. 14-15, Vol.2, 6. October 1997.

Rønningsbakk, Kjell: "Meglerne klatrer forbi Nord Pool" ("The brokers overtake Nord Pool"), Article in *Energi 5/97*, p. 4-5, 1997.

Shamansky, A., Solvang, E., Sæther, K.: "Opsjoner i kraftmarkedet" ("Options in the power market"), Thesis, *Bodø Graduate School of Business*, 1997.

Short, Mike J.: "Modern Power Systems", Lecture Notes, *Imperial College of Science and Technology*, London, 1996.