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Electricity forward curves with thin granularity: Theory and empirical evidence in the hourly EPEXspot market

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A B S T R A C T

We propose a constructive definition of electricity forward price curve with cross-sectional timescales featuring hourly frequency on. The curve is jointly consistent with both risk-neutral market information represented by baseload and peakload futures quotes, and historical market information, as mirrored by periodical patterns exhibited by the time series of day-ahead prices. From a methodological standpoint, we combine nonparametric filtering with monotone convex interpolation such that the resulting forward curve is pathwise smooth and monotonic, cross-sectionally stable, and time local. From an empirical standpoint, we exhibit these features in the context of EPEX Spot and EEX Derivative markets. We perform a backtesting analysis to assess the relative quality of our forward curve estimate compared to the benchmark market model of Benth, Koekekbakker, and Ollmar (2007).

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1. Introduction

The electricity forward curve is a key piece of information subsuming future views of power market participants. This quantity is a function mapping each element in a set of future time intervals into the corresponding fair price for forward delivery of one megawatt-hour of electrical element. A standard setting assumes evenly spaced and continuous time periods spanning the tradable maturity spectrum. Their length defines the curve granularity, which we refer to as “thin” for hourly frequency on. We consider the problem of building an electricity forward curve with hourly granularity. This is customarily referred to as the hourly price forward curve (HPFC). The driving principle underlying our approach is market representativeness. In particular, curve construction ought to use available market prices at best. The proposed analysis considers two major strands of market data. Risk-neutral information stems from futures price quotations. Forward prices with hourly granularity cannot directly be recovered from these figures: the inverse problem of getting hourly prices out of futures market quotes with longer maturities is by and large undetermined. Market practice tackles the issue to a limited extent by adopting the curve fitting toolkit borrowed from fixed income analysis. Unfortunately, a direct application of these methods leads to forward curves lacking most of the stylized features required by power market operators. Historical information emerges from the past evolution of quoted spot prices. Power quotations stem from the interaction between supply and demand of electricity. This interaction exhibits sharp periodical patterns at frequencies ranging from intra-day up to a season. It turns out that the implied averaging process leading to forward quotes over periods of varying length smoothes these patterns, making them undetectable upon recovering hourly forward prices from futures allows one to price most physical and financially settled power contracts (Burger, Graeber, & Schindlinayr, 2014).

1 Term structures of interest rates are primarily inferred from bond price data. Existing techniques ultimately combine appropriate bond price stripping methods coping with overlapping payment schedules and interpolation methods allowing for filling in gaps appearing across the maturity dimension (Anderson, Breedon, Deacon, Derry, & Murphy, 1996).
quotations. In addition, quoted delivery periods usually exhibit varying durations. This fact often entails observing quotations referring to intersecting delivery periods, what leads to an ambiguous forward price assessment over certain time intervals. A further complication is presented by a possible lack of futures quote records for some segments in the maturity domain, a fact which leaves the forward curve undetermined for those portions of time.

In summary, while risk neutral data represented by standing futures prices allows us to partially determine forward curve level, it provides little clue about the actual shape of the curve. This effect is noticeably exacerbated with increasing time granularity, a phenomenon which reaches its acme in hourly resolution. We argue that historical data offers the missing piece of information. A major contribution of this study is to unveil this finding and devise a way to use historical spot price data to sharpen the assessment of an HPFC compatible to market quotes in a rationally consistent manner.

The paper is organized as follows. Section 2 summarizes existing literature on the subject and points out a direction for this study. Section 3 develops the underlying rationale by inspecting the nature of market information and by introducing the notion of forward kernel. Section 4 proposes a metadefinition of rational forward curve and offers a corresponding algorithm. Section 5 describes preparatory steps, notably spot data outlier filtering and futures price segmentation. Section 6 implements the model into an algorithm leading to a constructive definition of HPFC. Section 7 empirically investigates the case of the EPEX power market and tests the quality of this proposal against a benchmark market model. Section 8 concludes with a few comments and suggestions for future research work.

2. Review of literature

Some of the issues described so far have been partially addressed by the existing literature. To the best of our knowledge, Fleiten and Lemming (2003) first apply curve fitting methods to electricity markets. Using the proprietary Multiarea Power Scheduling (MPS) model, these authors obtain weekly equilibrium prices and production quantities. They derive electricity forward curves through nonparametric estimates of daily forward prices obtained by minimizing the least-squares distance between target values and MPS equilibrium prices. The problem is solved under price constraints related to bid-ask spreads and curve smoothness properties.

Koekebakker and Os Adland (2004) and Benth, Koekebakker, and Ollmar (2007) propose a model whose terms are made fully available to the user. They assume that forward curves combine seasonal paths with fourth order polynomial splines. Using the maximum smoothness interpolation (MSI) method developed by Adams and van Deventer (1994), these authors derive a daily forward curve fitting a set of market quotes and minimizing a convexity measure of the curve shape. The construction algorithm is effectively applied to Panamax Time Charter freight and Nordpool electricity markets.

Borak and Weron (2008) observe that the two methods described above are sensibly prone to model risk. These authors focus on the tight dependence between seasonal component assignment and the output curve. They propose a dynamic semi-parametric factor model with no explicit representation of periodical terms. As a result, they deliver a parsimonious, smooth, and seasonal forward curve estimate with daily granularity. However, their algorithm may suffer from underfitting market prices and may fail to account for short-term periodical patterns.

The problem of building electricity forward curves with finer granularity than a single day has rarely been addressed by the existing literature. Hildmann, Kaffe, He, and Andersson (2012) propose a framework to calculate an HPFC by combining parametric estimation and future price prediction on an hourly basis. They estimate a linear model through suitable norm minimization under constraints. These constraints actually ensure model consistency to quoted forward price. They also prevent from arbitrage opportunities in agreements with arbitrage pricing theory. However, this study neither reports any quality assessments, nor does it investigate empirical performance.

Paraschiv et al. (2015) further refine the method offered by Benth et al. (2007) to account for hourly granularity. They obtain an HPFC by additively superposing an exogenously estimated hourly pattern to a seasonal component, which in turn combines daily and monthly dummies with weather-linked derivatives, in light of their ability to capture temperature related effects. Although peakload price fitting is out of their model scope and temperature forecasting is known to offer significant estimates primarily over a short time horizon, the proposed algorithm is shown to provide reasonable hourly forward prices.

The main contribution of this paper is to put forward a rational definition of HPFC with thin granularity that complies with desirable features unaccounted for by the existing literature. The attribute “rational” refers to the following five properties:

- Raw price series undergo a filtering procedure to finely detect and single out data outliers;
- Curve shape incorporates a comprehensive bundle of periodic patterns unveiled by past quotes;
- Curve level is jointly consistent to standing baseload and peakload futures quotations;
- Curve path satisfies regularity properties, including trajectory smoothness, monotonicity preservation, cross-sectional stability, and time localness (Hagan & West, 2006);
- Forward estimate quality is assessed through dedicated empirical tests.

We remark that the proposed definition is fully constructive and self-contained: we make no use of data (e.g., temperature records in Paraschiv et al. 2015) other than electricity spot and futures prices, nor do we adopt any exogenous model (e.g., the MPS in Fleiten and Lemming (2003)) to benchmark the proposed construction. As a result, we come up to a flexible algorithm covering virtually all electricity market instances.

3. Market prices and patterns

Constructively combining risk-neutral and historical price information into a term structure of forward prices requires that one defines the notion of forward kernel, a theoretical quantity generating forward curves with arbitrarily assigned granularity.

3.1. The forward kernel

Electrical power is useful for practical purposes provided it is continuously dispatched over a time frame. Deregulated power markets allow for trading contracts entailing physical delivery or financial settlement over a variety of time intervals in the future. As an example, we may consider the general structure of most electricity spot markets. Each day contracts are traded for physical dispatching power on each hour in the following day. By combining agents’ bid and offer quotes, the market exchange posts a day-ahead price for each contract. Day-ahead prices play the additional role of indices underlying power contracts tariffs, including most financial derivatives written on electricity.

* Appendix B.1 discusses the role of temperature records in the construction of forward curves.
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