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Forecasting next-day price of electricity in the Spanish energy market using artificial neural networks

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Abstract

In this paper, next-day hourly forecasts are calculated for the energy price in the electricity production market of Spain. The methodology used to achieve these forecasts is based on artificial neural networks, which have been used successfully in recent years in many forecasting applications. The days to be forecast include working days as well as weekends and holidays, due to the fact that energy price has different behaviours depending on the kind of day to be forecast. Besides, energy price time series are usually composed of too many data, which could be a problem if we are looking for a short period of time to reach an adequate forecast. In this paper, a training method for artificial neural nets is proposed, which is based on making a previous selection for the multilayer perceptron (MLP) training samples, using an ART-type neural network. The MLP is then trained and finally used to calculate forecasts. These forecasts are compared to those obtained from the well-known Box–Jenkins ARIMA forecasting method. Results show that neural nets perform better than ARIMA models, especially for weekends and holidays. Both methodologies calculate more accurate forecasts—in terms of mean absolute percentage error—for working days that for weekends and holidays. Agents involved in the electricity production market, who may need fast forecasts for the price of electricity, would benefit from the results of this study.

Keywords: Electricity market; Time series forecasting; Neural networks; Box–Jenkins; Backpropagation network; ART network

1. Introduction

This paper analyses the behaviour of energy price and demand variables on the Spanish electricity production market, and then proceeds to calculate price forecasts. The methodology used to obtain these forecasts is based on artificial neural networks (ANNs), which have been used successfully in recent years in many forecasting applications (Zhang et al., 1998). Forecasts obtained using this methodology are tested against forecasts calculated with Box–Jenkins (BJ) ARIMA models. The paper focuses on short-term forecasting, as the time series to be forecast is the next-day hourly energy price. Such forecasts could be of key importance for the agents involved in the Spanish electricity production market.

In the last few years, many papers have applied ANNs to short-term electricity demand forecasting (Pack et al., 1991b; Ho et al., 1992; Chen et al., 1992; Peng et al., 1992; Chow and Leung, 1996; Vermaak and Botha, 1998). Other studies calculate forecasts for temperature variables as a necessary step towards good electricity demand forecasting (Khotanzad et al., 1996; Gonzalez and Zamarreño, 2002). Yet, there is a dearth of studies on electricity markets: Nogales et al. (2002) and Contreras et al. (2003) have analysed the Spanish electricity market to achieve next-day electricity price forecasts. In particular, Contreras et al. (2003) use the ARIMA methodology to analyse Spain and California electricity markets.

The paper is structured as follows: Section 2 analyses the workings of the electricity market in Spain; Section 3 provides an overview of ANNs forecasting methodology; Section 4 describes the time series that are analysed in this study and the structure of the ANNs used to forecast. Section 5 discusses the results of forecasts compared with

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actual data. The paper is rounded off by Section 6, which draws relevant conclusions from the study.

2. Spain's electricity market

This section provides an overview of Spain's electricity production market functioning. More detailed descriptions of this market can be found at AFI (1998) and CNSE (1997, 1999). The Spanish electricity production market is a spin-off of the liberalisation process in the electricity sector in Spain. This electricity market is a stock exchange where purchase and sales operations are negotiated. Energy producers and energy purchasers both attend this stock exchange, presenting and matching purchasing and selling prices for electricity, establishing prices (once every hour), and settling the issue of negotiating quantities to be bought and sold by the market's different agents.

The fact that electricity cannot be stored means that amounts sold, amounts bought and amounts consumed must all coincide each and every time. There must thus be a number of mechanisms and devices to link the commercial side of the business (buying and selling) and its technical side (generating and consuming electricity), so that they are compatible.

The role of the daily market—an integral part of the electricity generation market—is to handle electricity transactions for the day after calculations are made. Sellers' offers are presented to the market operator and are included in a 24-h programmed matching process for the day following the one when the offer was made, which is divided into 24 consecutive programme periods.

Once the electricity purchase and sales offers have been received, checked and accepted (they must be received before 10 am every day), they are matched by the market operator, who calculates the marginal price and shares out production and demand amongst parties involved in the auction. The process can be either simple or complex, depending on whether all the offers are simple or whether there is a mix of simple and complex offers.

The basic working daily programme (BWDP), announced at 11:00 am, is the outcome of the above process of matching electrical supply and demand. Market operator determines the technical restrictions that have to be applied to the BWDP by using the information in the BWDP, the offers presented by the agents and the bilateral contracts that have been signed. The results from this process are sent to the system operator, who draws up the provisional feasible daily programme (PFDP) at 2 pm.

Transactions from the corrected matching and decisions on technical restrictions are forecasts that are unlikely to occur 100% of the time. Unforeseen circumstances may arise, such as breakdown of the electricity generating unit, the distributing unit or the transmission lines, a higher or lower than expected local temperature, or simply a forecasting mistake.

Furthermore, the electricity system is unable to exploit intermediate storage, which might have resolved the problem. As a result, the system operator must have production units that can either increase or decrease their production in response to demand. This spectrum of available power is called the secondary regulation service, and is used to respond to unforeseen events like those already mentioned. The result is called the final feasible daily programme (FFDP).

The electricity production market offers stakeholders the opportunity to modify their buying and selling positions, by participating in the inter-daily market, made up of six sessions held between 4 pm and 12 noon on the following day. Purchase and sales offers are matched each session, leading to the final timetable programme (FTP) after analysis and implementation of relevant technical restrictions.

One final point has to be highlighted: the Spanish electricity production market has been functioning for just eight years, and for the first two years it was partially regulated. As a result, sometimes prices were established externally instead of being matched as a result of the process reviewed above.

3. Forecasting with artificial neural networks

Before the early 1920s, forecasts were calculated by simply extrapolating time series. What might be dubbed as "modern forecasting" began in 1927, when Yule presented auto-regressive techniques to forecast the annual number of sun spots (Yule, 1927). His model calculated forecasts as a weighted sum of previous data. If good performance was to be achieved from this linear system, an external factor called noise had to be catered for, as this noise affects the linear system. This linear system with noise was widely used for the next 50 years, when research culminated in the ARIMA methodology proposed by Box and Jenkins (1970).

From this point onwards, strongly theory-based studies focused on non-stationary and/or non-linear series: bi-linear, bi-spectral or threshold models are examples of this to name but a few (Tong, 1983, 1990; Priestley, 1988; Tsay, 1991; Subba Rao, 1992).

During the 1980s, two crucial developments took place that changed time series research. On the one hand, ever-increasing capacity and enhanced features of personal computers meant that much longer time series could be handled and more sophisticated algorithms could be used. This went hand in hand with a second aspect—the development of machine learning techniques, such as ANNs.

ANNs are mathematical models based upon the functioning of the human brain, and are composed of three different layers—input, hidden and output layers—each of which are composed of a certain number of neurons. The literature explains certain characteristics of ANNs that make them particularly useful for forecasting time series. Two might be mentioned here: the ability to approximate practically any function (even non-linear