Essays on modeling the short-term electricity markets

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ESSAYS ON MODELING THE SHORT-TERM ELECTRICITY MARKETS

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Essays on modeling the short-term electricity markets

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Abstract

This thesis consists of an introduction and 3 self-contained papers on models of the short-term electricity markets. The papers all focus on incorporating the structure of the markets in the models.
The introduction provides a brief overview of the short-term electricity markets and the papers of this thesis. Each paper's foundation in relation to the markets and the literature is discussed followed by a discussion of how the developed models can be valuable for the market participants.
Paper A introduces a simulation approach for the hour based German day-ahead electricity auction. This approach is build on an empirical model, which is focused on capturing the market peculiarities created by the infrastructure of the auction. Specifically, the focus is on the within-day correlation structure of the market, i.e. the correlation among the prices of the 24 hour products traded on the same day, creating a valuable simulation tool for electricity producing assets with inherent production timing issues.
Paper B investigates the lag structure of the hour based German and French day-ahead electricity auction by modeling it through a structured regularization. The structured regularization is implemented by two versions of hierarchical lag selection, which prioritize the nearest price lags and allow for a weekly seasonality in the prices. This model bridges the gap between the structured models with a limited, prespecified lag structure and the models with a complex parameter set estimated through unstructured regularization already included in the literature. Thereby, further market insights are gained and tracking of the development of the lag structure is enabled.
Paper C describes a two-phase model of the 5 minute price changes of the hour based German continuous trade intraday market. The data is split into two distinct phases in order to adjust the model to the data structure of the intraday market, while also enabling the analysis of the development in trading behavior as the electricity products gets close to delivery. The model is found to generate a profit by a simple trading strategy and the estimated coefficients provide a range of interesting interpretations.

Resumé

Denne afhandling indeholder en introduktion og 3 selvstændige artikler, der alle omhandler modellering af de kortfristede engrosmarkeder for elektricitet. Fokus er i artiklerne på at inkorporere markedsinfrastrukturen i modellerne.

Introduktionen giver et kort overblik over markederne og præsenterer de 3 artikler. Disse sættes i kontekst i forhold til markederne og de eksisterende modeller i litteraturen, hvilket følges af en diskussion af den værdi, artiklerne bringer markedsaktørerne.

Artikel A beskriver en simuleringsmetode for det timebaserede tyske day-ahead marked for elektricitet. Metoden bygger på en empirisk model, der er sat op til at tage højde for korrelationer mellem hver af de 24 handlede timeprodukter for hver enkelt dag. Dette skaber et simuleringsværktøj, der er værdifuldt i forbindelse med prissætning af elektricitetsproducerende aktiver, der skal tage aktive valg vedrørende, hvornår de skal producere hver enkelt dag.

Artikel B undersøger lag-strukturen (den tidsmæssige forskydning) for det timebaserede tyske og franske day-ahead marked vha. estimering gennem struktureret regularisering. Den strukturerede regularisering implementeres gennem to versioner af hierarkisk variabeludvælgelse, som udelukker de fjerneste lags først og tillader en ugentlig sæson i modellen. Modellerne bygger bro mellem to modeltyper præsenteret i litteraturen: modeller med en struktureret, begrænset og prædefineret lag-struktur og modeller med et kompleks sæt af variable estimeret med ustruktureret regularisering. Dette skaber en yderligere indsigt i day-ahead markedet og dermed også muligheden for at følge udviklingen i markedets lag-struktur.

Artikel C beskriver en tofaset model for prisændringen på det timebaserede tyske kontinuert handlede intraday marked over 5 minutter. Data er splittet op i de to faser for at tilpasse modellen til datastrukturen genereret af intraday markedet, og faserne tillader også en undersøgelse af udviklingen af markedsaktørernes handelsmønstre. Modellen skaber profit gennem en simpel handelsstrategi, og de estimerede koefficienter har grobund for interessante økonomiske fortolkninger.

Contents

Preface

This thesis presents the articles that are the product of my research during my Industrial PhD-studies from January 2016 to February 2019. Specifically, the thesis consists of 3 self-contained articles:

- Paper A: Simulating the German day-ahead electricity market: preserving the within-day correlation structure

- Paper B: Estimating the autoregressive structure of day-ahead electricity markets

- Paper C: Forecasting the German continuous trade intraday electricity market

Paper B is written in corporation with Assistant Professor Ines Wilms, Maastricht University and Associate Professor David S. Matteson, Cornell University, while Paper A and C are written without co-authors.

During my PhD studies, I have worked with many people I highly appreciate. I am grateful for all your support.
I would like to thank my current supervisors, Ege Rubak, Rasmus Johansen and Lasse Bork, as well as, Johannes Tang Kristensen and Esben Høgh who have previously been part of the project. Without your knowledge, technical insights and willingness to help this thesis would not have been possible. I would like to give all my appreciations to Ege and Rasmus who have provided an emotional support during stressful times far beyond what can be expected of anyone.
The time spent with my colleagues at both Centrica Energy Trading and the Department of Mathematical Sciences, Aalborg University are greatly appreciated by me. Especially the community of PhD-students have helped make my PhD project more enjoyable, as it provided an atmosphere for both fun and work. I am especially grateful for the support from Andreas, Heidi and Anca, which have gotten me through tough times.

My stay at Cornell University provided me great insights personally and academically. It was a true pleasure and I am glad that the corporation with David S. Matteson and Ines Wilms still continues. They provide great guidance and friendship.
Lastly, I would like to thank my family and friends for their support through this project. Especially, my girlfriend Pernille, friend Lasse, siblings Esben and Astrid, and parents Mogens and Bodil have supported me immensely along the way. Without their support I would never have come this far.

Rune H. Nielsen
Aalborg University, February 17, 2019

Part I

Introduction

Introduction

The unifying theme of the articles presented in this thesis is that they all focus on modeling the short-term electricity markets while taken the underlying market infrastructure into account. Paper A introduces a simulation method of the German day-ahead electricity market by an empirical approach that mimics the correlation structure of the market closely. Paper B investigates the lag structure of the German and French day-ahead market prices by applying an estimation approach based on structured regularization. Paper C models the price movements of the German continuous trade intraday market. This model is specified and estimated to match the complex data pattern of the market.

Section 1 of this introduction introduces the structure of the short-term electricity markets and Section 2 discusses the research of the articles, how they relate to the literature and how they bring value to the industry.

1 Short term electricity markets

The short-term electricity markets for Germany and France consist of the day-ahead auction that runs at noon the day before delivery of the electricity and the continuous trade intraday market which opens at 15:00 the day before delivery and closes 30 minutes before the delivery commences. See Figure 1 for a visual representation of the markets.

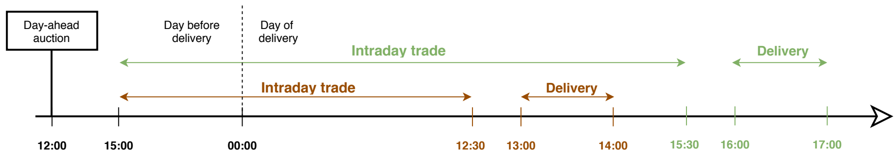

Fig. 1: Stylized example of the European short term electricity markets, as presented in Paper A of this thesis. The example illustrates the trading possibilities of hour product 14, electricity to be delivered between 13:00 and 14:00, (brown) and hour product 17, electricity to be delivered between 16:00 and 17:00 (green).

Different variants of electricity products are traded in both the day-ahead and the intraday markets. The product variants differ by the length of delivery period, i.e. the time frame over which the electricity is to be delivered. In the papers of this thesis the focus is on the hour-based electricity products. This is both done to ensure that the models are based on the products that are important for assets with intermittent electricity production, e.g. wind and solar farms, and to ensure sufficiently high trading volume. The high trading volume both shows the importance of the market for the market participants and provides a better data foundation, which is important in Paper C.

As mentioned, both the day-ahead and intraday markets are important for managers of intermittent electricity production facilities. Managers of e.g. wind farms use the day-ahead market as their main trading platform to sell the electricity produced by the farms. It is sufficiently close to the actual delivery of the electricity that reliable weather forecasts are available such that a good estimate of the production can be made. At the same time the auction is very liquid, hence it is possible to sell the production without many frictions. After the main sale of electricity at the day-ahead market, the wind farm managers will need to adjust their position if the weather forecasts are updated. This is done in the continuous trade intraday market where trading can be until 30 minutes before delivery commences.[1]

A third short-term electricity market also exists, the balancing market. This is where the cost of the difference between the market participants positions and their actual electricity deliverances, the imbalance, are settled. The market is not directly tradeable and it is usually not allowed to take positions in the market. The market has therefore not been a focus in the research for this thesis.

2 The foundations of the papers and their value propositions

The following provides insight into the methods presented in the papers of this article, how the methods are fit to the market infrastructure, their relationship to the current state of the electricity price forecasting literature and the value they bring to the market participants.

Paper A presents a method to simulate the short-term variation of the hour based German day-ahead electricity market with an emphasis on capturing the within-day correlation structure of this market. While other papers have simulated the market by a more classical continuous time stochastic process based approach, see e.g. Veraart & Veraart (2014), Paper A is based on

[1] Some markets allow for trading up to 5 minutes before delivery under specific conditions, but these limitations also make them negligible.

models which have previously proven successful for forecasting. The models implement vector autoregressive (VAR) models by regularization and are presented in Ziel (2016), Uniejewski et al. (2016) and Ziel & Weron (2018). The day-ahead electricity market is auction based, so all the 24 prices of the hour products for each day is set simultaneously. This is why the 24-dimensional VAR model captures the within-day correlation structure well.

The VAR model is used as a method to generate the expected prices simply by forecasting. In order to create the simulations, likely deviations from these expected prices are generated by draws of the residuals of the VAR model used to generate the expected prices. Several considerations needs to be put into the procedure of this draw in order to ensure that the 24 deviations for a day also mimics the true within-day correlation structure. This is done by a block simulation approach, where a block of all the 24 residuals of one specific day is selected at once.

Being able to simulate the day-ahead market while keeping the within-day correlation structure intact will be important when valuing electricity plants that face timing issues in relation to when to produce electricity. An example of this is a biogas fired electricity plant that is only able to produce electricity for a limited number of hours per day. Due to the limited production capacity, the timing of when to run the plant is important and capturing the intraday structure is therefore crucial.

Paper B is a collaboration with Assistant Professor Ines Wilms, Maastricht University and Associate Professor David S. Matteson, Cornell University. The idea for the paper originated at my stay at Cornell University and has been developed further after I returned to Aalborg University.

This paper is also related to the VAR models estimated by regularization in Ziel (2016), Uniejewski et al. (2016) and Ziel & Weron (2018). The models of these articles are estimated by means of the lasso or the elastic net and are therefore inducing an unstructured regularization. Estimation of these models with large parameter sets outperformed the previous models in the literature, which were focused on simpler, prespecified lag structures. These models are seen in the naive forecast of Conejo et al. (2005) and the expert models, as they were named by Uniejewski et al. (2016), first presented in Misiorek et al. (2006). The naive forecast and the expert models put an emphasis on the most recent lagged prices and a weekly seasonality. Specifically, the expert model is only relying on the autoregressive lags of 1, 2 and 7 days.

The goal of Paper B is to estimate the rich parameter set of the VAR models, while also incorporating the assumed structure of the expert models. The structure is incorporated by hierarchical lag selection as presented in Nicholson et al. (2016), where hierarchical vector autoregressive (HVAR) models are estimated. The hierarchies prioritize the regularization on the longest lags, setting coefficients to zero in a backwards elimination approach. The HVAR model were extended in Wilms et al. (2017), where exogenous variables were allowed in the hierarchical vector autoregressive models (HVARX) models. Our analysis is based on the HVAR model and a modification of the HVARX model that allows the weekly seasonality to be incorporated outside the hierarchy, which we refer to as HVARLX.

The HVAR and HVARLX models are implemented on different data periods for both the German and French day-ahead markets. The estimation results are used to analyze the autoregressive lag structure of the day-ahead markets, where we investigate how this structure compares to the assumed lag structure of the expert models, differences between the markets of the two countries and how the lag structure develops over time. We compare the differences of the lag structures for the different time periods with the fundamentals of the markets and find interesting relationships between these.

The paper brings value by describing the underlying lag structure of the market, relating it to the expert models and creating a way to estimate the lag structure consistently. The electricity markets is rapidly evolving due to the inflow of intermittent production facilities and the changing regulations of the markets. A consistent estimation of the lag structure is therefore important as it enables tracking of the changes over time, thereby facilitating evaluation of the effects of the developments in the electricity markets on its lag structure.

Paper C consists of a two-phase model of the 5 minute price change in the German continuous trade intraday market with a strong focus on an estimation procedure that fits the complex underlying data structure. The two stages considers the price developments of the prices that are between one and three hours away from market closure, *phase I*, and the prices of the last hour of trading, *Phase II*, as separate phases. Splitting the model into two phases is necessary in order to consistently estimate a model, that will mimic the data structure created by the intraday market. The split also creates an opportunity to investigate how trading behavior changes in the intraday market as trading closure approaches.

The intraday market has only very recently been a focus of the electricity price forecasting literature. Kiesel & Paraschiv (2017) propose an econometric model to analyze the price changes of the electricity products traded on the intraday market, which have a 15 minute delivery period. Paper C's model differs significantly by focusing on both the forecasting ability of the model, as well as its interpretation.

The 5 minute price change of hour product h is forecasted by an autoregressive term, lags of the price change for hour product $h-1$ and $h+1$, changes in the forecast of electricity produced by wind and solar farms and three variables describing the steepness of the bid and offer stacks. To my knowledge, similar models do not exist, hence a direct comparison is not possible. Instead the models are evaluated by their ability to earn a profit, which is the case for all versions of the models evaluated in the paper. An attempt to interpret the estimated coefficients is provided and reveals several interesting properties that are related to the trading behavior of the intraday market and how this behavior changes over time.

Being able to forecast the intraday market creates value to the market participants, especially the ones that manage intermittent electricity producing assets. As mentioned previously, these asset managers need to adjust their portfolio as weather forecasts are updated and reliable price forecasts enable the asset managers to do this in a cost-effective manner. The market insights the paper presents will also enable the asset manager to better rationalize their trading strategy.

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