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Short-term forecast of daily curves of electricity demand and price

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ABSTRACT

The features of the electricity, as well as the rules of the competitive electricity markets, create the need of accurate predictions of electricity demand and price in order to anticipate decisions. Mainly, the prediction task in energy markets has been studied in the literature with the aim of obtaining scalar (hourly, daily, ...) forecasts given scalar (and/or, less frequently, functional) historical data. This paper provides two methods to predict next-day electricity demand and price daily curves given information from past curves. They are based on using robust functional principal component analysis and nonparametric models with functional both response and covariate. In addition, the nonparametric proposal is extended to incorporate, in a linear way, exogenous scalar covariates. Results of these methods for the electricity market of mainland Spain, in year 2012, are reported. Their accuracy is compared with that of a naïve method as well as with the corresponding to combining forecasts. Scalar versions are also included in the comparative study. This work extends and complements the methods and results in Vilar et al. (2012), focused on scalar forecasts.

Introduction

Electricity demand and price forecasting is an important task for the agents and companies involved in the electricity market. The features of the electricity, that is a non-storable product, and also the rules of this competitive market create the need of accurate predictions of electricity demand and price in order to anticipate decisions. Traditionally, three types of forecasts are considered, according to the forecasting horizon's duration: short-term forecasts (this is 1 day ahead hourly forecasts), mid-term forecasts (several days ahead predictions for daily data) and long-term forecasts (one or more years ahead). In addition, a wide range of methodologies and models for forecasting are given in the literature. Some methods are based on statistical models (regression [2], time series [3], etc.) while other ones are based on computational intelligence models (neuronal networks [4], fuzzy neural networks [5], support vector machines [6], etc). See the book by Weron [7] for a nice monograph on electricity demand and price forecasting. See also [8,9] for reviews on electricity demand forecasting and electricity price forecasting, respectively.

Most of the works in the literature related to model and forecast electricity demand and price take information from scalar variables; that is the case of researches referred in the previous paragraph. Over the recent years, the use of functional data has spread to a large number of areas, including the energy markets. Functional data analysis (FDA) is a branch of statistics that analyzes data providing information about curves, surfaces or any other mathematical object varying over a continuum, often time. These curves are defined by some functional form and are known as functional data. The paper [10] offers a short tutorial as well as partial survey of the state of the art in FDA theory. The books [11,12] are nice general references for FDA from a linear modeling point of view, while the monograph [13] is devoted to nonparametric methods in the functional data context. See also [14] for a recent monograph on inference for functional data. Models for functional data were also used in the statistical literature to predict electricity demand and price. On the one hand, focusing on forecasting daily curves of electricity demand, the reader will find in [15] a parametric model to predict electricity consumption curves in Sardinia; [16] introduced a novel functional time series methodology that is applied to historical daily curves of load in Cyprus; [17] proposed a hybrid approach which was applied to French demand curves. See also [18,19] for procedures based on functional principal component analysis with applications to load data of South Australia and Germany, respectively, and [20] for the case of residual demand curves in Spain. On the other hand, when the interest is to forecast scalar values (not curves) from functional data, the reader can see [21], where the case of hourly electricity price forecasting is dealt, or [1] where, in addition, hourly electricity demand forecasting is considered. See also [22] for peak load forecasting.

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The aim of this paper is next-day forecasting of daily curves of electricity demand and price. Three approaches, taking information from a single endogenous functional covariate, are considered, as well as models including, in addition, exogenous scalar covariates. Combined forecasts are also implemented. Forecasts for the corresponding daily curves in the market of mainland Spain, year 2012, are obtained.

This paper can be seen as an extension in two ways of the proposal given in [1]. The first extension is related to the response in the models: [1] considered both nonparametric and partial linear models with scalar response (hourly electricity demand or price) and functional covariates. Meanwhile this paper deals, among others, with those same models but considering functional response (daily electricity demand or price curve). The second extension takes part in the information managed by the partial linear model: while [1] did not consider exogenous covariates, this paper will take into account information from weather variables and wind power production.

The rest of the paper is organized as follows. Section 'The data' presents the main features of electricity data, both demand and price. It also contains information about the exogenous variables used for prediction, temperature and wind power production. In Section 'Some approaches to forecast curves', the methods involved in the study are described. Such methods, as well as their combinations, are applied in Section 'Functional forecasting in action' for next-day forecasting of the daily curves of electricity demand and price in each day in year 2012. Finally, some conclusions and open questions are given in Section 'Conclusions and perspectives'.

The data

Our goal is next-day forecasting of the daily curves of electricity demand and price corresponding to mainland Spain, year 2012. Some information will be taken from past curves (endogenous functional variables). In addition, exogenous scalar covariates could be used. Specifically, our database contains information related to years 2011 and 2012: hourly observations of electricity demand and price, maximum daily temperature and daily wind power production. Then, each daily functional datum comes from the 24 hourly observations of demand or price in each day (note that smoothing techniques are used to convert the 24 hourly data in a functional observation). Scalar covariates are related to daily demand, temperature and wind power production.

This section presents the data involved in the application of the different methods included in this paper. First, we present the electrical data, both demand and price, used in the predictions and their main features. Then, also temperature and wind power production are described, as they are used as exogenous variables.

Electrical data

Data corresponding to electricity demand and price were collected in a database. Our data source was OMIE (Operador del Mercado Ibérico de Energía), which is the Market Operator. Together with System Operator, REE (Red Eléctrica de España), they compose the Regulators of the Electricity Sector in Spain. OMIE recorded the transactions of the electricity market since 1998, year of the deregulation of the market.

Historical demand (MW h) for the year 2012 in Spain, as both time series and sets of curves, can be seen in Fig. 1. Main features of electricity demand can be summarized in the daily and weekly seasonality, the calendar effect on weekend and also the presence of outliers. Plotting weekday's (from Monday to Friday), Saturday's and Sunday's daily curves separately, one can easily distinguish their different behavior. In the weekend the demand decreases due to the reduction in the industrial production and the change of the workers routine. Also there are a little difference between Saturdays and Sundays, cause in Sundays the demand has the lowest values of the week. This property of the data forces us to adapt the models for each kind of day. Therefore, some considerations will be taken in order to distinguish the predictions for a weekday, a Saturday or a Sunday.

Along the year also the demand varies, possibly due to the different climate, among other reasons. This can be seen in Fig. 2, where each quarter of the year is represented separately and, within each quarter, weekdays are plotted in black and weekend in red. Again, it is easy to see the different behavior in the demand of a weekday and in the weekend. Moreover, during the first and the fourth quarter of the year, when the weather is cold, the demand is generally higher than in the middle of the year. Last quarter also seems to be more unstable and variable than the rest of the year.

Electricity price shares some of the characteristics with the demand. However, it has some particular properties. The most notable one are the days with zero price. Looking at the time series of the electricity price (Cents/kW h) along 2012 in Fig. 3, one can see some days in which price decreases, reaching value zero. This is the real price obtained in the bidding of the daily market of the energy. The price decreases in some days due to the overproduction of wind power. In Spain, renewable energies are subsidized and have a preferential position in the auction, entering free of charges. For that reason, when the production of wind power increases, the price generally decreases, even until zero. There are also some variations in the behavior of the weekdays and the weekend, but it is not as significant as in the demand.

Daily curves for the electricity price remains in the same values along the year but, as in the demand, the last quarter of the year corresponds to a turbulent period in the market in which the variation is higher and so, the forecasting becomes a quite difficult task.

Jointly, both demand and price present some outliers that have to be identify in order to prevent misleading predictions. For that purpose, we use some tools to detect outliers in functional time series taking into account the dependence in the data, which is the case of the electricity data. Methods presented in [23,24] were applied to our data and the identified outliers were replaced by weighted moving average. Specifically, each identified outlier was changed by the weighted moving average of the four closest curves (in a temporal sense) in the same class that the identified outlier, the weights being 0.3 for the two closest and 0.2 for the other two. Note that, as a byproduct of this procedure, the effect of the public holidays that occur on the weekdays is avoided (or attenuated). As pointed out by a referee, another possible way to handle this is to use a functional clustering algorithm, as done in [25] in the context of modeling hourly traffic.

Temperature

Temperature has a high influence in the electricity demand; so, it can contribute to improve their predictions. In this study we consider the maximum daily temperature (°C) in Spain. AEMET (Agencia Estatal de Meterología) provided us the maximum daily temperature for each province of the country. By population-weighted average, we built the corresponding maximum daily temperature for Spain. Population data were collected from INE (Instituto Nacional de Estadística).

It is worthy to highlight the nonlinear effect of meteorological variables on the electricity demand. In the left panel of Fig. 4, one can see that the effect of the maximum daily temperature over the daily mean demand is U-shaped. This nonlinear relation has to do with the use of the heating, when the temperature is low, and