Nonlinear Empirical Pricing in Electricity Markets using Fundamental Weather Factors

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Outline

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Motivation

Weather factors are crucial in the price formation process of **electricity markets**.

- Renewable technologies in the process of energy generation are very weather sensitive.
- Demand in energy markets is strongly and clearly associated with weather.

Proposal

We propose a nonlinear pricing model for electricity markets based on fundamental factors related to weather, which is novel to the literature.

Our main contribution to the field is twofold:

1. We highlight the convenience of a nonlinear specification and the inclusion of weather factors when analyzing electricity prices through quantile regressions.
2. We compare how weather factors affect downside and upside risks (lower and upper quantiles of the prices) faced by the agents in the market.

Proposal

We incorporate **temperature, wind speed and precipitation**, into our nonlinear setup, adding to the market variables that signal expected consumption and the prices of inputs.

We estimate our model using data from the **Nord Pool** day-ahead market →Norway, Sweden, Denmark, Finland, Estonia, Lithuania and Latvia.

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Nord Pool Market

The **Nord Pool** is the leading power market in Europe and one of the biggest integrated markets worldwide.

In the day-ahead market (Elspot), producers and consumers make their bids for the delivery of electricity for each hour of the next day.

Nord Pool Market

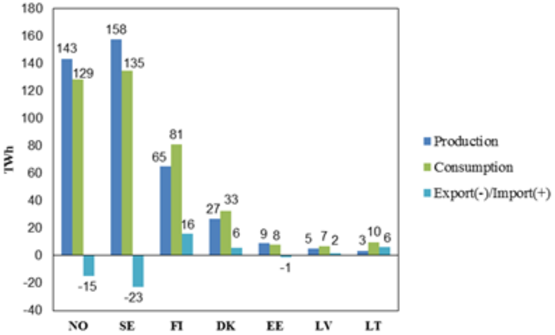
The markets that are part of the Nord Pool are divided into different bidding areas. Currently, there are 15 sub-areas plus the total area.

Table: Bidding Areas and Acronyms

Area	**Description**	**Area**	**Description**
SYS	System Price	NO1	Oslo
SE1	Luleå	NO2	Kristiansand
SE2	Sundsvall	NO3	Molde, Trondheim
SE3	Stockholm	NO4	Tromsø
SE4	Malmö	NO5	Bergen
FI	Finland	EE	Estonia
DK1	Western Denmark	LV	Latvia
DK2	Eastern Denmark	LT	Lithuania

Nord Pool Market

Figure: Production, Consumption, and Exchange of Electricity in the Nordic Region, 2015



Nord Pool Market

Table: Nordic Power Generation Matrix, 2012

Energy Source	Norway	Sweden	Denmark	Finland	Total	% Share
Hydropower	142.9	77.7	0.0	16.7	237.3	**57%**
Nuclear Power	0.0	61.2	0.0	22.1	83.3	**20%**
Fossil Fuels	3.4	4.6	16.4	17.1	41.5	**10%**
Wind Power	1.6	7.1	10.3	0.5	19.5	**5%**
Other Renewable	0.0	10.8	12.5	10.4	33.7	**8%**
Non-identifiable	0.0	0.0	0.0	0.9	0.9	**0%**
Total	**147.8**	**161.6**	**39.2**	**67.7**	**416.3**	**100%**

Nord Pool Market

The **pricing mechanism** functions as follows:

1. The system establishes the prices for each hour of the following day that balance aggregate supply and aggregate demand.
2. According to transmission capacity and congestion, different area prices may be established to solve bottlenecks.

Dataset

Our dataset of **dependent variables** consists of the day-ahead electricity prices, quoted in EUR/MWh, for the 16 bidding areas in the Nord Pool market.

The dataset of **explanatory variables** consists of temperature, wind speed, and precipitation for the seven countries that are part of the day-ahead Nord Pool Market and consumption of the bidding areas, natural gas price, coal price, and freight costs.

Dataset

The **frequency of the data** is daily: the sample period starts on January 1, 2013 and ends on March 30, 2016.

The electricity prices and consumption were obtained from the Nord Pool Spot, and the other explanatory variables were obtained from Bloomberg.

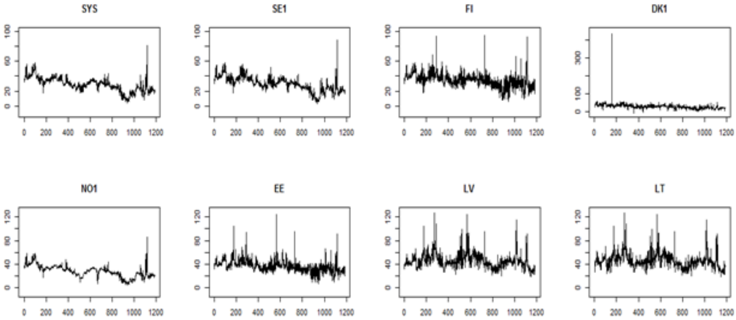
Descriptive Statistics

Table: Descriptive Statistics of the Electricity Prices (EUR/MWh)

	SYS	SE 1	FI	DK1	NO1	EE	LV	LT
Mean	29.14	30.02	35.22	30.14	27.91	36.87	46.03	46.25
Median	29.42	30.33	35.31	29.90	28.28	36.29	44.42	44.68
Maximum	80.99	88.10	94.78	436.33	86.39	124.77	126.32	126.32
Minimum	3.88	3.51	6.30	-6.28	3.65	6.30	18.34	18.34
Std. Dev.	9.31	9.90	9.32	15.67	9.87	10.03	12.29	12.30
Skewness	0.08	0.09	0.58	14.71	0.27	1.46	1.47	1.42
Kurtosis	3.76	3.84	7.17	382.56	3.96	11.88	8.37	8.30
Observations	1,185	1,185	1,185	1,185	1,185	1,185	1,185	1,185

Electricity Prices

Figure: Electricity Prices (EUR/MWh)



Weather Factors

We constructed **three weather factors** using temperature, wind speed, and precipitation data for the seven countries of the Nord Pool market.

To use as much information as possible, we aggregated each weather variable data into one factor by means of **Principal Components Analysis (PCA).**

Each factor represents a **latent factor** of the weather conditions in the Nordic area.

Market Factors

Table: Market Factors Summary

Variable	Description	Units	Stationarity
Consumption	Daily total for the 15 bidding areas.	MWh	The series present a stochastic trend.
Natural Gas Price	NGUSHHUB Index: natural gas for next-day delivery at the Henry Hub.	Index	The series presents a stochastic trend.
Coal Price	API2 index: steam coal delivered to the ARA region of Northwest Europe.	Index	The series presents a stochastic trend.
Freight Costs	Baltic Dry Index: A composite of the Baltic Capesize, Panamax, Handysize and Supramax indices.	Index	The series presents a stochastic trend.

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Factor Models

For $i = 1...N$ and $t = 1, ...T$, traditional linear factor models are summarized by:

$$\mathbf{x_t} = \alpha \mathbf{f_t} + \mathbf{e_t}$$

where $\mathbf{x_t} = (x_{1t}, \cdots, x_{Nt})'$, $\mathbf{f_t} = (f_{1t}, \cdots, f_{kt})'$, and $\mathbf{e_t} = (e_{1t}, \cdots, e_{Nt})$.

- $\mathbf{x_t}$ is an N-dimensional observable random vector of electricity prices.
- $\mathbf{f_t}$ a k-dimensional vector of latent factors $\rightarrow$ includes both weather-driven and market-driven factors.

Quantile Regressions

Following the seminal contribution by **Koenker and Bassett (1978)**, we expand the model as follows:

$$\mathbf{q}_{\mathbf{i}}^{\theta}(\mathbf{x}_{\mathbf{it}}|\mathbf{f}_{\mathbf{t}};\alpha) = \alpha(\theta)'\mathbf{f}_{\mathbf{t}}$$

where $\alpha(\theta)$ is a vector of coefficients that depends on the quantile θ, $\mathbf{q}_{\mathbf{i}}^{\theta}$.

Unlike traditional asset pricing factor theory, which focuses on the average impact of the factor on the endogenous variables, quantile estimates allow us to explore different fragments of the conditional distribution of electricity prices.

Quantile Regressions

Quantile regressions are known to be **robust to outliers**, and this is of particular importance for analyzing electricity prices, which are plagued by abrupt, short-lived, and generally unanticipated spikes.

They offer greater flexibility in the analysis of extreme scenarios likely related to distinctive weather conditions:

- Lower quantiles are related to abnormally low prices.
- Higher quantiles are naturally related to scarcity prices.

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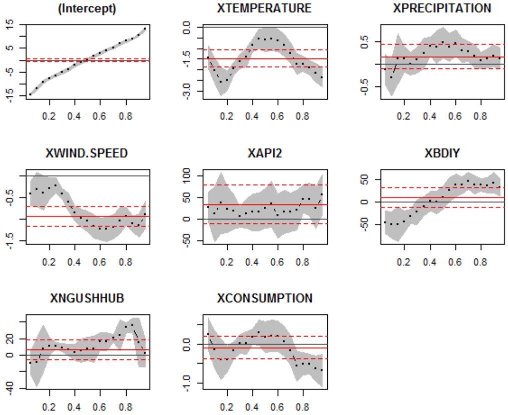
We estimated our factor model at **different quantiles** of the distribution of electricity prices (from the 5th to the 95th percentiles) for all the bidding areas within the markets of Norway, Sweden, Finland, Estonia, Latvia, and Lithuania and also for the integrated market of the Nord Pool.

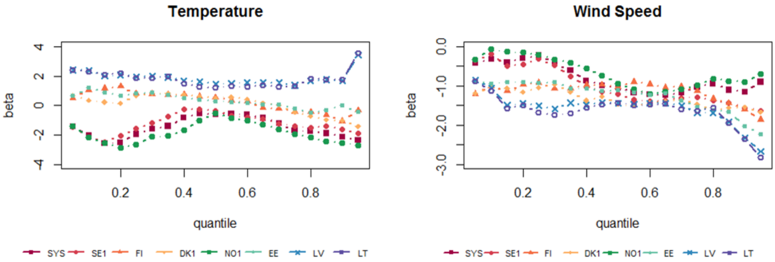
The performance of the model that includes **weather factors** is always superior compared with one that includes only market-related factors.

Figure: Effects of Weather and Control Variables on Electricity Prices (SYS)



Comparative Analysis between Nord Pool Markets

Figure: Comparative effects of weather on the electricity prices



Significance of Weather Factors

Figure: Summary of the Factors' Significance

Variable	% Significance
Intercept	93%
Wind Speed	91%
Temperature	76%
BDIY	49%
Consumption	42%
NGUSHHUB	41%
Precipitation	28%
API2	15%

Analysis of Extreme Percentiles

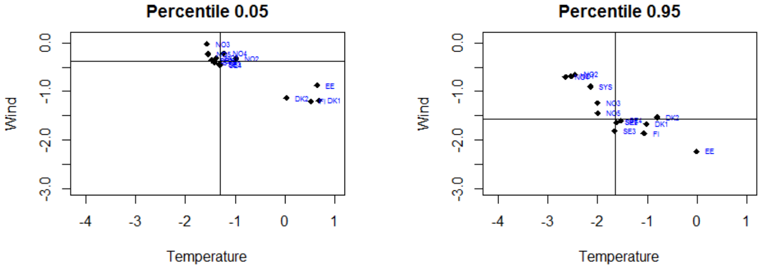
Higher prices are associated with greater demand requirements for the network → higher power transmission requirements.

Downside risk (low prices) is linked to producers' risk and **upside risk** (high prices) to consumers' risk → depending on the area where consumers are located, their risk exposure to weather factors differs greatly.

Producers tend to face a more homogeneous risk, regardless of their location.

Analysis of Extreme Percentiles

Figure: Risk Exposure to Weather on Extreme Percentiles



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We construct an **empirical model** for **electricity prices**, using **weather factors** in addition to market factors.

We show that **weather factors** induce a **significant and nonlinear influence** on electricity prices conditional on the prices quantile.

Temperature and **wind speed** are the most relevant factors when analyzing the cross-section of countries that comprise the Nord Pool market.

The main influence of weather occurs at the **tails** of the electricity price distribution, where abnormally **high and low prices** are recorded.

We also document important **asymmetries** among the price dynamics in the Nord Pool.

Although Norway and Sweden lead the market, Denmark, Finland and Estonia comprise a relatively homogeneous group in which the effect of temperature and wind is less pronounced and more stable across the percentiles of the price distributions.

The influence of **market factors** seems more homogeneous and less significant across the percentiles of the price distributions than that of the weather factors.

Weather as a genuine fundamental and structural factor that underlies the dynamics of electricity markets.

When prices are high, weather factors such as temperature and wind speed affect more diversely each area price than when prices are relatively low.

Agents hedging schemes should take into account weather factors' inherent volatility $\rightarrow$ defining different hedging levels according to different weather regimes.

Consumers and producers should have differentiated hedging strategies since weather factors do not affect homogeneously high prices and low prices.