Forecasting Weekly Electricity Prices at Nord Pool

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Summary

This paper analyses the forecasting power of weekly futures prices at Nord Pool. The forecasting power of futures prices is compared to an ARIMAX model of the spot price. The time series model contains lagged external variables such as: temperature, precipitation, reservoir levels and the basis (futures price less the spot price); and generally reflects the typical seasonal patterns in weekly spot prices. Results show that the time series model forecasts significantly beat futures prices when using the Diebold and Mariano (1995) test. Furthermore, the average forecasting error of futures prices reveals that they are significantly above the settlement spot price at the 'delivery week' and their size increases as the time to maturity increases. Those agents taking positions in weekly futures contracts at Nord Pool might find the estimated ARIMAX model useful for improving their expectation formation process for the underlying spot price.

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1. Introduction

Forecasting electricity prices is very useful for a number of market participants in the spot and derivative markets in order to optimize their trading strategies. Several studies have developed time series models that try to cope with the most prominent statistical features of spot electricity price behaviour (see for example Koopman et al., 2007). Time-series models typically use some external variables related with power demand and supply to improve the explicative power of spot prices. Nevertheless, no study has introduced external variables obtained from a closed related derivative market.

In fact, one of the most emphasized properties of futures prices is its leading function in incorporating any information on expected spot prices. Thus, it seems worthwhile exploring the introduction of lagged futures prices, or another related variable, in a time series model. Furthermore, if futures prices are considered as a market based prediction of futures spot prices, it will also be interesting to analyse its forecast power. In particular, in a non-storable commodity[1], such electricity, futures prices are not directly constrained by marginal net storage costs. Nevertheless, equilibrium considerations such as production plans and the price expectations of agents will play a central role in explaining price behaviour in electricity markets (Avsar and Goss, 2001, p. 482). Under this view, electricity futures prices can play an important informational leading role[2].

One way to obtain some insight about the forecasting accuracy of futures prices is to compare their forecasting performance with other predictors. This work presents a time series model with external variables (ARIMAX model, henceforth) which are demand and supply related and contains lagged information from the futures market. As far as I know, this is the first study comparing electricity futures prices forecasting accuracy with alternative forecasting methods. Hedgers and speculators in weekly futures contracts at Nord Pool might find the estimated ARIMAX model useful for improving their expectations formation process on the underlying spot price.

[1] Futures on non-storable commodities are studied in Fama and French (1987) and Yang *et al.* (2001). Fama and French (1987) point out that some animal futures contracts are just those with the stronger forecast power. Yang et al. (2001) found that "futures prices are more likely to be an unbiased estimate of cash prices in the long run for most storable commodities than for most non-storable commodities". Furthermore, Yang et al. (2001) found that futures prices lead cash prices in the long run on non-storable commodities, although not so well as they do on storable commodities.

[2] Electricity spot-futures price dynamics is studied in Shawky et al. (2003). They show that shocks in spot returns are the main source of information in the spot-futures price system.

Electricity markets deregulation started in the early nineties in the US and some European countries. One of the most important electricity markets leading the way in liberalisation is the Nord Pool (Sweden, Norway, Finland and Demark). Liberalisation of electricity markets in Nordic countries started in Norway in 1991 and progressively expanded to Sweden, Finland and Denmark. The Nordic Power Exchange or Nord Pool organizes the physical day-ahead market in these Nordic countries (physical market) and a developed derivatives market on electricity (financial market). Nord Pool was established in January 1993 in Norway, and became a common Norwegian-Swedish market in January 1996, Finland entered in June 15, 1998, western Denmark joined Nord Pool in July 1, 1999, and eastern Denmark in October 1, 2000.

In the Nord Pool electricity market, about 47% of power production is generated from hydropower reservoirs. Although electricity is a non-storable commodity, water is storable. The influence of reservoir[3] levels in electricity futures prices at Nord Pool has been studied by Gjolberg and Johnsen (2001), Botterud et al. (2002), Forsund an Hoel (2004) and von der Fehr et al. (2005). From this bibliography it can be said that hydropower reservoir levels are an important variable explaining futures and spot prices. Reservoir level seasonality is an especially important influence on electricity spot and futures prices. Under the theory of storage, inventory seasonals generate seasonals in the marginal convenience yield – and in the basis (see Fama and French, 1987, p. 56). If reservoir levels are taken as inventories of electricity, the effect of demand and supply shocks on spot and futures electricity prices will depend on reservoir levels and how they are managed. In this way, any demand or supply shock is easily offset when reservoirs are high. But when reservoirs are low, a demand or supply shock is more difficult to balance and will be somewhat persistent, allowing spot and futures prices to increase. To better understand the influence of reservoir levels on electricity prices, two extreme situations can be examined in a hydro dominated power generation market: very high reservoir levels and very low reservoir levels. When reservoirs are nearly full, water may overflow and this will reduce the potential gains of producers. In this

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[3] Gjolberg and Johnsen (2001) found a significant influence of monthly Norwegian reservoir level dynamics in weekly futures prices with 4 to 12 weeks to delivery. Botterud et al. (2002) suggest with a graphical analysis that reservoir level can explain risk premium one year ahead, but in their opinion, for 1 to 4 weeks ahead the change in reservoir levels is very limited and cannot contribute to futures pricing. Forsund and Hoel (2004) present a theoretical model relating electricity prices, reservoir levels, electricity demand and import/exports of electricity than match very well with electricity markets dominated by hydroelectric generation such as Norway or New Zealand. Finally, von der Fehr et al. (2005) deeply analyse the supply shock that hit the Nordic electricity market in 2002-2003.

situation, it is said that producers have a negative convenience yield, that is, they will prefer to sell power at a lower price instead of allowing overflows. As the main focus in hydropower management is to distribute the water in the periods (within the day, week or year), when reservoirs are nearly full, spot prices will be lower than usual and futures prices will be above spot prices. Conversely, when reservoirs are very low, the above-mentioned convenience yield will be positive and might include large values. In this situation, spot prices will be above short-term futures prices. If reservoir levels are not enough to satisfy power demand, electricity prices will probably increase together with power imports. Additionally, precipitation can play an important role in order to obtain an estimation of the water inflow to hydroelectric reservoirs and the expectation of a dry or rainy period (month, season or year) will be clearly affected by its values.

The behaviour of weather variables can also produce some predictable seasonal pattern in futures prices. The relationship between weather variables and electricity load and price has been studied in the literature by many authors. Weather variables considered in these studies are temperature, wind speed, humidity and precipitation. Li and Sailor (1995), and Sailor and Muñoz (1998), find in a sample of US states that temperature is the most significant weather factor explaining electricity and gas demand. The influence of air temperature in electricity demand and price has been considered by other authors, who obtained a significant explicative power in their modelling; see, for example, Peirson and Henley (1994), Henley and Peirson (1998), Engle et al. (1992), and Pardo et al. (2002).

Finally, electricity futures markets can be another important source of information about electricity prices. In futures markets, the basis is the difference between futures price and the underlying spot price. Academics and professionals frequently use the basis in analysing futures prices. Fama and French (1987) showed that the basis contains significant information about expected spot price changes and risk premiums in futures prices.

The objective of this paper is to obtain some insight regarding futures price forecasting capability. To do this, forecasts of a time series model with external variables will be compared with futures prices. External variables like temperature, precipitation, reservoir levels, power load and basis (futures price less the spot price) are introduced in a time series model. Results show that the ARIMAX forecasts significantly beats futures prices forecasts in *ex post* analysis, that is with the external variables taking the real observed values. Then

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again, when an *ex ante* approach is taken, that is when the model is estimated each time a new observation is added and electricity prices and external variables are then jointly forecasted, ARIMAX forecasts significantly beats futures forecasts in most cases. The lack of a significant forecast power of futures prices may be caused by the existence of risk premiums (constant or time-varying), or because of errors in the agent's expectation model in forecasting spot prices due to new information release, or both reasons. The question of whether futures forecasting errors are caused by the existence of risk premiums or not, is left for further research.

This paper is divided in six sections. Section 2 describes the data and its preliminary analysis. The ARIMAX model is presented in section 3. The forecast power of futures prices and ARIMAX forecasts is compared in section 4. Sections 5 and 6 contain the conclusions and references, respectively.

2. Data and preliminary analysis

This section describes data sources and the transformations carried out with the original data to obtain data series with economic content. In addition, a tentative analysis of those variables that may explain electricity price behaviour is also made. Plots and descriptive statistics are used here as the analytic tools.

Data used in this paper has several sources. Electricity futures prices and spot prices in the Nordic Power Exchange area are directly obtained from Nord Pool's FTP server files. In the spot market, hourly power contracts are traded daily for physical delivery in the next 24-hour period. This price is known as the system price and it is computed and published at midday the day before delivery. The system price is the spot reference for derivative contracts traded both at the Nord Pool market and OTC. There exists a wide range of electricity derivative contracts (forward, futures and options) traded at the Nord Pool exchange. At the moment, the most important are: daily and weekly futures, monthly, quarterly and yearly forwards, and European type options on the quarter and year forwards.

To select which futures/forward contracts can be included in this study two important considerations are necessary: (i) first, a large number of observations are required to obtain insightful results, (ii) second, non-overlapping futures contracts are preferable to avoid

artificially introducing autocorrelation in the data series. Therefore, it is necessary to balance the data frequency and delivery period length of the contracts to avoid introducing autocorrelation in the data series. For example, if yearly forwards are selected, you cannot introduce more than one price per year; otherwise, expectations on the underlying commodity cannot be completely renewed. As a result, well designed data series of yearly forward prices contain very few observations and no significant study can be carried out. Similar reasons can be argued for quarterly and monthly forward contracts. Therefore, the present study focuses on weekly futures, taking one price per week, with closing price each Friday, or the day before if non-tradable.

Futures prices in the Nord Pool database started to be collected at the end of 1995. In 1996 and 1997 important changes in the contractual conditions and trading system were introduced. Electronic trading was initiated at the end of 1996 and contracts with delivery periods longer than a week were changed from futures to forwards by the end of 1997. These changes are important enough to preclude the present study from using these years, taking them instead as a learning period. As a result, the data period analysed goes from January 1, 1998 until September 30, 2007. This period contains 509 weekly prices. During the sample period, 8 weekly futures contracts could be traded daily, but only the four contracts nearest to the delivery period are free from non-trading problems. With the four nearest to delivery weekly futures contracts, four data series of futures prices are built by maintaining the time to delivery constant. The following notation will help understand futures prices time series: $F(t,T_i)$ represent the futures price on week t to deliver in week T_i with $T_i = t+i$ and $i = 1, 2, 3$ and 4 weeks ahead.

In Nord Pool, settlement of futures contracts involves both daily mark-to-market settlement and a final cash settlement for those positions remaining open at maturity. Final settlement covers the difference between the last closing price of the futures contract and the system price in the 'delivery period'. The system price is the hourly spot reference of the physical market. Consequently, in weekly futures contracts the clearing spot reference is the average of the 168 system prices (24 hours × 7 days) of the week[4], Monday to Sunday of the 'delivering' week. This is the spot reference used in this paper. Figure 1 exhibits this time series jointly with each of the above presented futures price time series.

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[4] Each year, there is a week in spring with 167 hours and a week in autumn with 169 hours because of the daylight saving time.

[Insert Figure 1 about here]

Futures prices are taken on Fridays because the objective of this paper is to measure and compare the forecasting accuracy of futures prices with several spot price based forecasting alternatives. As futures closing prices are computed at 15:30 and only one price is taken each week, the fairest comparison with spot price based forecasting alternatives is to take the closing price of the last trading day of the week. For example, the Myopic forecasting method, appearing in section 4, takes the present weekly spot price (known at the Saturday midday[5]) as a forecasted price for the settlement price of the futures contracts; the price that is being forecasted. If another futures price is taken, for example, the Wednesday closing price, the relative forecast power of futures prices would be unfairly compared.

Hydropower reservoir levels (R_t henceforth) are compiled from the second week in 1990 to the end of the sample period. Reservoirs are expressed as a percentage of the total hydropower capacity available in the Nord Pool area (see Figure 2). The reservoir levels and capacity data are from Norwegian Water Resources and Energy Directorate (NVE), Svensk Energi (Swedenergy AB), and the Finnish Environment Institute (SYKE). Reservoirs from Sweden and Finland are considered just after their integration in the Nord Pool market. Denmark is not included because its power production resources does not include any hydropower reservoir plant.

Weather variables have an important influence in electricity prices, production and consumption. The weather variables used are the Nordic Temperature and Precipitation Indices (NTI and NPI henceforth). These indices take information from the two most important countries in the Nord Pool area: Norway and Sweden. These indices are computed by Merrill Lynch Global Commodities with the Swedish Meteorological and Hydrological Institute (SMHI) and Svensk Kraftmäkling AB (SKM). These indices were designed in cooperation with major Nordic energy companies and represent the average temperatures in the major population centres of Norway and Sweden, and average precipitations in the major hydro-electricity producing areas of Norway and Sweden[6]. The data series for the Nordic Temperature Index (degrees Celsius) and the Nordic Precipitation Index (mm of rainfall and

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[5] More specifically, Monday to Saturday system prices of each week will be already known at midday Friday . Nevertheless, to compute the weekly spot price, the Sunday system prices remain, but these prices will not be published until Saturday midday.
[6] For more technical details visit the web site <www.smhi.se/foretag/fm/smhi_index.htm>.

melted snow) available in this study goes from January 1, 1970, until September 30, 2007 in a daily frequency. The precipitation index NPI has been transformed to weekly frequency by accumulating each week (*t*) the daily precipitation from Monday to Sunday (*i*) (see Figure 3),

$$P_t = \sum_{i=1}^{7} NPI_{t,i} \, .$$

Temperature is very related to electricity demand, low temperatures increase electricity demand for heating and high temperatures raise electricity demand for cooling. The relationship between temperature and electricity prices is not so obvious. When there is a hot or cold wave, a limited power production capacity might cause an electricity price increase. In the Nord Pool area, this situation may appear only in low temperatures. Consequently, using the temperature index NTI, the Heating Degrees of each Week (HDW hereafter) is defined as

$HDW_t = \sum_{i=1}^{7} \left(18 - NTI_{t,i}\right)^{+}$. That is, HDW_t accumulates, for each week, the difference (if positive) between the comfort temperature of 18 Celsius degrees and the NTI of each day from Monday to Sunday (see Figure 4).

The following variable to be included in the analysis is the basis, namely futures price minus the spot price. Following Fama and French (1987), the basis reflects the expected change in the spot price until the delivery day plus the realised risk premium. Consequently, basis can have an important role in how expectations on future spot prices and risk premiums are formed. There are four basis series available in the database, one for each futures time series $B(t, T_i) = F(t, T_i) - S(t); \quad i = 1, 2, 3 \text{ and } 4$; where $F(t, T_i)$ is the futures price of the contract remaining *i* weeks to "delivery" and $B(t, T_i)$ is its basis. In the times series model of spot electricity prices only a basis series will be used to avoid multicolineality problems as all of them present a similar behaviour[7]. Specifically, in the times series model of spot electricity prices the first to "delivery" futures contract basis is chosen, but similar results are obtained with the other basis. Figure 5 exhibits this basis time series and reveals that the basis sign changes frequently over time. This variable is important when forecasting electricity prices as it can be considered an estimation of electricity price variation one week ahead obtained from the futures market if rational and risk neutrality hypotheses are assumed.

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[7] Correlation coeficients among them take values between 0.68 and 0.97.

[Insert Figure 2 about here]

[Insert Figure 3 about here]

[Insert Figure 4 about here]

[Insert Figure 5 about here]

Preliminary analysis is now undertaken. Table 1 displays the basic statistics of spot and futures prices. Panel (B) shows the unit root tests of these series where $S(t)$ represents the weekly Nord Pool System Price and $F(t,T_i)$ with $T_i = t+i$ and $i = 1, 2, 3$ and 4; represents the weekly futures prices traded at Nord Pool remaining 'i' weeks to 'delivery' and $F(t+1,T_1) = S(t+1)$. It can be seen that the null hypothesis of the existence of a unit root in the data series could not be rejected at 1 per cent of significance level, in any case, but it would be rejected at 10 per cent of significance level in the five series. The existing literature[8] shows that the time series of daily electricity prices in Nord Pool have low mean reversion with long memory and a unit root hypothesis is quite acceptable. This result is completely different to other spot price time series around the world – where mean reversion is stronger[9]. In a hydro-dominated power generation market an electricity price time series typically has lower mean reversion as hydropower reservoirs allow inter-temporal substitution between inputs. As Escribano et al. (2002) says, for "… modelling purposes like forecasting, cointegration, etc., the mistake one can make by imposing that there is a unit root in the Nord Pool when in fact it is slowly mean reverting should not be important and it could even be of some help, …".

[Insert Table 1 about here]

Looking at the medians and means of the differenced series in the Panel (A) of the Table 1 some features are relevant. The mean of the differenced series is significantly different from zero at 5% of significance level in three cases: the first, second and third futures contract closest to 'delivery'. Furthermore, its value is negative. This behaviour shows that futures prices will decay as maturity date nears. This feature is especially important for those futures users taking market positions of one or more weeks. The Kruskal-Wallis test contrasts the null of median equality between spot and futures differentiated series. Results show that the null is more acceptable as the maturity date nears. At 5% of significance level, it will be acceptable

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[8] Nord Pool daily spot time series is studied by Escribano et al. (2002), Koopman et al. (2007) and Goto and Karolyi (2004). Escribano et al. (2002) and Koopman et al. (2007) analyse the daily system price in the period 1993-1999. Goto and Karolyi (2004) investigate statistical properties of electricity prices in nine different trading areas of the Nord Pool in the period 1993-2003..

[9] Evidence for daily electricity prices from Argentina, Australia, France, Germany, Netherlands, Spain and United States can be found in Goto and Karolyi (2004), Escribano et al. (2002) and Koopman et al. (2007).

for the three futures contracts closest to maturity – and it will be rejected for the fourth futures contract closest to maturity.

Table 1 displays the standard deviation of the analysed series. The standard deviation values are very high compared to mean values. This is partially due to the presence of some extreme values in the autumn and winter between years 2002 and 2003, as will be discussed later. The Levene test contrasts the null of variance equality between spot and futures differenced series. Results show that the null is rejected in the first and fourth contracts nearest to maturity, and it cannot be rejected in the other two cases at any significance level. It is also interesting to see that the nearest to 'delivery' futures price has the lowest volatility value.[10]

The five series analysed in Table 1 have significant skewness and excess kurtosis. The skewness is negative in the spot and first to 'delivery' futures contract price changes, but positive in the remaining futures contracts. Maximum and minimum values of the five series help to explain the above results, especially the skewness sign and the high kurtosis. Finally, the Ljung-Box test with twenty lags detects significant autocorrelation in the differentiated and its squared data series.

An initial conclusion comes from the descriptive analysis carried out in Tables I. The first to 'delivery' futures contract price difference has very similar properties to the spot price difference, but the same cannot be said for the remaining futures contracts[11]. Furthermore, futures prices significantly decrease as maturity approaches. Obviously, these results are important for electricity price risk management, as it points out that only those futures contract positions held until maturity will ensure a good risk reduction to hedgers. If futures positions are cancelled before, the statistical differences between spot and futures prices will probably cause a bad performance. Moreover, those agents maintaining long (short) futures

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[10] The 'Samuelson Effect' in futures markets refers to the fact that futures price volatility increases as the delivery date approaches. This effect fits the idea that spot price has an important mean reverting component as no arbitrage exists. A first test of this hypothesis for the Palo Verde and California-Oregon Border electricity futures was carried out by Walls (1999). After controlling the volume of trade, Walls(1999) obtained preliminary evidence for this hypothesis on the contracts traded in 1996. Hong (2000) proposes an equilibrium model with informed and uninformed investors. It is shown that, in the absence of information asymmetry, the Samuelson effect holds. Furthermore, in this case the open interest tends to decrease as the delivery date approaches. When information asymmetry is allowed, market equilibrium is compatible with the inverse Samuelson effect and an increasing open interest pattern as the delivery day approaches. The standard deviation values reported in Table 1 do not show any conclusive pattern relative to the Samuelson effect.

[11] It must be remarked that the first to "delivery" futures contract difference is computed as the clearing price of the contract minus the closing price of the futures contract in the last trading week ($\Delta F(t,T_1) = S(t+1) - F(t,T_1)$ with $T_1 = t+1$). Note that the clearing price is just the spot price average of the "delivery" week.

positions during several weeks and cancelling their positions close to maturity, will, probably, have negative (positive) returns. Further research is needed on this point to be more precise.

The objective of this section was to collect variables related with electricity spot prices.[12] In the next section, an ARIMAX model on weekly spot electricity prices with the above 'external' variables, is proposed and estimated.

3. The forecasting model

The first step in building a forecasting model for electricity prices with simultaneous external variables is to estimate a model for each external variable. As can be seen in figures 2 to 4, reservoir levels (R_t), heating degrees weeks (HDW_t) and precipitation (P_t) have a clear sinusoidal trend. Following Campbell and Diebold (2005), the following general model is proposed for each of these variables,

$$X_t = \alpha + \beta t + \sum_{i=1}^{p} \left(\gamma_i \sin \frac{2\pi}{52} it + \delta_i \cos \frac{2\pi}{52} it \right) + \sum_{j=1}^{k} \theta_j X_{t-j} + u_{tt} \tag{1}$$

Where t represents the time measured in weeks and X_t will represent P_t, R_t or HDW_t. The optimal number of terms in the sinusoidal trend and the number of lags in the autoregressive term is chose by minimizing the Akaike information criteria. These equations were estimated by least squares and no autocorrelation remained in the residuals. For the reservoir levels variable (R_t) the lineal trend was ruled out, $p = k = 3$ and the adjusted regression determination coefficient value was 99.73%. For the precipitation variable (P_t) the lineal trend was ruled out, $p = 1$, $k = 3$ and the adjusted regression determination coefficient value was 22.82%. Finally, for the heating degrees week variable (HDW_t) the model was determined by $p = 2$, $k = 3$ and the adjusted regression determination coefficient value was 91.15%.

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[12] In a preliminary version of this paper, electricity consumption was considered as a further external variable. Nevertheless, electricity consumption can introduce multicollineality in a regression model as correlation coefficient between this variable and HDW_t is very high (51%). As a result, it is almost impossible to find in a regression model explaining electricity prices HDW_t and electricity consumption. As electricity consumption coefficient was not significant, it was excluded from the paper.

For the basis, a somewhat different model was proposed. Specifically, the following four equation model is estimated,

$$B(t,T_i) = \alpha + \sum_{i=1}^{p}\left(\gamma_i\,sin\frac{2\pi}{52}it + \delta_i\,cos\frac{2\pi}{52}it\right) + \sum_{j=1}^{k}\sum_{i=1}^{4}\theta_{ij}B(t-j,T_i) + u_t;\quad i=1,2,3,4 \quad (2)$$

The selected model was determined by $p = 5$ and $k = 8$ for $i=2$, 3 and 4; and $p = 0$ and $k = 1$ for $i=1$. Adjusted determination coefficients of 24.98% for $i = 1$, 49.09% for $i = 2$, 61.18% for $i = 3$ and 62.15% for $i = 4$ were obtained. Results are not showed to avoid space but are available upon request.

The existence of a unit root in the Nord Pool system price time series is a quite acceptable hypothesis and it was discussed in the above section; consequently, electricity spot price will be differentiated when introduced into the model. From the preliminary analysis carried out in the previous section, the proposed model follows:

$$(1-L)S(t) = c + \alpha_1\,sin(2\pi t/52) + \alpha_2\,cos(2\pi t/52) + \beta R_t + \gamma P_t + \delta HDW_t + \phi B(t-1,T_1) + \mu_t$$

$$(3)$$

$$\mu_t = \psi_1\mu_{t-1} + \psi_2\mu_{t-2} + \psi_3\mu_{t-3} + \psi_4\mu_{t-4} + \varepsilon_t$$

where L is the lag operator, μ_t the residual, autoregressive lagged errors were added to eliminate autocorrelation and the residual ε_t is a white noise $\left(N\!\left(0,\sigma^2\right)\right)$. In the following section, the forecasting experiment will be carried out by splitting the sample period in two sub-periods: *ex post* sub-period and the *ex ante* sub-period. The estimation results reported in Table 2 correspond to the *ex post* analysis. The adjusted determination coefficient (58.75%) seems quite high and indicates that an important part of electricity price movement can be anticipated. [13]

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[13] Other simpler specifications where considered as for example the same model but without external variables. In this case, the model will be quite similar to the proposed by Koopman et al. (2007) for daily prices, but adapted to weekly prices. This pure time series model obtained an adjusted determination coefficient of 13.23% and was the worst performing forecasting method (even worse than the 'myopic' forecasting method that will be presented in the following section). Finally, when only the basis is excluded in the model, an adjusted determination coefficient of 32.16% is obtained and the forecasting ability significantly improves (better results than the 'myopic' forecasting method but worse than futures forecasting method are obtained). Results of these models are not reported but are available upon request.

Looking at the above result, it can be said that bases dynamics contains important information on the expected change in the spot price – and consequently futures prices include relevant information involving the expected spot changes. To further analyse this issue, the following section compares futures price predictions of the spot price with ARIMAX model forecasts.

[Insert Table 2 about here]

4. Forecasting electricity prices

There are several ways of studying forecasting efficiency in futures markets (see Goss 1992, pp. 4-7). This paper examines whether futures prices reflect public information by comparing futures prices to the forecasts obtained from a time series model of the spot price with external variables. This approach implicitly assumes the rationality and risk neutrality of agents in the futures markets. If futures prices forecast power is lower than an the alternative prediction model, the forecasting efficiency of futures prices is rejected. Rejection of futures prices forecasting efficiency can be caused because: the rational expectation hypothesis fails; large expectation errors are made; or/and because of the existence of risk premiums.

To compare the forecasting accuracy of the ARIMAX model, two alternative forecasting methods are considered. Firstly, the Myopic method that takes the present spot price as a forecasted settlement price at 'delivery' week of each futures contract. The Myopic method can be considered as the minimum accuracy required from any forecasting method. And secondly, the Futures method that takes the present futures prices as a forecasted settlement price in the corresponding forecasting horizon.

In the forecasting analysis, the whole period has been split in two sub-periods. The *ex post* sub-period beginning the 1st week in 1998 and finishing the 39th week in 2003 with 300 observations, and the *ex ante* sub-period from 40th week in 2003 until the 39th in 2007, containing 209 observations. In the *ex ante* sub-period, the model in the equations (1) to (3) is re-estimated each time a new observation is considered, and then weekly electricity prices one, two, three and four weeks ahead are forecasted.[14] The low reservoir level and the lack of precipitations at the beginning of the winter between the years 2002 and 2003 set electricity

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[14] The program RATS 7.0 was used to write the code in the forecasting analysis.

prices in turmoil[15] – and this episode is included in the *ex post* period because of its exceptionality. The influence of this unstable phase on Nord Pool electricity prices can be better understood with Lucia and Torro (2008). These authors show that spot prices have noticeably increased after the turbulent period, and also that the seasonal patterns seem to have faded away. These facts are consistent with tighter conditions in the Nordic electricity area.

The forecasting exactness of three methods are compared by using the Mean Square Error[16] criteria (MSE from now on). Results are shown in Table 3. To obtain greater insight regarding the significance of MSE differences, the Diebold and Mariano[17] (1995) statistic, S_1, is displayed in Table 4. Panels (A) and (B) of both tables display the *ex post* and *ex ante* results, respectively. The most accurate forecasting method is the ARIMAX method in all cases – with one exception. In the one week horizon case in the *ex ante* sub-period, the Futures method has the significantly lowest MSE. In all the remaining cases, the MSE of the ARIMAX predictions is significantly lower than the MSE of futures and myopic predictions, at the 10% of significance level. The Futures method offers the second lowest MSE in five cases, and the Myopic method in two cases. But Futures forecasts significantly beats Myopic forecasts in two cases at the 5% of significance level. Consequently, Futures forecasting accuracy is slightly better than Myopic.

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[15] The analysis carried out in von der Fehr et al. (2005) shed some light on the causes of 2002-2003 price turmoil at Nord Pool. The autumn of 2002 was a dry season that pushed the hydro reservoirs into a sharp reduction (54% of average inflow for the preceding 20 years). In the late autumn and winter of the period 2002-2003 the spot prices registered a very high level (twice to three times the normal level, with 850NOK/MWh in January 2003). Because of the severe drought suffered, other factors could be important for such a price behaviour, see von der Fehr et al. (2005), for more details.

[16] The MSE is computed as follows:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2$$

where y_i and $\hat{y}_i$ denote the actual and its forecasted value.

[17] The Diebold and Mariano (1995) test compares the statistical significance of MSE differences of two competing forecasting methods. The Diebold-Mariano statistic is simply the *t* statistic of the square error difference mean of two competing forecasting alternatives whose covariance matrix is estimated consistently by accounting for the autocorrelation introduced in multi-step forecasts. The Diebold and Mariano (1995) statistic, S_1, formula is

$$S_1 = \frac{1}{T}\sum_{t=1}^{T}\left[(e_{it})^2 - (e_{jt})^2\right] \bigg/ \sqrt{\frac{2\pi\, f(0)}{T}}$$

where $e_i = y_i\text{-}\hat{y}_i$ and $e_j = y_j\text{-}\hat{y}_j$ are the forecast errors for observation *t* in two alternative models *i* and *j*, *T* is the sample size and *f*(0) is the spectral density of the difference of the square prediction errors at frequency zero. The software used for this test is available in the program RATS 7.0.

To obtain some insight about possible causes of the low forecast power of futures prices, average values of the forecasting errors are studied. Table 5 shows forecasting error average values and the standard deviation of each method. In all cases, the average bias of Futures forecasts is significantly different from zero and negative at the 5% significance level using the *t*-statistic. That is, Futures prices are significantly above the settlement spot price at 'delivery'. Furthermore, biases and their standard errors increase as the time to maturity increases, both *in the sample* and in the *out of the sample* sub-periods (see Panels (A) and (B) in Table 5).

The forecasting error of futures prices displayed in Table 5 can be understood as an ex post or realized risk premium (also known as a *forward bias* or *forward premium*) if rational expectations are assumed. In equilibrium models, risk premiums are linked to risk factors affecting futures participants. In the classical view of hedging pressure[18] as a determinant of futures premiums, when the forward bias is positive (futures prices below expected spot prices), the futures market is said to be in *normal backwardation* (short hedging pressure). On the other hand, if the *forward bias* is negative (futures prices above expected spot prices), the futures market is said to be in *contango* (long hedging pressure)[19]. Nevertheless, it is possible that stationary time-varying risk premiums exist and it might be very difficult to split the futures price into expected spot price and risk premiums. In this last case, indirect evidence relating risk premiums with some risk measure is usually enough[20]. Whether the forecasting errors of futures prices are risk premiums, or not, is left for further research.

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[18] Bessembinder (1992) find a strong relationship between futures returns and hedging pressure, or a return to speculation in agricultural contracts. These results support the classical view of hedging pressure as a determinant of futures premiums. Moulton (2005) shows that NYMEX electricity futures contracts on the Palo Verde and California-Oregon Border transmission hubs could have failed because of the lack of incentive to speculators to be counterparts to the long-short hedging disequilibrium. An alternative source of risk premium can be the existence of price manipulations or collusion in the spot and forward markets. In this sense, Robinson and Baniak (2002) suggest that generators (monopoly on the supply side in the spot and derivative market) in the English and Welsh electricity pool created volatility in the spot market in order to benefit from risk premia in the derivative market. Specifically, the authors found significant evidence of volatility increase after the coal contract in force from 1990 to 1993 and during the price cap existing in the 1994-1996 period. The increased volatility increased the risk premium (suppliers supposed to be more risk averse than generators), so generators had greater incomes after the coal contract and during the price cap. Furthermore, it was not evident that generators were manipulating contract prices as they achieved this by increasing volatility and indirectly increasing prices with larger risk premium. Moulton (2005) says that for a futures market succeed it is necessary to remunerate speculators for taking risky positions so that differences in the timing of long and short hedging are acted on by speculators. These results go against the theoretical findings of forward equilibrium model of Bessembinder and Lemon (2002) where expected volatility is inversely related to risk premiums, but obviously, prices in the referred market were not obtained in equilibrium.

[19] See Duffie (1989, chapter 4) and Hull(2006, p. 121) for more details about these concepts.

[20] In Shawky et al. (2003), it is found that price volatility is a very important variable in pricing futures on electricity at the California-Oregon Border traded at NYMEX. Shawky et al. (2003) measured (*ex post*) risk

[Insert Table 3 about here]

[Insert Table 4 about here]

[Insert Table 5 about here]

5. Conclusions

This paper has analysed the forecasting ability of short-term futures prices traded at Nord Pool. In testing the forecast power of weekly futures contracts at Nord Pool, predictions of spot electricity prices obtained from futures are compared to those obtained from an ARIMAX model. The ARIMAX model introduces as external variables: weather variables (temperature and precipitation), reservoir levels and basis (futures minus spot price); which generally reflect seasonal patterns in the weekly spot price. Results show that the most accurate forecasting method is the ARIMAX method in all cases but with one exception. In the case of the one week horizon in the *ex ante* sub-period, the Futures method has the lowest MSE. At the 10% significance level, the MSE of the ARIMAX predictions is significantly lower than the MSE of futures predictions in seven cases. Furthermore, the forecasting error average of futures prices is significantly different from zero – showing that futures prices are significantly above the settlement spot price at 'delivery'. Moreover, biases and their standard errors increase as the time to maturity increases.

Significant forecasting errors average can be interpreted as risk premiums but further analysis is necessary linking these forecasting errors with risk factors. Anyway, the results obtained are consistent with a wholesaler dominated power market where futures prices will probably be above the expected spot price. If this is the case, agents with long positions in futures markets will pay a risk premium to their counterparts. Whether the forecasting errors of futures prices are risk premiums, or not, is left for further research.

6. References

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premium of the California-Oregon-Border futures contract in NYMEX. They obtained a significant average value of 0.1328% per day (an equivalent monthly premium of 4%) in the period 1998-1999. Avsar and Goss (2001) reject the efficient market hypothesis for the California-Oregon-Border and Palo Verde electricity futures contract in the period 1996-1999. The predictive efficiency is rejected because of the presence of time-varying risk premium. The inverse relationship between traded volume and forecast errors for the California-Oregon-Border contract suggests that agents were still learning the true model driving this market.

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Table 1
Summary statistics of weekly spot and futures price differences and unit root tests

In this table $\Delta S(t) = S(t+1) - S(t)$; represents the weekly price variation in the Nord Pool System Price, where the weekly system price is computed as the average price from Monday to Sunday of the total weekly hours (24 hours per 7 days). $\Delta F(t,T_i) = F(t+1,T_i) - F(t,T_i)$ with $T_i = t+i$ and $i = 1, 2, 3,$ and 4; represents the weekly price variation in the weekly futures closing prices remaining 'i' weeks to 'delivery' traded at Nord Pool the last trading day of the week t and $F(t+1,T_1) = S(t+1)$. The *Kruskal-Wallis* statistic tests the median equality of $\Delta S(t)$ and $\Delta F(t,T_i)$. The *Levene* statistic tests the variances equality of $\Delta S(t)$ and $\Delta F(t,T_i)$. *Skewness* means the skewness coefficient and has the asymptotic distribution N(0,6/T) under normality, where T is the sample size. The null hypothesis tests whether the skewness coefficient is equal to zero. *Kurtosis* means the excess kurtosis coefficient and it has an asymptotic distribution of N(0,24/T) under normality. The hypothesis tests whether the kurtosis coefficient is equal to zero. $Q(20)$ and $Q^2(20)$ are Ljung Box tests for twentieth order serial correlation in the differentiated and its squared series, respectively. The *ADF* and *PP* refers to the Augmented Dickey and Fuller (1981) and Phillips and Perron (1988) unit root tests on the time series $S(t)$ and $F(t,T_i)$, $i = 1, 2, 3$ and 4. One-sided p-values computed following Mackinnon (1996) for the *ADF* and *PP* test are displayed as ⟨.⟩ (corresponding to the process with intercept – but without trend). The number of lags in the ADF test and the truncation lag in the PP test are obtained by information criteria (Schwarz and Newey and West, respectively). Marginal significance levels are displayed as [.] in the remaining tests.

Panel (A): Summary Statistics

	$\Delta S(t)$		$\Delta F(t,T_1)$		$\Delta F(t,T_2)$		$\Delta F(t,T_3)$		$\Delta F(t,T_4)$	
Mean	0.05	[0.96]	-3.86	[0.00]	-4.20	[0.00]	-2.63	[0.04]	-1.31	[0.27]
Median	-0.02		-2.54		-2.48		-2.00		-0.75	
Kruskal-Wallis			10.35	[0.00]	12.75	[0.00]	6.32	[0.01]	1.70	[0.19]
Standard Deviation	27.76		22.45		33.52		30.04		27.01	
Levene			10.98	[0.00]	0.00	[0.99]	0.38	[0.54]	2.93	[0.09]
Skewness	-1.57	[0.00]	-4.43	[0.00]	3.13	[0.00]	2.61	[0.00]	1.01	[0.00]
Kurtosis	35.47	[0.00]	45.20	[0.00]	70.57	[0.00]	56.56	[0.00]	46.74	[0.00]
Minimum	-293.07		-247.59		-277.13		-250.00		-255.00	
Maximum	189.98		105.01		436.06		363.50		290.50	
Q(20)	100.00	[0.00]	100.38	[0.00]	57.75	[0.00]	57.67	[0.00]	49.53	[0.00]
$Q^2(20)$	160.68	[0.00]	295.59	[0.00]	110.12	[0.00]	124.81	[0.00]	182.83	[0.00]

Panel (B): Unit root tests

	$S(t)$		$F(t,T_1)$		$F(t,T_2)$		$F(t,T_3)$		$F(t,T_4)$	
ADF	-2.88	⟨0.04⟩	-3.24	⟨0.01⟩	-3.37	⟨0.01⟩	-2.63	⟨0.08⟩	-2.66	⟨0.08⟩
PP	-3.04	⟨0.03⟩	-3.53	⟨0.01⟩	-3.17	⟨0.02⟩	-2.99	⟨0.03⟩	-2.98	⟨0.03⟩

Table 2
ARIMAX model for the Nord Pool spot price with external variables

This table reports the estimated coefficients and *t*-ratios of the following ARIMAX model

$$(1 - L)S(t) = c + \alpha_1 \sin(2\pi t / 52) + \alpha_2 \cos(2\pi t / 52) + \beta R_t + \gamma P_t + \delta HDW_t + \phi B(t - 1, T_1) + \mu_t$$

$$\mu_t = \psi_1 \mu_{t-1} + \psi_2 \mu_{t-2} + \psi_3 \mu_{t-3} + \psi_4 \mu_{t-4} + \varepsilon_t$$

The model is estimated using non-linear squares with the Gaus-Newton algorithm. $Q(p)$ is the Ljung-Box test for p order serial correlation. $Q(p)$ is distributed as a χ_p^2 and the 10% critical values are $\chi_{10}^2(0.1) = 15.99$ and $\chi_{20}^2(0.1) = 28.41$. In the last row, $\overline{R}^2$ refers to the adjusted regression determination coefficient.

In the sample sub-period
(December 29, 1997 to October 5, 2003 (300 weeks))

Coefficients	Estimates	*t*-ratios
c	-55.81	-4.25
α_1	-5.61	-1.13
α_2	-28.37	-4.84
β	0.41	2.55
γ	-0.24	-2.76
δ	0.45	5.23
ϕ	0.58	13.03
ψ_1	0.38	6.23
ψ_2	-0.37	-5.77
ψ_3	0.16	2.56
ψ_4	0.12	2.09
SE of Regression		20.21
Durbin-Watson		2.01
Log Likelihood		-1299.76
Q(10)		7.40
Q(20)		12.38
$\overline{R}^2$		58.75%

Table 3
Forecasting Performance Measures

This table exhibits the *Mean Square Error* when forecasting electricity spot prices. Three forecasting methods are compared: (i) the Myopic method that takes the present spot price as a forecasted value, (ii) the Futures method that takes the present futures price of the electricity to be delivered in the forecasting horizon, and (iii) the ARIMAX method that takes the forecasted electricity price to each horizon from the model appearing in section 3. Panel (B) displays *out of the sample* results where ARIMAX forecasts are obtained by re-estimating the models for electricity prices and the external variables each time a new observation is considered.

Panel (A). *In the sample* sub-period
(December 29, 1997 to October 5, 2003 (300 weeks))

	Forecasting Method		
horizons	Myopic	Futures	ARIMAX
1 week ahead	1001.57	714.95	408.72
2 weeks ahead	2202.84	2162.59	1157.80
3 weeks ahead	2596.00	2924.13	1669.35
4 weeks ahead	3139.85	3534.13	2134.99

Panel (B). *Out of the sample* sub-period
(October 6, 2003 to September 30, 2007 (209 weeks))

1 week ahead	476.09	266.05	306.07
2 weeks ahead	1079.18	987.69	847.25
3 weeks ahead	1713.24	1901.76	1369.86
4 weeks ahead	2364.17	2712.43	1919.75

Table 4
Test of equal accuracy of two competing forecasts

This table reports the Diebold and Mariano (1995) statistic S_1 comparing the forecasting ability of two competing methods. Diebold and Mariano show that S_1 is asymptotically distributed as a standardized normal, N(0,1). The null hypothesis of this test is that mean square errors of two competing forecasting methods are equal. Below S_1, in brackets, the p-value of the null is shown. If S_1 is positive (negative), the mean square error of the first (second) method is larger than that generated by the second (first) one. Those S_1 statistics with p-values lower than 0.1 are marked with one asterisk (*). If S_1 is positive (negative), the mean square error of the first (second) method is larger to the generated by the second (first) one.

Panel (A). *In the sample* sub-period
(December 29, 1997 to October 5, 2003 (300 weeks))

	1 week	2 weeks	3 weeks	4 weeks
Futures *vs* ARIMAX	1.8027*	1.3978*	1.3807*	1.5273*
	(0.03)	(0.08)	(0.08)	(0.06)
Myopic *vs* ARIMAX	2.4857*	2.3724*	3.2101*	1.5185*
	(0.00)	(0.00)	(0.00)	(0.06)
Myopic *vs* Futures	1.8865*	0.1537	-0.5811	-0.3967
	(0.03)	(0.44)	(0.28)	(0.34)

Panel (B). *Out of the sample* sub-period
(October 6, 2003 to September 30, 2007 (209 weeks))

	1 week	2 weeks	3 weeks	4 weeks
Futures *vs* ARIMAX	-1.5076*	1.3222*	1.5973*	1.3572*
	(0.06)	(0.09)	(0.05)	(0.08)
Myopic *vs* ARIMAX	2.6222*	2.1315*	1.9343*	1.5383*
	(0.00)	(0.01)	(0.02)	(0.06)
Myopic *vs* Futures	2.8263*	0.7517	-0.6392	-0.6750
	(0.00)	(0.22)	(0.26)	(0.24)

Table 5
Forecasting Errors: Average and Standard Deviation

This table reports the average value of the forecasting error of each forecasting method. Below each average value appears its standard deviation between brackets. Those average values significantly different and below zero at 5% significance level using the *t*-statistic are marked with one asterisk (*). Any other average value is significantly different, or superior to zero at 5% significance level.

Panel (A). *In the sample* sub-period
(December 29, 1997 to October 5, 2003 (300 weeks))

	1 week	2 weeks	3 weeks	4 weeks
Myopic	0.36	0.84	1.29	1.72
	(31.70)	(47.00)	(51.02)	(56.10)
Futures	-3.91*	-6.29*	-7.11*	-7.21*
	(26.11)	(45.59)	(53.09)	(58.57)
ARIMAX	-0.78	-1.74	-2.64	-3.54
	(20.23)	(34.04)	(40.84)	(46.15)

Panel (B). *Out of the sample* sub-period
(October 6, 2003 to September 30, 2007 (209 weeks))

	1 week	2 weeks	3 weeks	4 weeks
Myopic	-0.29	-0.56	-0.87	-1.24
	(21.87)	(32.92)	(41.48)	(48.72)
Futures	-3.89*	-10.54*	-15.56*	-18.42*
	(15.88)	(29.68)	(40.84)	(48.83)
ARIMAX	0.87	0.65	0.39	0.15
	(17.51)	(29.17)	(37.09)	(43.91)

Figure 1. System and weekly futures prices.
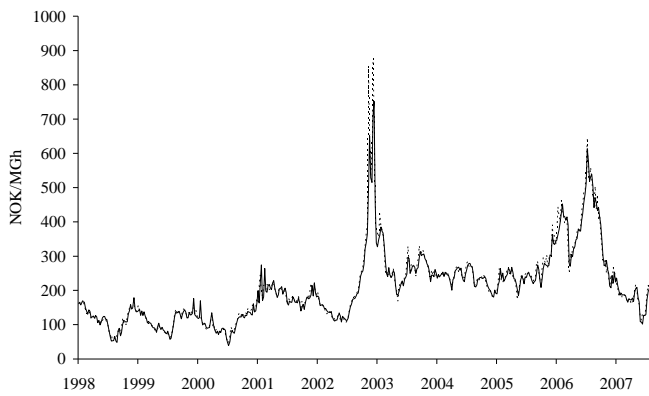
Figure 1(a). System price (——) and the first
to 'delivery' futures price (- - -)
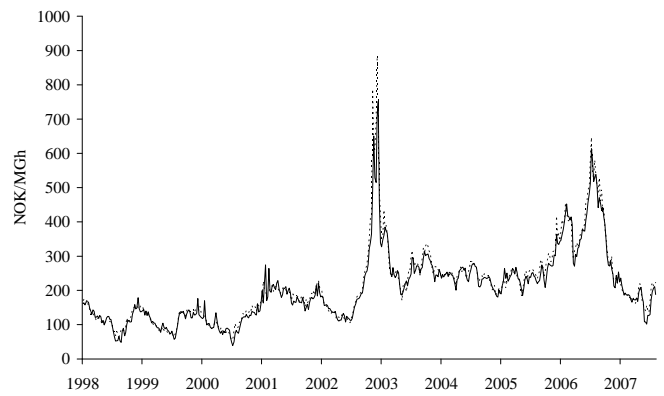
Figure 1(b). System price (——) and the
second to 'delivery' futures price (- - -)
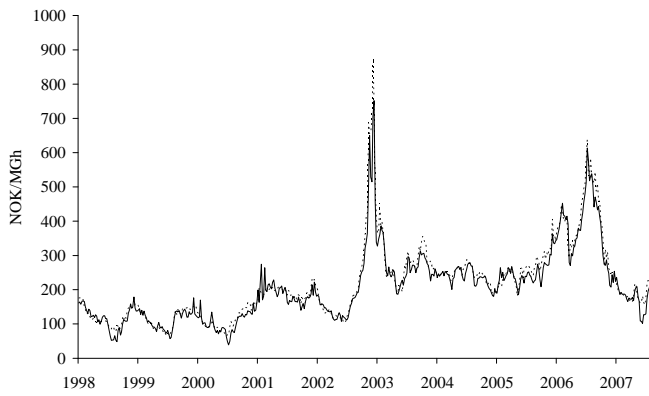
Figure 1(c). System price (——) and the third
to 'delivery' futures price (- - -)
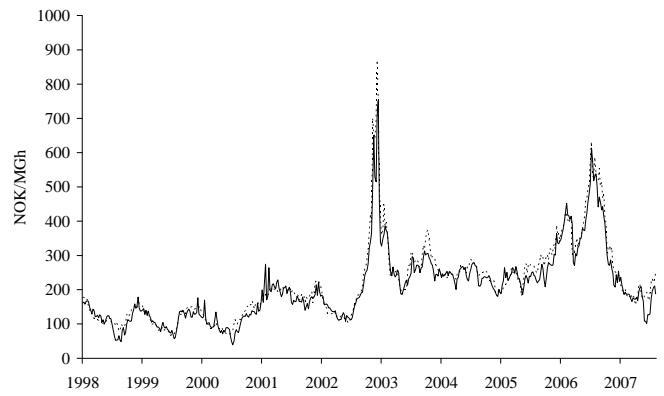
Figure 1(d). System price (——) and the
fourth to 'delivery' futures price (- - -)

Figure 2. Hydropower reservoir levels.
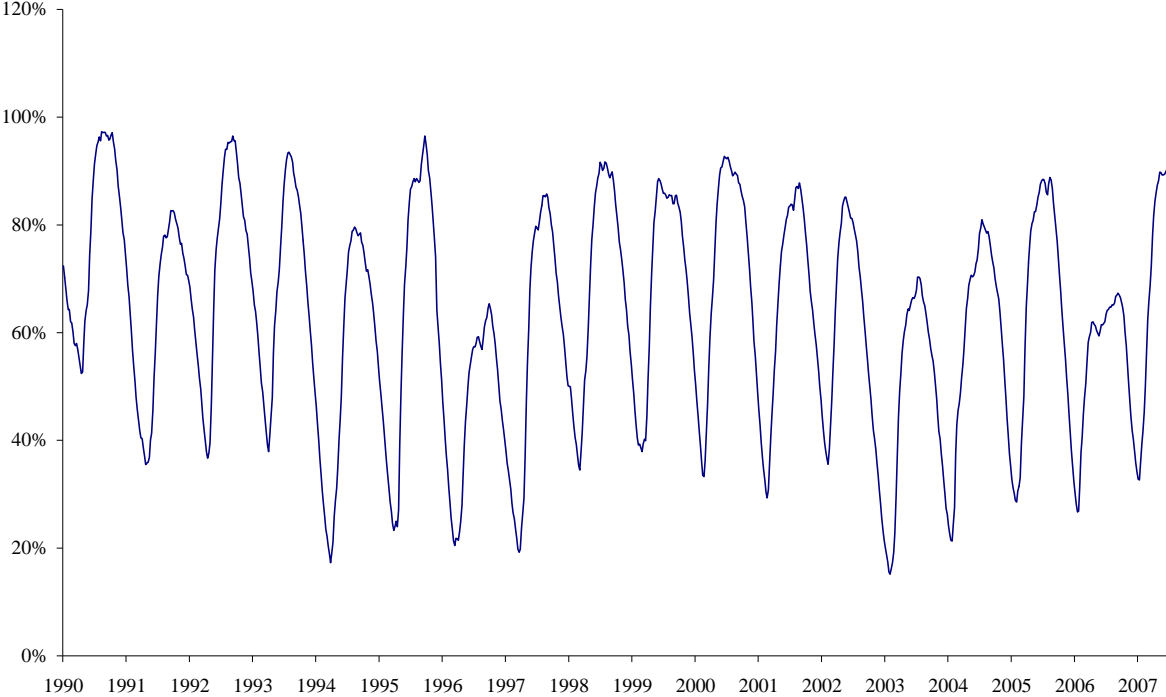
Figure 3. Weekly Nordic Precipitation Index.
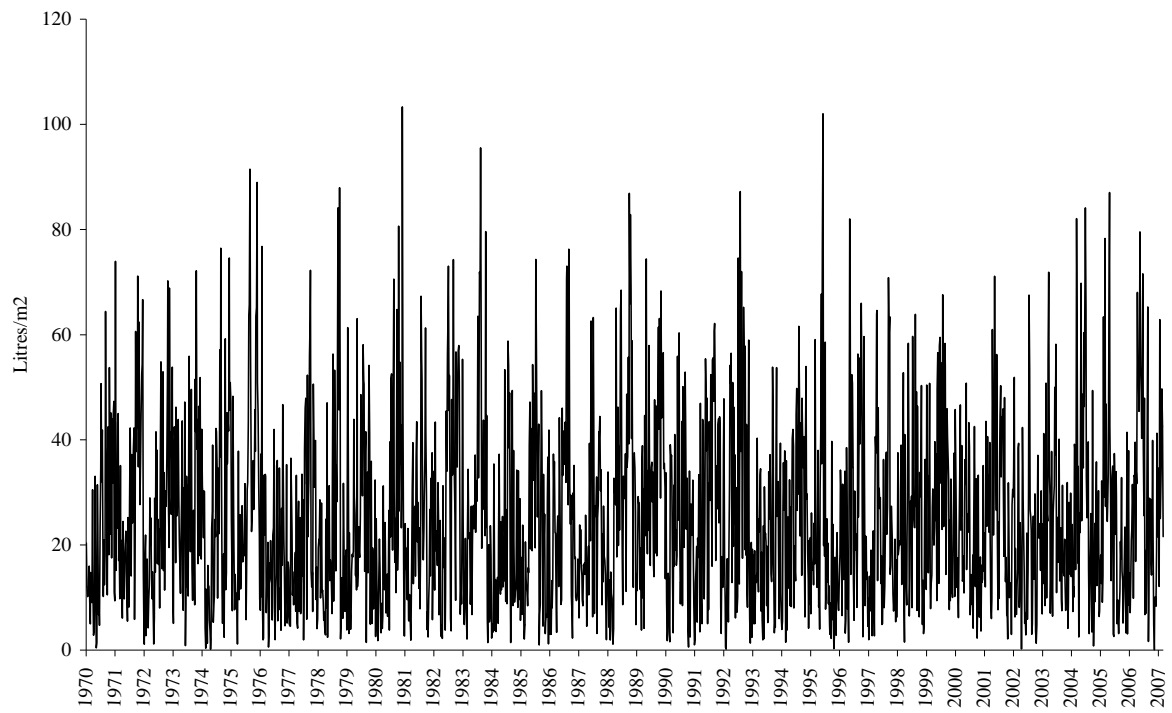
Figure 4. Heating degrees week.
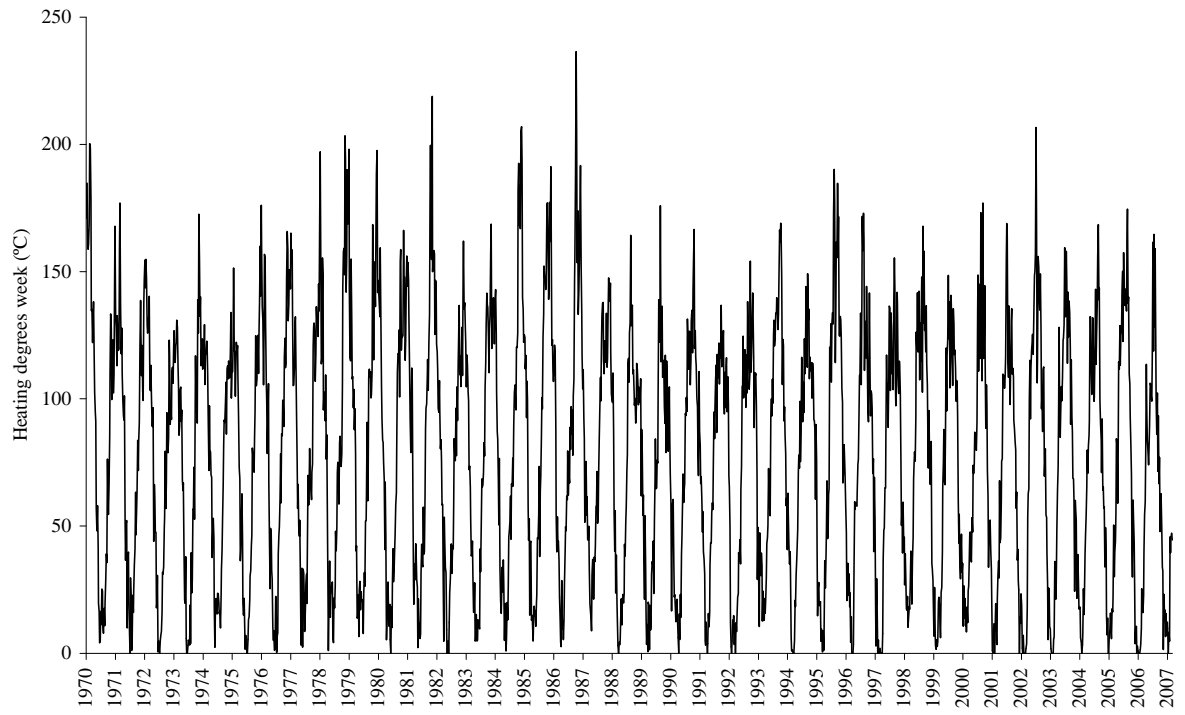
Figure 5. Basis of the first to delivery weekly futures contract.
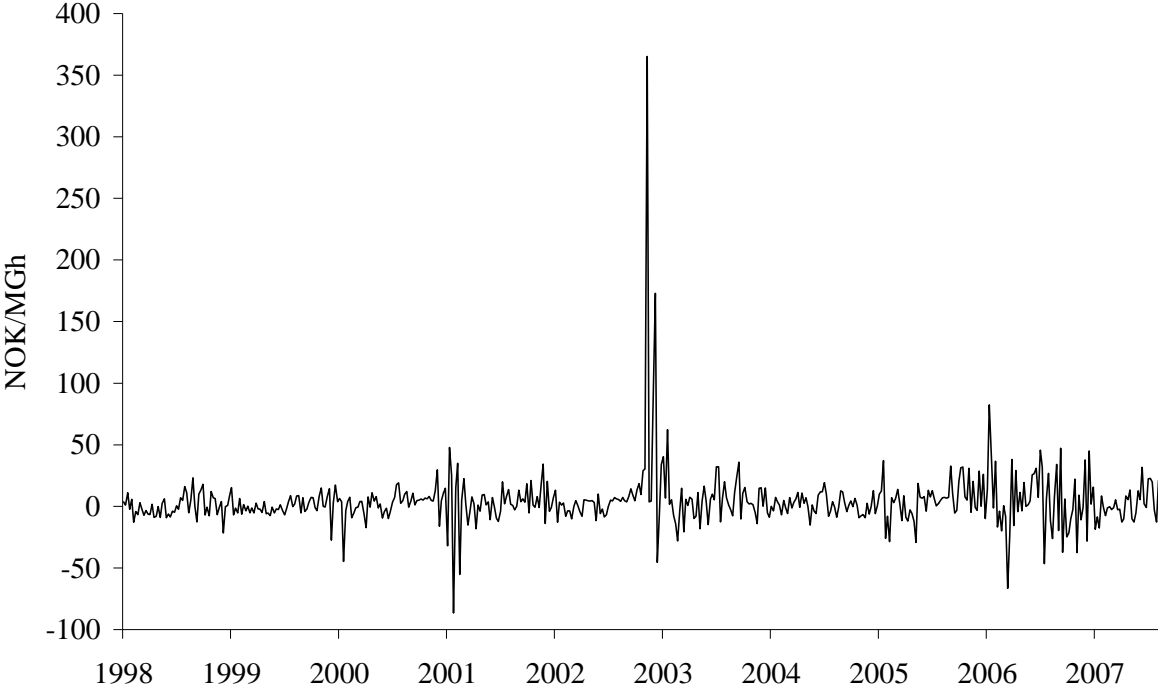
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