Electricity Price and Quantity Uncertainty

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Electricity is usually traded in a short-term market (spot market) and a long-term market via contracts for future delivery (forward contracts). The electricity market is characterized by being highly volatile when compared to other commodity markets. This high volatility in terms of price and quantity is due to market circumstances (e.g., expectations or strategies of each company and economic dynamics) and physical conditions (e.g., climate, water availability, fuel production, or damage to the power transmission network).

Keywords: semi-nonparametric approach ; multivariate distribution ; electricity markets ; forward contracts

1. Overview

Energy transactions in liberalized markets are subject to price and quantity uncertainty. This paper considers the spot price and energy generation to follow a bivariate semi-nonparametric distribution defined in terms of the Gram–Charlier expansion. This distribution allows us to jointly model not only mean, variance, and correlation but also skewness, kurtosis, and higher-order moments. Based on this model, we propose a static hedging strategy for electricity generators that participate in a competitive market where hedging is carried out through forward contracts that include a risk premium in their valuation. For this purpose, we use Monte Carlo simulation and consider information from the Colombian electricity market as the case study. The results show that the volume of energy to be sold under long-term contracts depends on each electricity generator and the risk assessment made by the market in the forward risk premium. The conditions of skewness, kurtosis, and correlation, as well as the type of the employed risk indicator, affect the hedging strategy that each electricity generator should implement. A positive correlation between the spot price and energy production tends to increase the hedge ratio; meanwhile, negative correlation tends to reduce it. The increase of forward risk premium, on the other hand, reduces the hedge ratio.

2. Electricity Trading

Electricity is usually traded in a short-term market (spot market) and a long-term market via contracts for future delivery (forward contracts). The electricity market is characterized by being highly volatile when compared to other commodity markets. This high volatility in terms of price and quantity is due to market circumstances (e.g., expectations or strategies of each company and economic dynamics) and physical conditions (e.g., climate, water availability, fuel production, or damage to the power transmission network [1]).

Electricity trading implies the consideration of three main characteristics: (i) the limitation of storage for large amounts of electricity and long periods, (ii) the technical difficulties or environmental and social restrictions for long-distance transmission, and (iii) the intensive use of capital required for expanding systems at a large scale, which presents long and uncertain payback periods. Under those conditions, multiple uncertainties exist in both the electric power system and market operation. As far as the electric power system is concerned, the need for preserving the stability of the system involves different issues—e.g., economic dispatch, unit commitment, optimal power flow and power system expansion planning—that are subject to various uncertainties, including demand variations, transmission interruptions, generator failure, fuel availability, weather conditions, as explained by [2][3], and regulatory modifications, among other causes. Those real-time conditions affect the electricity pricing and imply uncertainties over the financial results for the market agents (sellers and buyers) that can drive to significant financial losses or even bankruptcy [4]. These uncertainty levels are rising due to the increase of renewable energy sources in electric power systems [5]. All of these factors explain how reliable and economically viable operations of electric power systems depend on a collection of optimization problems to coordinate electric power systems.

To achieve the best results for electricity generators, reduce their risk levels, and reach their business objectives, they must define the quantity of electricity to be sold through forward contracts and to be traded at a spot price. It should be noted that electricity generators face price and quantity uncertainty, unlike in other types of financial products; [6] explains the spot price volatility, because electricity cannot be economically stored and must be produced instantaneously to satisfy the demand. In these circumstances, [7] considers the implications of load uncertainty that cannot be perfectly hedged applying financial derivatives. [8] describes how demand unpredictability is a regular matter for any commodity. Holding inventory is an answer to mitigate quantity risk for those commodities that can be economically stored; this is mentioned by [9] as a limitation to execute intertemporal arbitrage in electricity markets.

Quantity risk (or volumetric risk) is driven by different conditions, such as the economic cycle, fuel availability, hydrologic inflows, or climate. These conditions also affect price; hence, generated quantity and price tend to be correlated. Due to the limitations regarding electricity storage for extended periods (i.e., months or years), the cost-of-carry valuation is not applicable to value the theoretical forward price. Therefore, market agents set the forward price based on their expectations and the risks they assume, which gives rise to the forward risk premium (FRP).

This FRP has been studied by [10][11] for the Pennsylvania–New Jersey–Maryland (PJM) electricity market; [12] for the Nord Pool; [13] for the Colombian electricity market; [14] for the European Electricity Exchange (EEX); and [15] for the British electricity market [16]. The incorporation of an FRP immediately leads to a difference between the forward price and the spot price expectations. Regarding the behavior of uncertainty sources, the literature studies typically address the hedging problem in electricity markets by assuming normality either on the variables or on their logarithm. Although this is a common assumption—used by [7][8], and [17], among other authors—to properly select the number of forward contracts to hedge the risk associated with transactions in electricity markets, it presents limitations to deal with problems that involve cases of skewness and kurtosis.

Nevertheless, [18] indicates that some variables in electricity markets exhibit conditions of skewness and kurtosis and higher-order moments that are not adequately represented only using normal distributions. These authors show that semi-nonparametric (SNP) distributions allow a better fit for hydrologic inflows, spot price, and even demand for electricity data. [19] shows that SNP distributions serve to treat historical variables featuring skewness and heavy tails. [20] uses SNP modeling to describe the co-movements of price and volume in the stock market of the United States (US), and [21] also employs the SNP distribution to model returns in the US and United Kingdom (UK) stock markets. Other works that adopt SNP approaches to expand series beyond the traditional normal or lognormal distributions are those by [22], who measures the productivity of researchers worldwide, and [23], who estimates the size distribution of US firms.

In this study, we go a step further by considering the uncertain components of each electricity generator's price and energy generation understudy to follow a joint SNP distribution. [24] described this type of distribution and explained how it is estimated, and more recently [25][26] applied related densities to forecast financial variables. However, to the best of our knowledge, this is the first attempt to model electricity markets in a multivariate SNP framework. Furthermore, the joint modeling of price and quantity through a SNP distribution allows us to capture not only the correlation between both variables but also the dependence between all moment structures. All of these features pay a fundamental role on the risk positions of electricity generators and their strategies.

As a direct application of the model, we propose a static hedging strategy for electricity generators that participate in a competitive market where hedging is carried out through forward contracts that include a risk premium in their valuation. We consider the spot price and energy generation variables to follow a bivariate SNP distribution in terms of the Gram–Charlier expansion. This distribution allows us to not only model the mean, the variance, and their correlation but also the skewness, the kurtosis, and higher-order moments. We employ Monte Carlo simulation to analyze the effect of three risk indicators (standard deviation, value-at-risk (VaR), and conditional VaR (CVaR) on energy sales. We consider the Colombian electricity market as the case study, where the energy sources are predominant renewables.

The main contribution of the paper to the analysis of electricity markets is the structuring of an energy portfolio that does not impose the assumption of normality in both price and energy generation. The results show that the optimal quantity of energy to be sold through forward contracts is dependent not only on the conditions of spot price and quantity uncertainty but also on the way market agents weigh the assumed risk levels. Particularly, this methodology is used for hydropower generators affected by flow regimen aspects. Furthermore, the number of forward sales is determined by the correlation between price and energy generation and the FRP.

3. Conclusions

This paper proposes a static hedging strategy for electricity generators that participate in a competitive market where hedging is carried out through forward contracts that include a risk premium in their valuation. We considered the spot price and energy generation variables to follow a bivariate SNP distribution defined in terms of the Gram–Charlier (Type

A) expansion. This distribution allowed us to not only model the mean, the variance, and their correlation but also the skewness, the kurtosis, and higher-order moments. Moreover, we used Monte Carlo simulation to analyze the effect of three risk indicators (standard deviation, VaR, and CVaR) on the net profit from energy sales, using information from the Colombian electricity market as the case study. We found that positive correlation between the spot price and energy production tends to increase the hedge ratio; meanwhile, negative correlation tends to reduce it.

This work's main contribution is the modeling and analysis of the risk faced by electricity generators through flexible SNP multivariate distributions, as well as the structuring of a hedging portfolio that does not impose the assumption of normality on price and energy generation, which is a novelty in this academic field, where, as far as we know, multivariate semi-nonparametric technics have been used before. The performance of the model for implementing forward contracts hedging strategies is assessed though the Monte Carlo simulation of bivariate SNP pdfs and by studying the sensibility of risk measures to the different parameters affecting forward electricity markets.

In general, a negative FRP increases an electricity generator's net profit from its energy sales in the contract market, thus, favoring electricity forward sales. Moreover, the FRP affects the behavior of the mean, VaR, and CVaR indicators regarding the amount of electricity to be sold under forward contracts. This situation does not occur for the standard deviation, whose behavior, instead, is affected by the contracting level, regardless of the FRP value in the market.

The results show that the optimal quantity of energy to be sold through forward contracts is dependent not only on the conditions of spot price and quantity uncertainty but also on the way market agents weigh the assumed risk levels. Therefore, to reduce the risk levels faced by generators, such optimal quantity will depend on the conditions of price and energy generation uncertainty explained by variance, skewness, kurtosis, and higher-order moments. Furthermore, the number of forward sales is determined by the correlation between price and energy generation and the FRP, or an increment on correlation or FRP, tends to reduce the hedge ratio.

The decision-making criteria also modify the optimal hedge ratio. The VaR-maximization criterion implies a larger hedge ratio than the CVaR-maximization criterion; this criteria selection could have more impact on the optimal decision than the FRP modifications. It suggests that electricity market practitioners must pay significant attention to market conditions and the adequate risk measures that accomplish each business strategy. It is necessary to find coherence among strategy, risk aversion, and risk retention capacity.

All in all, we recommend experts in electricity markets to structure company-specific portfolios based on the market conditions on which the analysis is performed. They should also consider flexible modeling that captures a more significant number of moments than those allowed by a normal distribution for the variables involved and the correlation between the spot price and energy generation. The multivariate SNP distribution can be an appropriate tool for this purpose. As a final remark, although this work is done for a hydropower-dominated market, the convenience of this methodology for other electricity markets should be studied for further works.

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