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GARCH-based put option valuation to maximize benefit of wind investors

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HIGHLIGHTS

- We propose a methodology of put options pricing for users investing in wind projects.
- ARIMA–GARCH models for forecasting electricity prices are used to capture second-order effects.
- Pricing derivatives considers conditional heteroskedasticity and martingale behavior.

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ABSTRACT

A method based on Empirical Martingale Simulation (EMS) is presented to evaluate investments in wind energy. Risk-neutral prices are calculated, where electricity market prices are modeled using an ARIMA–GARCH method which shows conditional heteroskedasticity. The values of the put options are calculated a week ahead and it is observed that wind producers that invest in the options market can hedge against price risk and can also maximize their benefits. The use of Monte Carlo simulation with the EMS method in periods of high volatility is especially useful for investors facing price volatilities in order to improve their returns. The model is applied to the Colombian electricity market.

1. Introduction

In the last decade many countries have started the process of deregulation of their electrical systems, in particular transmission and distribution grids. The process has been accompanied by a rapidly growing presence of small generators of various technologies, especially renewable energy sources [1], with goals such as the reduction of greenhouse gas emissions and reliability [2]. Efficient integration of distributed generation requires network innovations, new communication technologies at all levels [3–6], implementation of technologies that involve dispatch with intermittent sources [7–9]. These activities require their own financial evaluation before implementation [10].

In this way, recent research has been focused on renewable sources integration in pool-based electricity markets in order to identify the optimal placement and size of renewable resource investments [11–14], or to assess the future impact of renewable generation [15].

In this context the users should make better decisions suited to their circumstances, therefore, it is relevant to study risk management decisions faced by them. Several studies have been conducted to define hedging instruments for users with distributed generation, either by replacing the fuel typically used for generation with renewable sources [16], or by reducing or shifting consumption [17,18], in which case energy storage devices may contribute viably [19].

1.1. Literature review: price forecasting and put options

The main characteristics of energy prices are: seasonal patterns, peak rates, mean reversion, price-dependent volatilities and non-stationarity in the long term [20]. Pricing models have been developed to capture these characteristics, for which different analysis techniques have been used.

Analysis techniques that have been used to model price series are: Markov regime changes [21–24], GARCH models [25,26],

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Nomenclature

A. Parameters

ϕ_i	autoregressive parameter i
Φ_i	seasonal autoregressive parameter i
θ_i	moving average parameter i
Θ_i	seasonal moving average parameter i
h	height at which wind speed is estimated in m
h_0	reference height in m
α	parameter for different types of soil roughness
k	shape parameter of the Weibull distribution
c	scale parameter of the Weibull distribution
ρ	air density in kg/m^3
Area	surface perpendicular to the wind flow in m^2
r	risk-free rate in %
T	maturity date of option set in 7 days
a	annual discount rate in %
n	project lifetime of a wind project in years
V_0	reference wind speed at height h_0 in m/s
Rate	regulated fixed fee to be paid by the wind producer in €/MWh
CE	energy produced used for consumption of user in kWh
d	option price in €/MWh
SE	energy produced injected into the network in kWh

B. Variables

P_{wb}	electricity price for week w and block b in €/MWh
K	average wind cost in €/kWh
P_t	electricity price at time t in €/MWh
ε_t	error at time t
σ_t	volatility estimated by GARCH at time t
error	forecast error
OMC	operation and maintenance cost in €
AC	annual cost of a wind project in €
I	level of investment of a wind project in €
v_t	wind speed at time t in m/s
$V(h)$	wind speed at height h in m/s
EG_{hmn}	energy generated in hour h of month m for each series n in kWh
v_{hmn}	wind speed at hour h of month m and series n in m/s
ET_y	total energy produced in year y in kWh
ND_m	number of days of month m
EG_{hm}	average energy produced in hour h of month m in kWh

neural networks [27], and stochastic processes [28–30]. In particular, GARCH models have been instrumental in the valuation of derivatives. These types of models were initially proposed by Bollerslev [31] and their main characteristic is the existence of conditional heteroskedasticity, which means that the structure of the conditional variance depends not only on past errors but on past conditional variances.

The main goal of having these price models is the valuation of financial instruments for hedging against price risk. A particular instrument for hedging is the Financial Option, which is one of the most widely used derivative contract types. This financial option gives the holder the right, but not the obligation, to buy (call) or sell (put) an underlying asset at a fixed price at some time in the future.

In order to find the fair price of the financial option, Black and Scholes [32] derived an equation for option pricing based on the principle of no arbitrage. This principle implies the existence of a martingale measure equivalent to the actual probability measure, under which the asset price discounted at the risk-free interest rate is a martingale. A martingale is a stochastic process without a trend. One consequence is that its expected value is constant. This probability measure is also known as "risk-neutral probability".

The Black–Scholes equation [32] was developed under the assumption that fluctuations in underlying asset prices are described by an Itô process, and that volatility is constant. These two assumptions have been relaxed in different studies. Some studies have suggested that the asset instantaneous changes follow an ARMA process; option pricing models have been applied, except that the constant volatility is dependent on the AR and MA parameters [33]. In the latter work, the authors find that if the sum of the AR and MA parameters is zero, option pricing using the ARMA model provides the same results as the Black–Scholes model. They conclude that using the Black–Scholes formula to price the option is correct even if the stock price follows an ARMA process. Otherwise, if the sum of the AR and MA parameters is greater than zero (or less than zero), option pricing using Black Scholes undervalues (overvalues) ARMA option prices.

Stochastic volatility has been modeled in continuous and discrete time [34–36]. Continuous models have assumed the existence of correlation of the stochastic processes involved (asset price and volatility) [35], as well as risk neutrality. Discrete models assume that the variance follows a GARCH model. Under this assumption the authors derive a closed-form expression to calculate the value of European options in Heston and Nandi [36]. This theoretical development has generated conflicting results [37,38]. Given these controversies, most researchers have opted for Monte Carlo simulation in the valuation of derivatives. A weakness of this tool is that the simulated price paths do not have the martingale property. Due to this difficulty, in Duan and Simonato [39] they have made a simple correction to the standard procedure used in Monte Carlo simulation, which ensures that the simulated price trajectories are martingales in an empirical sense. This correction is called Empirical Martingale Simulation (EMS). The authors have applied their proposal for European and Asian call options using both the Black and Scholes and GARCH option pricing frameworks. The consistency of the estimator of the option price using the EMS method has also been tested [40]. The authors define the EMS correction as a recursive scheme because the payment of the option or the dynamics of the underlying asset price can be path-dependent, so the simulation must be carried out recursively until the expiration of the option.

Huang [41] has extended the EMS procedure from a risk-neutral context to a dynamic measure, P, which he calls P-Empirical Martingale Simulation (EMPS). The author proposes to generate a process of change of measure and the objective is to ensure that the simulated processes of the underlying asset price and the values of the change of measure are both empirical P-martingales. The author explains that the EMPS method is more lexile and ;[42] under risk neutrality, especially when an explicit expression of the risk-neutral model is not readily available.

Based on the EMPS method [41,42] have conducted an empirical study to investigate the performance of GARCH models in the context of option pricing. These authors outlined the procedure for calculating option prices under GARCH with: (i) adjustment of the GARCH model with historical prices, (ii) transformation of the dynamics from a GARCH model to a risk-neutral GARCH, and (iii) calculation of the option prices with Monte Carlo under a risk-neutral GARCH model.