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Risk asymmetries in hydrothermal power generation markets

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ABSTRACT

Accurate decisions regarding exposure to and hedging against market risk, both of which are crucial for electricity producers and consumers, depend on a correct assessment of electricity price dynamics. This paper proposes a comprehensive empirical methodology to model price variations in electricity markets based on hydrothermal power generation. This proposal combines advances in time-series econometrics related to regime modeling, conditional heteroskedasticity, and extreme events. The study considers stylized facts of the series describing electricity prices, which are especially relevant for accurate risk pricing. More importantly, the proposed methodology enables the description and characterization of asymmetries at almost every level: intraday patterns, seasonal components, spikes, volatility regimes and extreme values; and the estimation of the effects of such asymmetries on traditional risk measures, such as VaR and CVaR. Different tail behaviors of positive and negative electricity returns are documented, which are relevant for assessing the risks of selling and buying strategies. In addition, asymmetries in risk that are conditional on the time at which the transaction occurs are found.

1. Introduction

Empirical literature has shown that electricity prices present several stylized facts, such as mean reversion, spikes, seasonal patterns, and long-range memory, among others Ref. [1]. Thus, modeling and forecasting these prices has become a challenge for academics and practitioners in the electricity industry. The importance of this exercise is indisputable in economic and financial terms, as decisions on selling and buying are a daily necessity for producers and consumers in the market. Needless to say, electricity is a main input for most economic activities in modern economies. Correct assessment of electricity price dynamics depends on accurate decisions about exposure to and hedging against market risk, both of which are crucial for electricity producers and consumers (household and real-sector firms).

For the aforementioned reasons, numerous approaches have been proposed in the empirical literature to model and forecast electricity prices. One approach is based on the techniques of time-series econometrics, such as exponential smoothing models or ARMA-GARCH models. Nevertheless, the literature has mainly ignored several asymmetries hidden in the process of price formation that are highly relevant for the agents involved in market transactions. There has been a consistent lack of studies providing a complete and coherent framework useful for quantifying market risk in electricity markets that take into account the whole set of documented stylized facts of electricity prices.

For example, some models are not sufficiently flexible to capture the different risks faced by consumers and producers in the market, which becomes evident from an independent estimation of tail parameters, scales, and thresholds at the lower and upper tails of the electricity return distributions. Some other models, working with daily data, ignore the idiosyncrasies of the stochastic processes describing the data at different times within a day. Such idiosyncrasies are important given the marked contrast in terms of electricity demand and power-generation alternatives depending on the hour at which an electricity transaction occurs. Finally, electricity prices are subject to weather conditions, which are known for their strong seasonal patterns and are by no means fully predictable. The latter is not properly recognized in a considerable branch of the empirical literature.

This paper aims to help fill this gap in the literature. It is argued that these asymmetries have important implications for risk measurement and modeling and, thus, for derivative pricing. Hence, it is sought to highlight and describe such asymmetries, and therefore contribute to the understanding of electricity price dynamics, which merit special consideration when modeling market risk in electricity markets. The description presented in this document of these asymmetries to assess the market risk that producers of electricity face in comparison to consumers is considered a novel approach. Currently, with new power-generation technolo-

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gies, consumers have gained a new role in the market—they can connect to the system and sell electricity—hence, there is a knowledge gap about the risk they face and how to manage it. This paper also contributes to the literature by measuring the market risk that agents face according to different transaction blocks within a day and by different volatility regimes.

The methodological approach lies within the reduced-form and statistical model groups, as characterized by Ref. [2]. On the one hand, reduced-form models are mainly inspired by traditional financial approaches, which are used to model stock prices, interest rates, and exchange rates. They aim to capture price dynamics rather than forecast them because these reduced-form models are mainly used for derivative pricing and hedging. On the other hand, statistical models are based on an econometric framework, particularly time-series analysis. Some approaches classified in this category are the similar-day method, exponential smoothing models, ARMA-GARCH models, threshold autoregressive models, and smooth-transition autoregressive models.

ARMA and seasonal ARMA approaches have frequently been used to fit the first moment of electricity prices, taking into account autocorrelation and seasonal patterns (e.g., Refs. [3,4]). Additionally, authors such as [5] estimate ARMA models with exogenous variables, like weather conditions and demand loads. They measure the effect of these variables on electricity prices. In addition, the literature has explored hybrid models that combine ARMA and computational intelligence models (see for example Ref. [6]). Regarding modeling and forecasting of demand loads, authors such as Ref. [7] have also used ARMA models, and furthermore, Ref. [8] have included seasonal cycles in a multi-timescale framework to enhance the forecast.

One main drawback of the ARMA-family models is that they assume a constant variance for the residuals. However, it is known that time series, such as electricity prices, tend to be characterized by conditional heteroskedasticity and volatility clustering. Thus, features regarding the series' second moments have been mainly addressed by generalized autoregressive conditional heteroskedasticity (GARCH) models Refs. [9–15].

The main disadvantage of traditional statistical models is their generally poor performance under the presence of spikes in the series. No clear consensus exists in the literature about whether spikes should be removed before estimation because removing or replacing them has direct effects on the model interpretation, for instance, in terms of the market's supply and demand shocks. Hence, Markov-switching models have been explored with the aim of adequately capturing spike regimes (see for example Refs. [16–20]). However, only Ref. [21] modeled electricity price volatility with Markov-switching GARCH models, as done here. This alternative explicitly addresses possible changes in the regime of electricity returns with unconditional volatilities, which are likely associated with changes in terms of weather conditions and unexpected demand and supply shocks.

With respect to the behavior of extreme negative or positive returns, which is also a target of this study, the closest antecedent is Ref. [22], who uses extreme value theory (EVT) with filtered data to analyze the risk faced by agents trading in the Nord Pool market. However, Ref. [22] focuses only on modeling one tail of the distribution, making it impossible to study possible asymmetries, such as the differences between the risk faced by consumers and producers, as pursued here. The author also does not study plausible switching behavior between volatility regimes.

Finally, unlike most of the studies referenced above, in this study, intraday electricity prices are used to capture as much information as possible from the price dynamics. Researchers such as Refs. [23,24] highlight the importance of using intraday data when modeling electricity prices. However, they do not include risk measurements in their studies, nor do they consider other

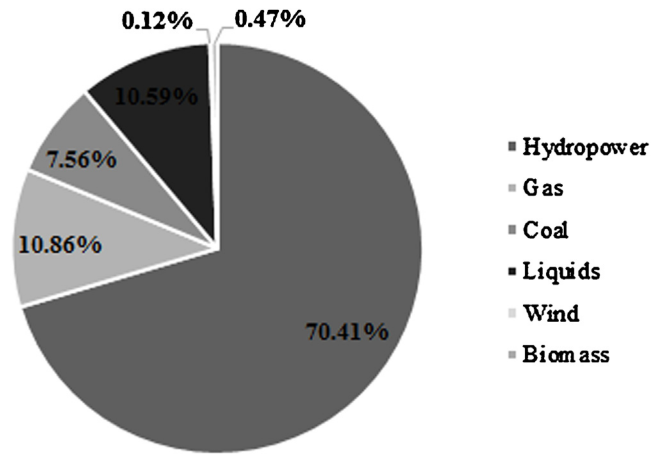

Fig. 1. Participation by technology in the power generation matrix.
Source: XM Information System

forms of asymmetries, such as (i) intraday patterns, (ii) seasonal components, (iii) spikes, (iv) volatility regimes, and (v) asymmetric extreme values (in terms of both shape and scale parameters).

In summary, none of the studies in the previous literature focus on highlighting the asymmetries that characterize electricity prices at almost every level, as done here. To illustrate the main message of the paper, the effects of such asymmetries on traditional risk measures, such as Value at Risk (VaR) and Conditional Value at Risk (CVaR), are also estimated, which are standard benchmarks in the industry. Thus, the objective is not to forecast or compare different modeling strategies; instead, it is to use a comprehensive methodology that allows for the description of several asymmetries hidden in the formation of electricity prices and to estimate their consequences in terms of risk for market agents. Table 1 presents a summary of the advantages and disadvantages of the main traditional methods used to model electricity prices. The proposed approach is a mixture of these methods in order to consider all of the features of electricity price dynamics.

In the empirical application, power-generation prices from the Colombian electricity market are used. This offers a unique opportunity to consider a market with heterogeneous power alternatives, and with a small capacity in terms of renewable-energy providers (which could act as smoothers of the volatility regimes, preventing dramatic changes in electricity prices). Colombia has an energy system based mostly on hydropower and thermal generation (see Fig. 1). Hydropower generation is the base of the system, while thermal generation is a backup technology for periods of high demand, or vulnerability in the hydric generation, due to the exposure to "El Niño", which decreases the levels of water reservoirs. Therefore, the costs of electricity generation are highly weather dependent in the short and long runs. Regarding renewable energy, its production is in an incipient phase. Producers are evaluating wind power-generation projects, and households are interested in solar power generation.

A hydro-thermal-based electricity market was selected for the empirical application because it presents large differences in the marginal costs of generation that depend on the type of technology used. This translates into prices characterized by spikes, seasonal patterns, and different volatility regimes, which make the proposal herein especially relevant in terms of risk measurement and management. Nevertheless, the empirical results of this document are of general interest.[1]

[1] According to International Energy Agency (IEA) statistics, in 2012, the following countries also had energy systems based on hydropower generation: Austria (63.7%),