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Modelling electricity futures prices using seasonal path-dependent volatility

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HIGHLIGHTS

- A no-arbitrage term structure model is applied to the electricity market.
- Volatility parameters of the HJM model are estimated by using German data.
- The model captures the seasonal price behaviour.
- Electricity futures prices are forecasted.
- Call options are evaluated according to different strike prices.

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ABSTRACT

The liberalization of electricity markets gave rise to new patterns of futures prices and the need of models that could efficiently describe price dynamics grew exponentially, in order to improve decision making for all of the agents involved in energy issues. Although there are papers focused on modelling electricity as a flow commodity by using Heath et al. (1992) approach in order to price futures contracts, the literature is scarce on attempts to consider a seasonal volatility as input to models. In this paper, we propose a futures price model that allows looking into observed stylized facts in the electricity market, in particular stochastic price variability, and periodic behavior. We consider a seasonal path-dependent volatility for futures returns that are modelled in Heath et al. (1992) framework and we obtain the dynamics of futures prices. We use these series to price the underlying asset of a call option in a risk management perspective. We test the model on the German electricity market, and we find that it is accurate in futures and option value estimates. In addition, the obtained results and the proposed methodology can be useful as a starting point for risk management or portfolio optimization under uncertainty in the current context of energy markets.

1. Introduction

During the past two decades we have seen comprehensive electricity sector liberalization and deregulation in all EU countries. The electricity market, once monopolistic, has become a competitive market where electricity prices are derived by the interaction of supply and demand. This new context, joined with the physical characteristics of electrical power, has generated new price patterns, never seen before, neither in financial markets, nor in commodity markets. Electricity is a flow commodity characterized by its very limited storability. The lack of economic storage opportunity makes the supply completely inelastic to price changes. Prices show extremely high volatility and sudden consistent jumps in their levels, called “spikes”. Market participants, both producers and consumers, are dramatically exposed to uncertainties in electrical power prices, and risk management techniques play a fundamental role in quantifying and mitigating price risk. Several studies have been addressed to the analysis of electricity prices, because they are generally used as reference for decisions done in energy trading. Therefore, well-performing forecast methods for day-ahead electricity prices are essential for energy traders and supply companies. In Keles et al. [1], a methodology based on artificial neuronal networks is presented to forecast electricity prices. The forecasting reveals being an important instrument for dealer generally in all the commodity markets: Baruník and Malinska [2] explain the term structure of crude oil prices using the dynamic

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Nelson–Siegel model and propose to forecast oil prices using a generalized regression framework based on neural networks.

García-Martos et al. [3] extract common features in the volatilities of the prices of several commodity prices: the common volatility factors obtained are useful for improving the forecasting intervals and the results obtained and methodology proposed can be useful as a starting point for risk management or portfolio optimization under uncertainty in the current context of energy markets.

Since the beginning of liberalization, researchers and practitioners have been focusing their attention on studying electricity price evolution by setting up mathematical models able to capture the main features of price behaviour, in order to allow both derivative pricing and risk hedging. With the emerging of the electricity wholesale, a lot of interest has grown in electricity financial instruments in order to manage price risks: most of electricity futures and options on futures are traded on the New York Mercantile Exchange (NYMEX), while a large variety of electricity derivatives is traded in the OTC markets. Call and put options are the most effective tools available to merchant electrical power plants or power marketers for hedging price risk because electrical power generation capacities can be essentially viewed as call options on electricity, in particular when generation costs are fixed. Electricity is referred to as a flow commodity: all contracts guarantee the delivery of an established amount of electricity (MW h) continuously over a specific future time period (1 h, 1 month, 1 quarter, 1 year). It can be settled with physical delivery or simply financially. The energy market is made of two segments: a market for spot trading and a derivative market. In the spot market, electricity is traded in an auction system for standardized contracts, and every day hourly contracts for each of the 24 h of the coming day are evaluated. This is called the day-ahead market, characterized by physical delivery. In the derivative market, electricity forward contracts and futures contracts are settled either financially or with physical delivery. They usually have a monthly, quarterly, or yearly delivery period. Recently, European and Asian options with electricity futures as underlying have been launched in the more developed Electricity Markets (Nord Pool, Scandinavia and NYMEX, New York) and are becoming extremely important in the commodities markets, offering advantages to both the consumer (buyer) and the producer. The literature on electricity price modelling has rapidly developed in the last few years because of the growing need for obtaining models that describe electricity price behaviour in a realistic and accurate way. Indeed, from a risk management point of view, robust forecasts for electricity prices lead to proper hedging strategies being defined through the accurate pricing of financial derivatives, like options. According to Weron [4], there are various approaches that have been developed to analyse and predict electricity prices, and in particular we can distinguish five groups of models: *(i) Multi-agent models*, that consider the interaction among heterogeneous agents and build the price process by matching demand and supply in the market; *(ii) Fundamental (structural) methods*, which model the impact of important physical and economic factors in order to determine electricity price dynamics; *(iii) Reduced-form (quantitative, stochastic) models*, which investigate the statistical properties of electricity prices over time in order to describe their dynamics with the ultimate objective of derivatives evaluation and risk management; *(iv) Statistical approaches*, which consist in applying statistical techniques of load forecasting or implementing econometric models; *(v) Computational intelligence techniques*, which use the neural network approach to study the complex dynamic system. Obviously, there can be models that contemplate hybrid solutions, combining techniques from two or more of the groups. Although the classification of Weron allows us to characterize the research field according to the modelling approach, we can identify two macro-areas of research: *(a)* the traditional one that concentrates on modelling electricity spot price dynamics and *(b)* the alternative approach that describes and represents directly electricity futures prices. According to this partition, we have reviewed some of the existing literature.

With regard to the spot price modelling, Lucia and Schwartz [5] model the natural logarithm of the spot price by assuming a mean reverting process estimated by using spot price data in the Nordic market. The price evolution of a futures contract is then determined by applying expected value under an appropriate martingale measure equivalent to the objective one. Other authors, such as Pilipovic [6] and Eydeland and Wolyniec [7] suggest a two factor model, in order to take into account the influence on the spot price given both by a short term and a long term source of randomness. According to Clewlow and Strickland [8], and Eydeland and Wolyniec [7], the introduction of a jump diffusion process appears the natural way to account for spikes, even if market incompleteness is introduced. Skantze et al. [9] develop a model of electricity prices taking into account the important characteristic of seasonality, by studying the load and supply behaviour. Other papers focus directly on peak price dynamics by specific volatility settings: in particular regime switching models are used in order to predict price spikes [10], by switching between the high-price regime and the low-price regime, according to the two transition probability functions. Huisman and Mahieu [11] and Deng [12], among others, suggest Markovian regime switching models for electricity price, characterized by the occurrence of stable and turbulent periods. Cuaresma et al. [13] investigate the forecasting abilities of a battery of univariate models on hourly electricity spot prices, using data from the Leipzig Power Exchange. They find that an hour-by-hour modelling strategy for electricity spot prices improves significantly the forecasting abilities of whole time-series models, and that the inclusion of simple probabilistic processes for the arrival of extreme price events can also lead to better forecasts. Diongue et al. [14] propose an approach based on the k-factor GIGARCH process for investigating conditional mean and conditional variance forecasts and modelling electricity spot market prices. They apply the proposed method to the German electricity prices market providing forecasting prices up to one month ahead. Higgs and Worthington [15] propose a mean-reverting model and a regime-switching model to capture some features of the Australian national electricity market: high price volatility, strong mean-reversion and frequent extreme price spikes. Tan et al. [16] define a day-ahead electricity price forecasting method based on wavelet transform combined with ARIMA and GARCH models. This method is examined for MCP prediction in the Spanish market and LMP prediction in the PJM market. Huisman and Kiliç [17] examine the development of day-ahead prices in five European markets through a regime switching model. In particular, they distinguish between prices under normal market conditions and under non-normal market conditions. Aid et al. [18] develop a structural risk-neutral model for electricity spot price that is particularly well-suited for spread options on the spot price since it is based on the economic relation that holds between fuel prices and electricity spot prices. Finally, an interesting approach is used by Nowotarski et al. [19] for estimating the seasonal components of electricity. They show that wavelet-based models outperform sine-based and monthly dummy models. The major disadvantage of spot price models is that forward/futures prices are given endogenously from spot price dynamics. Therefore, the obtained dynamics of futures prices are most of the time not consistent with the observed market prices.

Regarding the futures prices modelling literature, Clewlow and Strickland [8] have been among the first researchers to introduce the futures price curve modelling approach to the energy market in the framework of Heath et al. [20]. They use only few stochastic