Computational Statistics and Data Analysis 56 (2012) 3459–3476

Contents lists available at SciVerse ScienceDirect

Computational Statistics and Data Analysis

journal homepage: www.elsevier.com/locate/csda

Modelling and forecasting wind speed intensity for weather risk management

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ARTICLE INFO

Article history:
Received 9 December 2009
Received in revised form 17 June 2010
Accepted 17 June 2010
Available online 3 July 2010

Keywords:
Gamma Auto Regressive
Auto Regressive Gamma
ARFIMA–FIGARCH
Wind speed modelling
Wind speed simulation
Weather risk management

ABSTRACT

The main interest of the wind speed modelling is on the short-term forecast of wind speed intensity and direction. Recently, its relationship with electricity production by wind farms has been studied. In fact, electricity producers are interested in long-range forecasts and simulation of wind speed for two main reasons: to evaluate the profitability of building a wind farm in a given location, and to offset the risks associated with the variability of wind speed for an already operating wind farm. Three approaches that are capable of forecasting and simulating the long run evolution of wind speed intensity are compared (wind direction is not a concern, given that the recent turbines can rotate to follow wind direction). The evaluated models are: the Auto Regressive Gamma process, the Gamma Auto Regressive process, and the ARFIMA–FIGARCH model. Both in-sample and out-of-sample comparisons are provided, as well as some examples for the pricing of wind speed derivatives using a model-based Monte Carlo simulation approach.

1. Introduction

Wind conditions represent a relevant source of risk for every wind farm. The risk exposure can be associated with two elements that characterize the wind: the overall wind speed, or wind speed intensity, and the wind direction. However, most turbines currently built have mechanisms for automatic rotation of blades in the appropriate wind direction. Therefore, in practice, the most relevant weather exposure of wind farms can be measured by analyzing only the wind speed intensity (an approximation is included since blade rotation is not immediate). In order to mitigate this wind risk, we often use insurance contracts or wind derivatives, making a direct connection between atmospheric elements, financial markets, and economic implications. For a survey of the literature on wind risk evaluation and modelling; see Brix et al. (2005).

From a meteorological point of view, wind speed intensity is just one of the variables generally modelled to provide robust short-term weather forecasts. However, for the purpose of wind risk evaluation, on the one hand, we need long-term forecasts and simulations, while, on the other hand, the interest in weather variables other than wind may be limited. As a result, meteorological models are not appropriate for long-range wind speed intensity forecast and simulation, while statistical approaches are viable. The scientific literature includes some contributions on that topic, for example, Brown et al. (1984), Castino et al. (1998), Aillot et al. (2006), and Møller et al. (2008), among others. However, few authors have yet considered the economic and financial point of view; that is, studying problems associated with the modelling of wind speed intensity for evaluating wind risks, and for the pricing of wind derivatives (see, for instance, Leroy, 2004; Yamada, 2008).

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doi:10.1016/j.csda.2010.06.019

In this framework, the main interest is in the evaluation (even by simulated methods) of a wind index, which is a transformation of wind speed intensity into a quantity proportional to the energy power potentially produced by a turbine over a given period. Simple and naïve approaches focus on low frequency (from monthly to yearly, usually) wind data time series. These data are fitted with an unconditional density, which we then use to simulate wind speed paths. In turn, these paths determine simulated wind indices. However, these unconditional approaches fail to consider the periodic evolution of wind speed intensity, or the presence of serial correlation. We can capture both of these features by alternative methods based on higher frequency data. Moreover, the normality assumption of wind indices is questionable.

Our present paper contributes to the weather derivatives and environmental finance literature in several ways. First, we consider a set of models that capture serial correlation; these have already appeared in scientific contributions, but generally in different contexts. We consider the ARFIMA–FIGARCH model of Beine and Laurent (2003), as used in many frameworks including financial time series analysis, as well as for the study of average temperature sequences, see Caporin and Prés (2009). We adapt the ARFIMA–FIGARCH model to the logarithms of wind speed intensities, adding periodic deterministic components to capture the yearly seasonal cycle. We then consider two competing approaches that introduce serial correlation in Gamma densities: the Gamma Auto Regressive (GAR) model of Tol (1997) (already used by the author to model wind speed intensity) and the Auto Regressive Gamma (ARG) of Gourieroux and Jasiak (2006), which has been proposed for modelling intertrade durations.

Our second contribution is to provide a methodology for comparing wind speed models by focusing on both in-sample and out-of-sample model performances. In-sample, we compare the model fit with traditional statistical methods. Out-of-sample, we compare the alternative models and specifications using both one-step-ahead wind speed point and density forecasts, as well as in terms of the model's ability to simulate the evolution of wind indices. This last element will provide fundamental results, given that wind indices are the relevant element for the pricing of contracts covering wind risks. From a different point of view, the ability to simulate wind indices will also be interesting for the identification of optimal locations for wind farm construction. All of the considered models, approaches, and methods we will compare using a number of daily wind speed intensity time series obtained from meteorological stations based in Poland. By simulation based methods we will verify the model performance, and we will provide theoretical prices of wind derivatives, comparing these to the ones provided by simpler unconditional methods.

This paper differs from other contributions on wind speed modelling in a number of ways. Firstly, we do not base the models on data transformations, such as the Box-Cox in Brown et al. (1984), but on actual original data, for which we postulate a specific stochastic structure whose components have a direct interpretation. In detail, we assume that wind speed intensities are function of periodic deterministic components and of stochastic components. As a result, we incorporate serial correlation in stochastic processes, defined over a positive support. Secondly, the models we propose are able to capture the yearly seasonal evolution of wind speed and, with generalization, can capture intra-daily periodicity created, for instance, by the differences between day and night wind speed intensities. However, the dataset we consider in the empirical analysis contains only average daily wind speed intensities, and thus we are not able to recover intra-daily patterns. The empirical results of our work show how alternative models appropriately fit historical data, while their forecasting performances may differ.

The paper proceeds as follows: Section 2 introduces the modelling approaches and the techniques we consider for model comparison. Section 3 presents the empirical estimates of the models and a first comparison across these. Section 4 compares the fitted model within a wind risk management framework. Section 5 concludes the paper.

2. Modelling wind speed intensity

Meteorological stations measure wind speed intensities and direction at regular frequencies, typically in minutes. These data present a superimposition of several elements: the stochastic nature of the series evolution, the intra-daily periodic evolution governed by the alternation of day and night, and the long-term seasonal component driven by the sequence of seasons. The models we propose in this paper appropriately capture these components. All of the models we consider presume that the periodic components are purely deterministic and we could filter these out a priori, before modelling the underlying stochastic process. We note that we could follow alternative approaches. For instance, by assuming a stochastic nature of the periodic components, we could specify a GARMA processes as in Guégan and Diongue (2009), or Periodic ARMA models, see Lund and Basawa (2000), Basawa and Lund (2001), and Roy and Saidi (2008), or, finally, models based on Markov chains, possibly with a limited number of states. Alternatively, removing the impact of leap years, yearly differencing could be considered as an approach for deseasonalization, and SARIMA models could be taken into account. The evaluation of our modelling approach with those considering stochastic periodic components is left to future researches. In this paper we focus on the stochastic nature of the seasonally adjusted series.

In the following section, we describe the structure of the periodic evolution of wind speed intensities and show possible ways to estimate and filter out this component. The subsequent sections will then introduce the alternative models (dealing with their structure, estimation and simulation), and the approaches for their comparison.

2.1. Periodic component

We consider two alternative specifications of the periodic deterministic component: the first is multiplicative and we apply it to wind speed levels (we can also recast it into an additive periodic function using logs); the second models the