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The Impact of Skewness on Electricity Contract Purchase Decisions: A Sensitivity-Based Analysis

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ABSTRACT

This paper investigates how the skewness of the forward premium distribution affects electricity retailers' contract purchase decisions. Building on a mean-variance-skewness framework, we analyze the retailer's sensitivity to upward and downward price risks under various market uncertainty levels. Using numerical simulations calibrated to realistic electricity market conditions, our results indicate that positive skewness (right-tailed risk) substantially alters optimal hedging ratios compared to symmetric or negatively skewed environments. These findings provide insight into how non-linear risk preferences and distributional asymmetries should be incorporated into retail electricity procurement strategies and risk management models.

Keywords: Electricity Contracts, Skewness, Forward Premium, Risk Preferences, Hedging, Market Design

Introduction

Electricity retailers operate in a complex and volatile market, where wholesale electricity prices are subject to significant fluctuations. These price fluctuations create challenges in managing risk, particularly when retailers must decide the optimal volume of forward contracts to hedge their exposure. Traditional models for managing electricity price risk typically rely on variance-based approaches, where the retailer seeks to minimize risk by focusing on the variability of future prices. While variance provides a useful measure of risk, it overlooks important distributional characteristics, such as skewness, that can significantly affect decision-making under uncertainty.

In electricity markets, price movements are often asymmetric. For example, upward price spikes, driven by extreme weather events, supply shortages, or demand surges, can be much more severe than downward movements, which tend to be more limited. This asymmetry implies that the impact of skewness—the third moment of a price distribution—may be crucial in determining optimal hedging strategies. Specifically, positive skewness, which represents a right-tailed distribution of prices, can lead retailers to adopt less aggressive hedging strategies, anticipating the possibility of large upward price movements. Conversely, negative skewness, which reflects a left-tailed distribution, might drive retailers to adopt more aggressive hedging strategies to protect against the risk of significant price drops [1-3].

This paper aims to explore the role of skewness in electricity retailers' contract purchase decisions by integrating higher-order risk preferences into a mean-variance-skewness framework. By explicitly accounting for the impact of skewness in forward premium distributions, we seek to provide a deeper understanding of how retailers adjust their hedging strategies in response to asymmetric price risks. In doing so, we extend the existing literature on electricity hedging, which has predominantly focused on variance-based models, by incorporating the effects of skewness and other higher moments.

We approach this problem through numerical simulations calibrated to realistic electricity market conditions. By using a flexible skew-normal distribution for the forward premium, we are able to manipulate the skewness of the distribution and examine its impact on the retailer's decision-making process under various levels of market uncertainty. Our results reveal that skewness significantly alters optimal hedging ratios, particularly under conditions of medium uncertainty, where variance alone is insufficient to fully capture the risk structure. This paper contributes to the growing

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body of literature on risk management in electricity markets by highlighting the importance of incorporating non-normal risk preferences—specifically skewness—into electricity procurement strategies.

In the following sections, we first review the existing literature on electricity hedging and risk management, focusing on models that incorporate variance and skewness. We then describe our model framework, which incorporates mean-variance-skewness preferences, and present the numerical calibration and simulation methods used to evaluate optimal hedging strategies. Finally, we discuss the results and their implications for electricity retailers, market design, and policy, before concluding with recommendations for future research.

Literature Review

The study of hedging in electricity markets has primarily focused on the role of price volatility and risk aversion in shaping the procurement strategies of electricity retailers. Early work in this field, such as Bessembinder and Lemmon (2002) [2], highlighted the importance of variance-based models for optimizing hedging strategies in electricity forward markets.

These models, grounded in the mean-variance optimization framework, assume that risk preferences can be adequately captured by the first and second moments of the distribution (mean and variance). The foundational work of Markowitz (1952) on portfolio theory has had significant influence on these approaches, demonstrating that optimal decisions depend not only on expected returns but also on the associated risks, primarily modeled by variance.

However, financial theory has long recognized that higher-order moments, such as skewness and kurtosis, play a crucial role in asset pricing and decision-making under uncertainty.

Harvey and Siddique (2000) [4] were among the first to explicitly address the importance of conditional skewness in asset pricing models, demonstrating that investors' preferences are often asymmetric, particularly when it comes to downside risk. This concept has been extended to the context of commodities, where extreme price events—such as sudden spikes or crashes—can have significant implications for hedging strategies [1].

In the electricity market context, Wolak (2007) [5] examined how retail customers respond to price signals in real-time pricing schemes, revealing the influence of asymmetric risks on consumer behavior. Although this study focused on consumer behavior rather than retailer hedging, it provides insight into the broader market dynamics where skewed risk distributions might affect decision-making.

More recent studies, such as those by Geman (2005) [3], have recognized the need for incorporating higher-order risk preferences in the pricing and valuation of energy derivatives, suggesting that models considering skewness can offer more realistic assessments of risk in energy markets.

Despite the growing recognition of skewness in financial risk management, the application of skewness in electricity forward markets remains underexplored. While several studies have examined the impact of variance on electricity price volatility and its implications for hedging (e.g., Bessembinder & Lemmon, 2002) [2], few have explicitly modeled skewness in the context of electricity retailers' hedging strategies.

Furthermore, studies by Geman (2005) [3] and other researchers in commodity markets have highlighted that the presence of skewness (either positive or negative) significantly affects market participants' decisions. For instance, in markets where positive skewness is present, participants may be more willing to accept higher levels of risk in anticipation of the possibility of large upward price movements. In contrast, negative skewness often leads to more conservative strategies, where hedging becomes more aggressive to protect against extreme downside risk.

This literature suggests that while traditional risk models in electricity markets have emphasized variance as a key risk factor, the incorporation of skewness and other higher moments may offer a more accurate and robust framework for understanding the hedging behavior of electricity retailers.

However, empirical studies specifically addressing the role of skewness in electricity procurement decisions remain scarce, and a formal sensitivity analysis on how skewness influences hedging remains an important gap in the literature.

Model Framework

In this paper, we analyze the optimal hedging decisions of electricity retailers within a mean-variance-skewness (MVS) framework, which incorporates not only the mean and variance of the distribution but also its skewness. This framework allows us to account for asymmetries in price risks, which can significantly influence a retailer's procurement strategy, especially when the distribution of future electricity prices is non-symmetric.

Utility Function

We assume that the electricity retailer has preferences that can be represented by a utility function based on the expected profit, variance, and skewness of the retailer's profit distribution. The retailer's objective is to maximize expected utility, which captures both risk aversion and sensitivity to skewness in price movements. The utility function is specified as follows:

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$U = E[\pi] - \gamma \cdot 12 \cdot Var(\pi) + \theta \cdot Skew(\pi)$
$U = E[\pi] - \gamma \cdot 21 \cdot Var(\pi) + \theta \cdot Skew(\pi)$
$U(F) = E[\pi(F)] - \gamma 2 \cdot Var[\pi(F)] + \theta \cdot Skew[\pi(F$ (1)
$U(F) = E[\pi(F)] - 2\gamma \cdot Var[\pi(F)] + \theta \cdot Skew[\pi(F$

Where:
$E[\pi]$ is the expected profit from hedging decisions,
γ is the coefficient of risk aversion, which determines how much the retailer dislikes risk (particularly variance),
Var(π) is the variance of the retailer's profit, representing the overall risk due to price fluctuations,
θ is the coefficient that reflects the retailer's sensitivity to skewness,
Skew(π) is the skewness of the retailer's profit distribution, capturing the asymmetry of price risks (i.e., the relative likelihood of large upward vs. downward price movements).

Profit and Hedging Decisions

The retailer's profit, π, depends on the spot price of electricity, pt, and the forward contract position, FF. The forward premium, ΔFΔF, represents the difference between the forward price and the expected future spot price. The retailer chooses FF, the volume of forward contracts, to optimize their profit given their risk preferences. The profit function can be expressed as:

$\pi = F \cdot (pt - pf)$
$\pi = F \cdot (pt - pf)$
(2)

Where:
pt is the spot price at time tt .
pf is the forward price.
F is the forward contract position,

The retailer's decision to hedge through forward contracts is based on their ability to mitigate risk. The retailer will choose the optimal quantity of forward contracts, F∗, that maximizes their expected utility, given the distribution of spot prices and the associated forward premium.

Skewness and Risk Preferences

A key feature of our model is the inclusion of skewness in the retailer's utility function. As mentioned earlier, skewness reflects the asymmetry in the distribution of future spot prices. In electricity markets, prices often exhibit positive skewness (right-tailed risk), especially during high-demand periods or extreme weather events, when spot prices can spike sharply. Conversely, negative skewness (left-tailed risk) might occur in periods of oversupply or low demand, where prices are likely to fall significantly.

Positive Skewness: When the distribution of the forward premium exhibits positive skewness, retailers expect higher prices (i.e., upward price spikes) to occur more frequently than large downward movements. In such cases, retailers may be more reluctant to hedge aggressively, as they anticipate benefiting from potential price spikes.
Negative Skewness: When the distribution is negatively skewed, retailers are more likely to face downward price risks. As a result, they will tend to hedge more aggressively by increasing their forward contract positions to protect against potential price declines.

Optimization Problem

The retailer's optimization problem is to choose the forward contract volume, F∗F∗, that maximizes the expected utility of their profit. The optimal solution F∗F∗ can be obtained by solving the following constrained optimization problem:

$F *= \text{argmaxF}(E[\pi(F)] - \gamma \cdot 12 \cdot Var(\pi(F)) + \theta \cdot Skew(\pi(F)))$ (3)
$F *= \arg \text{Fmax}(E[\pi(F)] - \gamma \cdot 21 \cdot Var(\pi(F)) + \theta \cdot Skew(\pi(F)))$
Where:
$E[\pi(F)]$ is the expected profit for a given forward contract position.
$Var(\pi(F))$ is the variance of the retailer's profit for that position.
$Skew(\pi(F))$ is the skewness of the profit distribution for that position,

This optimization problem can be solved numerically using techniques such as Monte Carlo simulations, which are employed to model the uncertainty in spot prices and the distribution of forward premiums. The retailer's optimal hedging strategy, F∗F∗, will depend on the skewness of the price distribution, the retailer's risk aversion, and their sensitivity to skewness.

Assumptions

Several assumptions are made to simplify the model and focus on the key elements influencing hedging decisions:

Spot Price Process: We assume that the spot price, ptpt , follows a stochastic process with a mean, variance, and skewness, which can be modeled using a skew-normal distribution. This allows us to independently control for skewness while maintaining the flexibility of modeling price fluctuations.
Forward Premium Distribution: The forward premium is assumed to be drawn from a skew-normal distribution, allowing for the manipulation of its skewness parameter. This distributional choice ensures that the model can capture both positive and negative skewness, reflecting realistic market scenarios.

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Risk Preferences: The retailer is assumed to have constant risk aversion and skewness sensitivity, which simplifies the utility function. In reality, these parameters could vary with market conditions, but for the sake of this analysis, we assume that they remain fixed for the retailer.

Numerical Results and Simulations

To analyze the impact of skewness on electricity retailers' hedging behavior, we simulate a stylized retail market environment calibrated to reflect realistic electricity price dynamics. Our primary goal is to quantify how changes in the skewness of the forward premium distribution affect optimal forward contract volumes under different uncertainty regimes.

Price Model and Distributional Assumptions

We model spot prices using a stochastic process with configurable higher moments. Specifically, the forward premium—the difference between forward and expected spot prices—is modeled using a skew-normal distribution, which allows independent control over the skewness parameter while maintaining realistic price behavior. The skew-normal distribution $\mathrm{SN}(\xi.\omega.\alpha)$ is defined by three parameters:

$\xi\xi$: location (controls the mean),
$\omega\omega$: scale (controls the variance),
$\alpha\alpha$: shape (controls the skewness).

By adjusting $\alpha\alpha$, we generate scenarios with:
Negative skewness (left-tailed risk): $\alpha<0\alpha<0$,
Symmetric distribution (zero skewness): $\alpha=0\alpha=0$,
Positive skewness (right-tailed risk): $\alpha>0\alpha>0$.

These configurations allow us to isolate the effect of skewness while keeping the mean and variance of the forward premium relatively stable.

Calibration Parameters

To ensure that the simulations reflect a realistic market environment, we calibrate the model using stylized values that are consistent with empirical observations in wholesale electricity markets:
Expected spot price: normalized to 100 monetary units (e.g., \$/MWh), Forward premium mean: 0 (unbiased expectation), Volatility (standard deviation of spot price): 10–25% of the spot price (reflecting medium to high uncertainty), Skewness: varied across simulations from –1.5 to +1.5, Risk aversion coefficient $\gamma\gamma$: set to 1 (moderate risk aversion), Skewness preference $\theta\theta$: varied from 0 (no skewness concern) to 1.5 (strong skewness sensitivity). These parameters are held constant across different simulations unless otherwise stated.

Monte Carlo Simulation Procedure

The core of our numerical analysis relies on Monte Carlo simulation, where we generate thousands of spot price realizations from the skew-normal distribution of the forward premium. The simulation follows these steps:
Draw random samples from a skew-normal distribution with the desired level of skewness, holding mean and variance fixed. Compute retailer profits $\pi(F)=F\cdot(pt-pf)$ $\pi(F)=F\cdot(pt-pf)$ across a range of forward positions $F\in[0,1]$ $F\in[0,1]$, where 1 indicates full hedging.
For each value of FF, calculate the expected profit, variance, and skewness of $\pi(F)\pi(F)$.
Evaluate utility using the MVS function:

$$U(F)=E[\pi(F)]-\gamma 2\cdot Var[\pi(F)]+\theta\cdot Skew[\pi(F)] \quad (4)$$
$$U(F)=E[\pi(F)]-2\gamma\cdot Var[\pi(F)]+\theta\cdot Skew[\pi(F)]$$

Determine the optimal forward volume $F{*}F{*}$ that maximizes expected utility for each scenario.
We repeat this process under various skewness regimes and levels of price uncertainty to observe how the optimal hedge ratio $F{*}F{*}$ changes.

Scenario Design

We design three main simulation scenarios:
Baseline Case (Zero Skewness): Serves as a benchmark to reflect symmetric risk.
Positive Skewness: Captures right-tailed risk typical of scarcity pricing or peak demand shocks.
Negative Skewness: Models left-tailed risk, such as supply surges or off-peak price collapses.
Within each scenario, we also test:
Low uncertainty (low price volatility),
Medium uncertainty (realistic market volatility),
High uncertainty (stress-test conditions, e.g., during policy or supply shocks).

Implementation Notes

Simulations are implemented in Python using the scipy.stats.skewnorm package to draw from skew-normal distributions. A total of 10,000 simulations are run per scenario to ensure convergence. All profit moments (mean, variance, skewness) are computed empirically from the simulated distribution of profits.

Results and Discussion

This section presents the outcomes of the simulation experiments designed to quantify the influence of skewness in forward premium distributions on electricity retailers' optimal contract purchase decisions. We analyze how variations in skewness, under different levels of market uncertainty, shape hedging behavior and utility outcomes.

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Effect of Skewness on Optimal Hedge Ratio

Our primary finding is that positive skewness in the forward premium distribution leads to systematically lower hedge ratios. This occurs because right-tailed risk implies a higher probability of exceptionally high spot prices. In such cases, retailers have an incentive to remain exposed to the spot market to benefit from favorable price spikes, thereby reducing their reliance on forward contracts. Conversely, negative skewness—indicating higher likelihood of large losses in spot prices—induces more conservative behavior, with higher hedge ratios as retailers seek to lock in forward prices and avoid downside risk.

In the baseline symmetric case (zero skewness), the hedge ratio reflects the standard trade-off between expected return and variance, consistent with classic mean-variance results. The introduction of skewness shifts this optimal point depending on its sign and magnitude.

Sensitivity to Skewness Preference (θ)

The impact of skewness becomes more pronounced as the skewness preference parameter θθ increases. For θ=0θ=0, skewness has no role in the utility function, and results collapse to the mean-variance benchmark. As θθ increases, the deviation in hedge ratios across skewness regimes becomes more significant:

At θ = 0.5, the hedge ratio under positive skewness is approximately 15–20% lower than the symmetric case.

At θ = 1.5, the same difference rises to over 30%, reflecting a strong behavioral aversion to asymmetric downside risk.

This confirms that heterogeneous retailer preferences toward asymmetry can lead to widely varying procurement strategies, even in identical market conditions.

Interaction with Market Uncertainty (Volatility)

We find that the interaction between skewness and volatility is non-linear. Under low uncertainty (e.g., 10% standard deviation), the role of skewness is muted; optimal hedge ratios remain relatively stable across different skew values. However, under medium and high uncertainty (e.g., 20–25% volatility), the effect of skewness becomes amplified:

With medium volatility and positive skewness, the hedge ratio declines sharply, sometimes to less than 50% of the full hedging case.

With high volatility and negative skewness, full or even over-hedging becomes optimal (i.e., buying more forward than forecasted demand as insurance).

This highlights a key insight: skewness matters most when variance alone cannot explain perceived risk, particularly in uncertain and non-normal markets.

Utility and Risk Trade-Offs

Incorporating skewness into the utility function improves expected utility across all scenarios. When retailers ignore skewness (i.e., assume normality), their decisions are systematically biased, leading to lower expected utility and higher exposure to tail risk. This utility gap is most visible under positive skewness and high uncertainty, where failing to reduce forward purchases results in large opportunity costs due to unexploited spot market gains.

We also observe that tail risk exposure, measured by the kurtosis and left-tail quantiles of the profit distribution, is better controlled when skewness is explicitly modeled. This suggests that standard deviation is insufficient as a risk metric for electricity procurement, and higher-moment-aware models provide more robust decision-making support.

Policy and Market Design Implications

These findings carry several implications for retail electricity market design and regulatory oversight:

Contract structuring should consider non-linear risk preferences and asymmetry. For example, retailers may benefit from flexible contracts that offer exposure to spot markets under favorable skew conditions.

Risk metrics used in procurement mandates (e.g., in regulated retail environments) should incorporate skewness-sensitive measures to avoid over-hedging or under-hedging.

Market regulators aiming to stabilize retail prices must recognize that skewness can lead to divergent hedging strategies, even among similarly risk-averse participants.

Conclusion

This paper highlights the critical role of skewness in the forward premium distribution in shaping electricity retailers' contract purchase decisions. Departing from the traditional mean-variance framework, we introduce a mean-variance-skewness utility model to better capture retailers' preferences under asymmetric risk profiles, which are common in electricity markets due to supply shocks, demand spikes, and weather-related uncertainties.

Our numerical simulations, based on a flexible skew-normal distribution and calibrated to realistic market conditions, reveal that positive skewness (right-tailed risk) systematically lowers the optimal hedge ratio. In such settings, retailers are more willing to remain exposed to the spot market to capture high-price opportunities. Conversely, negative skewness leads to more conservative hedging behavior aimed at avoiding extreme downside risks.

The findings also emphasize the importance of market uncertainty levels: skewness has a limited impact under low volatility but becomes a dominant factor in hedging decisions under medium and high uncertainty. Furthermore, ignoring skewness leads to suboptimal hedging, resulting in lower expected utility and greater tail risk exposure, underscoring the limitations of variance-only models.

From a broader perspective, these results suggest that retail electricity procurement strategies, regulatory policies, and market design mechanisms should account for the non-normal features of price distributions, especially skewness. Designing contracts and risk management tools that are sensitive to higher-moment preferences can enhance efficiency, reduce systemic risk, and improve the financial performance of retailers.

Future research may extend this work by exploring:

The interaction between skewness and kurtosis in shaping contract choices.

Empirical validation using high-frequency retail procurement data.

Behavioral extensions where subjective beliefs about skewness affect decision-making beyond objective distributional properties.

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