Applied Energy 216 (2018) 132–141

Contents lists available at ScienceDirect

Applied Energy

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

Usefulness of economic and energy data at different frequencies for carbon price forecasting in the EU ETS

Xin Zhao[a,b], Meng Han[a], Lili Ding[a,b,*], Wanglin Kang[c]

[a] School of Economics, Ocean University of China, China
[b] Marine Development Studies Institute of OUC, Key Research Institute of Humanities and Social Sciences at Universities, Ministry of Education, Beijing, China
[c] School of Economics and Management, Shandong University of Technology and Science, China

HIGHLIGHTS

- A real-time forecast procedure is established to predict the weekly carbon price.
- Combination-MIDAS models provide better performance than traditional models.
- Mixed frequency economic and energy data are useful to forecast carbon price.

ARTICLE INFO

Keywords:
Carbon price
MIDAS regression
Forecast combination

ABSTRACT

This paper presents a real-time forecasting procedure that utilizes multiple factors with different sampling frequencies to predict the weekly carbon price. Novel combination-MIDAS models with five weight-type schemes are proposed for evaluating the forecast accuracy. The evidence shows that combination-MIDAS models provide forecasting performance gains over traditional models, which supports the use of mixed-frequency data that consist of economic and energy indicators to forecast the weekly carbon price. It is also shown that, *Coal* is the best predictor for carbon price forecasting and that forecasts that are based on *Crude* have similar trends to actual carbon prices but are higher than the actual prices.

1. Introduction

Global climate change, which has been a hindrance to the economic development and human health, is attracting increased attention. Its negative impact is predominantly manifested as a decline in economic welfare. For example, droughts and degraded water quality due to climate change have diminished the food supply. Reduced carbon dioxide emissions are generally accepted as part of the solution to the climate change problem. The Kyoto Protocol, which came into force on February 16, 2005, specifies the greenhouse gas emission reduction targets that were established by developed and industrialized countries. In April 2016, the Paris Agreement, which is a new global climate agreement, was signed to plan a global response to climate change after 2020. Essentially, these global emission reduction agreements put forward strategies for the marketization of carbon emissions.

To more efficiently control the amount of carbon dioxide emissions, the European Union Emission Trading Scheme (EU ETS) was established to implement a pricing mechanism for carbon dioxide through an emission allowance. Through this marketization, policy makers give firms an incentive to move towards clean-energy or less-fossil-fuel-intensive production. One main issue in the market is the accurate prediction of carbon prices to form significant references. First, information on carbon price prediction and a good grasp of its determinants are important for all market participants, such as carbon traders, brokers and firms, who use price information to manage and hedge their portfolios. Second, as the carbon price reveals information on marginal abatement costs, policy makers can assess climate policy and adjust the emission cap [1]. Therefore, more accurate carbon price forecasts are critical for establishing a more robust and reasonable carbon market, which could also facilitate the pricing of other carbon financial products, e.g., carbon futures and carbon options. This paper studies carbon price forecasting since many puzzles remain to be solved by researchers through empirical work, especially concerning the adjustment of carbon prices according to the economic environment and energy market.

The growing academic literature on carbon price forecasting has focused on two major perspectives. Some scholars forecast carbon price trends are based on time-series data using price-only forecasting

* Corresponding author.
E-mail address: llding@ouc.edu.cn (L. Ding).

https://doi.org/10.1016/j.apenergy.2018.02.003
Received 14 October 2017; Received in revised form 1 February 2018; Accepted 2 February 2018
0306-2619/

models. In the literature, the autoregressive integrated moving average (ARIMA) model is one of the most popular models for forecast carbon price. However, the ARIMA model can only reflect linear changes. In practice, the carbon price is always characterized by nonlinear patterns. The generalized autoregressive conditional heteroscedasticity (GARCH) models, empirical mode decomposition (EMD) models and computational intelligence techniques (CITs) perform well in forecasting carbon prices because of their ability to reflect nonlinearity.

In recent years, extended models that are based on GARCH have been introduced for improving the precision. Markov regime-switching GARCH (MS-GARCH) outperforms other Markov regime-switching or simple GARCH models [2], although the differences in forecast precision between GARCH and other regime-switching models are very small [3]. However, GARCH models require the standard returns to be normally distributed, which is not true of financial series. To address this drawback, the heterogeneous autoregressive model of the realized volatility (HAR-RV) is applied to forecast carbon futures prices with high accuracy [4]. Markov-switching multifractal models can provide a simple uniform framework for both long-term persistence in volatility and structural breaks through regime switching. Recently, these models have been applied to forecast the volatility of carbon price and have produced more accurate results than GARCH models [5].

EMD is a self-adaption data analysis approach that is suitable for nonlinear and nonstationary time series. It can decompose time series into several intrinsic mode functions and a residue from different scales and reconstruct them into various components. The forecasts of the components can be integrated into a carbon price forecast. Several models have been combined with the EMD model to forecast carbon prices. Artificial neural networks (ANNs) that are trained by genetic algorithms (GAs) (GAANNs) are used to forecast the components and have been shown to outperform single random walk (RW), ARIMA, ANN and GAANN models without EMD preprocessing, and the ARIMA model with EMD preprocessing [6]. In addition, least squares support vector regression (LSSVAR) is applied to forecast each mode of EMD and the forecasts are added to the final results, which show that the EDM-LSSVAR-ADD model outperforms ARIMA, LSSVAR and their hybrid [7]. The combination of GARCH and EMD preprocessing also improves the precision [8].

Additionally, computational intelligence techniques are used to predict carbon prices. Multilayer perceptron (MLP) neural network prediction models show good performance in forecasting carbon prices with strong nonlinearity [9]. Moreover, the neuro-fuzzy controller forecast system, which is called PATSOS, outperforms ANN and an adaptive neuro-fuzzy inference system because the PATSOS model can form a closed-loop feedback mechanism [10]. In addition, other types of models are used to forecast carbon prices. The combination of the group method of data handling (GMDH), particle swarm optimization (PSO) and least squares support vector machines (LSSVM) (GMDH-PSO-LSSVM) is utilized to predict carbon prices with improved forecast accuracy [11]. A novel hybrid methodology that combines the strengths of LSSVM and the ARIMA model has also been established for forecasting carbon futures prices [12].

The above price-only forecasting models represent predictive technology systems for carbon price. These models ignore relative factors, which causes a decline of prediction accuracy. The price of carbon is classically determined by the balance between supply and demand in the market [13,14]. On the supply side, the carbon allowances are allocated by National Allocation Plans (NAPs), which are harmonized at the EU level by the European Commission. On the demand side, the use of allowances is a function of many factors, which can affect the expected carbon dioxide emissions, e.g., economic activities and energy prices [15]. Analysts explicitly recognize that the energy market plays a central role in shaping the carbon prices under current market conditions. The reason is that marginal fuel-switching costs from highly carbon-intensive sources of energy, e.g., coal, to less-carbon-intensive sources for power and heat generation, e.g., gas, form an important determinant of the carbon price [16–18]. The demand for allowances can also be affected by economic activities [19–21]. As economic activities increase, associated carbon emissions increase and, therefore, lead to demands for higher carbon emission allowances by firms to cover their carbon emissions.

In this light, several papers have indicated the importance of the information that is contained in economic and energy data for forecasting and monitoring carbon prices. They still focus on ARIMA and GARCH models in examining the relationship among these data [22]. We call the corresponding models multi-factor forecast models. Chevallier introduces two dynamic factors, which are extracted from a factor-augmented VAR model into GARCH model as exogenous regressors, for forecasting the volatility of European Union Allowances (EUAs): EUA futures and the CER futures carbon price [23]. Byun and Cho confirm that the GARCH model that includes Brent oil, coal and electricity prices has higher precision than GARCH model without these variables [24]. Although the multi-factor forecast models consider the influences of exogenous variables, they are used to forecast the carbon prices under the premise of forecasting the exogenous variables at the same frequencies. These models will unavoidably result in the problem of error accumulation, which will result in inaccurate carbon price predictions. In practice, the related data may be published at different frequencies, such as annually, quarterly, monthly and daily. The current research shows that the effective information that is carried by high-frequency data is neglected when forecasting carbon price. Hence, it is necessary to explore new methods for using the effective information that is contained in high-frequency exogenous variables to improve the accuracy of carbon price forecasts.

This paper introduces the mixed data sampling (MIDAS) regression models for forecasting carbon price, which consist of time-series regressions that allow the regressand and regressors to be sampled at different frequencies. The MIDAS approach, which was proposed by Ghysels et al. in 2004 [25], is derived based on the distributed lag model. MIDAS regression models have been widely used to analyze financial markets [26–28] and macroeconomic problems. e.g., GDP [29], CPI [30] and inflation [31]. This approach was developed in this area to explain financial or macroeconomic variables at low frequencies (e.g., annually or quarterly) with high-frequency explanatory variables based on monthly, daily or intra-daily data. Compared with the traditional methods of frequency conversion, MIDAS method has the following two advantages. One is that high-frequency data can be fully utilized to avoid substantial loss of sample information, thereby enhancing the forecast accuracy. The other one is that, by using the latest revealed high-frequency data, the real-time forecasts can be performed. However, there are few comparative studies that use MIDAS regression models to analyze carbon prices. Interestingly, a similar mixed data analysis is needed for the carbon price forecast problem. Typically, the change trend of carbon price over a long horizon is more important to risk managers and options traders, even though most papers study short-term forecasting, such as daily forecasting. Therefore, our paper utilizes a set of mixed-frequency data in forecasting the weekly carbon prices. The reasons are two-fold: First, the main traders (e.g., electricity generation firms) in the carbon market are concerned with the change of carbon price over a long horizon because it enables them to optimize their trading strategies. The planning horizon for electricity generation firms typically spans weeks. Hence, models are needed that can forecast the average weekly carbon price. Second, the weekly carbon price forecast has more practical significance for policy makers for ensuring the stable development of the carbon market.

The aim of this paper is to develop a combination-MIDAS regression model to perform real-time forecasts for weekly carbon price, using the latest revealed high-frequency economic and energy data. The main contributions can be categorized into two aspects. Firstly, this paper analyzes the forecasting interactions among carbon price, economic and energy variables at the mixed frequencies, and assesses the nowcasting performances of the combination-MIDAS regression models by