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Using neural networks and extreme value distributions to model electricity pool prices: Evidence from the Australian National Electricity Market 1998–2013

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A R T I C L E I N F O

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A B S T R A C T

Competitors in the electricity supply industry desire accurate predictions of electricity spot prices to hedge against financial risks. Neural networks are commonly used for forecasting such prices, but certain features of spot price series, such as extreme price spikes, present critical challenges for such modeling. We investigate the predictive capacity of neural networks for electricity spot prices using Australian National Electricity Market data. Following neural net modeling of the data, we explore extreme price spikes through extreme value modeling, fitting a Generalized Pareto Distribution to price peaks over an estimated threshold. While neural nets capture the smoother aspects of spot price data, they are unable to capture local, volatile features that characterize electricity spot price data. Price spikes can be modeled successfully through extreme value modeling.

1. Introduction

Australia's economic success relies heavily on the reliability of electricity supply, as 72.3% of electricity is consumed by the business sector, including commercial, mining and metals. More than 90% of electricity is generated by the burning of fossil fuels, with a massive 81.1% generated by brown and black coal, a resource abundantly available in Australia, but one whose use has dire environmental effects. Australia's rich quantity of fossil fuels has provided the nation with relatively cheap production (in monetary terms) of electricity to the world's longest interconnected power system, spanning approximately 5000 km from Queensland to South Australia.

Deregulation of Australia's electricity supply industry in 1997/1998 saw the privatization of existing state utilities. These were split into sub-organizations that operated separately from each other and focused on one of generation, transmission or retail of electricity. The idea was to introduce competition and efficiency into the marketplace through wholesale electricity trading. This deregulation paved way for the National Electricity Market (NEM), a wholesale market supplying electricity to retailers and end-users. Currently more than $A10 billion of electricity is traded annually in the NEM to meet the demand of more than 8 million end-use consumers.

The major responsibility of the NEM is to ensure that the supply of electricity meets demand as competitively and efficiently as possible. Consisting of five regions making up the eastern states of Australia, the NEM operates wholesale trading by instantaneously matching supply against demand through a pool system, which then determines the most cost effective solution to meet demand. Electricity is sold in dollars per megawatt-hour (MW h). Each megawatt is equal to one million watts and each megawatt hour is equal to the amount of energy required to power ten thousand 100-watt light globes for an hour.

Dispatch instructions are sent to selected generators at five-minute intervals by matching five-minute-ahead expected demand with half-hourly supply bids. Generators submit offers to supply differing quantities of energy for each five-minute period in a day at particular prices, twenty-four to forty-eight hours in advance. This is done via the pool where they are chosen to dispatch energy in order of increasing price. The half-hourly regional pool price is set at the beginning of a period and is calculated as the average of the six five-minute pool prices that make up the half-hourly period. The five-minute pool price is set to be the price of the last unit of electricity required to meet regional demand at that time. The spot price, quoted in dollars per megawatt-hour ($/MW h), is what retailers pay and generators receive for the amount of electricity traded in that half-hour period. This is set to be the average of the regional pool prices.

Since electricity cannot be stored for future use and generators are obliged to produce enough electricity to meet the demands of

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retailers and end-users at any time, market prices vary drastically, resulting in price spikes during periods of very high demand and even negative prices during periods of very low demand. During periods of extremely high demand, all generators may be called by the NEM to dispatch full loads, resulting in generators supplying electricity at full capacity and for the highest possible price. Currently the NEM caps the highest allowable price at $A12,500 per MW h, an amount known as the Market Cap Price. The reason generators are willing to pay the NEM to dispatch electricity during off-peak times is due to the time and cost of switching the generator off and on again – thermal units cannot be power cycled on short notice, and energy must be supplied continually.

Price volatility is also subject to bidding strategies, marginal costs, extreme weather conditions or shifts in demand and quantities available for supply. Generator outages, planned or unplanned, will cause shifts to the supply curve, which will in turn cause prices to rise above the mean for that particular demand period. Without the Market Cap Price, prices could be potentially infinite, because in the short term retailers are indifferent to these costs.

Interconnectors supply electricity between states allowing for inter-regional trade when there is price disparity between regions, or when supply is not able to meet demand in that particular region. There are limits to the quantity of electricity able to flow across an interconnector, so prices between regions can still differ greatly. Interconnectors are privately operated separately from the other supply arms and some are regulated while others are not. The deregulated interconnectors must rely on wholesale trading to earn revenue. This added competition in the trading market further encourages price volatility.

As a result of these many influences that affect price behavior, electricity prices are extremely challenging to model, and traditional time-series models as well as more modern statistical methods such as neural networks have been used to forecast short-run prices. This paper investigates the ability of the nonparametric neural network model to capture the volatility described previously, in the context of half-hourly electricity spot price data from December 7, 1998 to January 1, 2014 – over 250,000 data values – for each of the five regions comprising Australia's National Electricity Market (NEM): New South Wales, Victoria, Queensland, South Australia and Tasmania.

Short term or next day forecasts are crucial to generators who can utilize accurate information to devise next day bidding strategies in order to maximize returns. The retailers of electricity require this information to hedge against large prices since they charge their customers standard amounts for electricity consumption throughout the day. Hedging against this extra cost allows retailers to maximize their revenue, as periods of high demand cost the retailer more than it charges. In the short term, a retailer may achieve this if it has the ability to operate on self-production.

Derivative securities based on half-hour spot prices are used to mitigate the financial risks for both the generation and retail sectors. The pricing of derivative securities in general requires the specification of a no-arbitrage price process that is used to define replicating strategies for the derivative. However, the usual no-arbitrage pricing methods fail in this case since unlike other commodities, electricity cannot be stored and the value of derivative contracts cannot be replicated by trading in the underlying commodity. It thus should be emphasized that while nonparametric models may be effective forecasting tools leading to informative decision making when deciding what derivative contract to trade in for the purpose of insuring against downfall, they cannot be used explicitly to formulate trading strategies.

This paper focuses on building a short-term pricing model using neural networks. In doing so, it assesses the prediction potential of neural networks on time dependent data, with the inclusion of other explanatory variables. It does not employ the usual parameter estimation techniques used in classical statistical models and therefore provides an alternative to parametric models. The main departure from standard statistical models is its ability to deal with non-linear behavior. Neural networks are able to map any complex smooth function through their use of many weights or parameters. This feature results in some drawbacks, e.g. lack of interpretability and overfitting. The main aim of the model building exercise is to achieve the highest amount of prediction accuracy possible. This results in choosing a model based on its ability to minimize prediction error for a validation set based on a model built on training data.

Unfortunately, the prospects for the routine use of neural nets in predicting electricity spot prices are not promising, based on our investigation. The tendency for infrequent but extremely high price observations that are of unpredictable timing and size is characteristic of electricity price data, and neural nets seem unable to adequately capture the timing and size of such spikes. Therefore, we adopt an extreme value modeling approach to price spikes that are not captured by our neural net model, fitting a Generalised Pareto Distribution (GPD) to the peaks-over-threshold price spike process that is not captured by the neural net model. This modeling provides an understanding of the price spike process, including estimation of an appropriate threshold and a probability model for the peaks over that threshold. Explicitly modeling the stochastic features of the price spike process is a critical part of understanding the nature of price spikes, with the neural net model providing an adequate fit to the "smooth" remainder of the data.

2. Background

The use of neural networks to predict electricity demand, load and price has attracted significant attention in the energy literature, as practitioners have sought to move beyond traditional econometric approaches to prediction in such settings. The attractions of nonparametric statistical learning techniques are that they offer flexible modeling of non-linear behavior and require little in the way of distributional assumptions.

Metaxiotis et al. [15] surveyed the use of artificial intelligence techniques in electricity load forecasting, a problem that is directly related to electricity price forecasting. The use of neural nets in electricity load forecasting is widespread, with that survey paper containing 34 of 76 references that were obviously related to neural net forecasting. There have been many other papers promoting the use of neural nets in forecasting electricity load; also see the review paper by Hippert et al. [12] and the references therein. Hybrid methods that combine neural net approaches with other feature extraction techniques such as wavelet methods to capture sharper features of the data have also been considered – see, for example, Bashir and El-Hawary [3]. Note, however, that the extreme spikes found in electricity spot-price data are not so prevalent in electricity load data.

Chang and Minjun [5] was an early paper suggesting that neural networks were a promising approach for real-time price prediction in electricity markets. They proposed fitting a neural net based on inputs such as load, previous prices and some weather variables, using price data from the Victorian Power Exchange. They reported that the modeling was "feasible and effective", also basing this assessment on simulated data. Sapeluk et al. [27] and Ramsay and Wang [23] presented other early attempts to use neural nets in this context, to model UK electricity pool prices.

Yamin et al. [31] considered the use of neural nets in modeling short-term electricity prices for the California power market using data for the first nine months of 1999. They concluded that the use of neural nets was an effective approach to accurately model the price data, but they modeled data for which price spikes had been deliberately limited or excluded. The notion of excluding price spikes clearly makes the problem of predicting electricity prices