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Using computational intelligence to forecast carbon prices

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ABSTRACT

European Union has introduced the European Trading System (ETS) as a tool for developing and implementing international treaties related to climate changes and to identify the most cost-effective methods for reducing greenhouse gas emissions, in particular carbon dioxide (CO_2), which is the most substantial. Companies producing carbon emissions must effectively manage associated costs by buying or selling carbon emission futures. Viewed from this perspective, this paper provides a model for managing the risk by buying and selling carbon emission futures by implementing techniques that leverage computational intelligence. Three computational intelligence techniques are proposed to provide accurate and timely forecasts for changes in the price of carbon: a novel hybrid neuro-fuzzy controller that forms a closed-loop feedback mechanism called PATSOS; an artificial neural network (ANN) based system; an adaptive neuro-fuzzy inference system (ANFIS). Results are based on 1074 daily carbon price observations collected to comprise a useful time-series dataset and for evaluation of the proposed techniques. The extra-sample performance of the proposed techniques is calculated. Analysis results are compared with those produced by other models. Comparison studies reveal that PATSOS is the most accurate and promising methodology for predicting the price of carbon. It is stated that this paper registers a first attempt to apply a hybrid neuro-fuzzy controller to forecasting carbon prices.

1. Introduction

An organization's ability to achieve its business objectives and its financial well being can be seriously affected by environmental risk. Existing and forthcoming legislation and regulations can influence an organization's financial performance. EU-ETS was introduced in 2005 to address the problem of growing greenhouse gas emissions. ETS represents a major milestone in the EU climate policy, being the first large-scale policy aiming to reduce global emissions, and it remains the largest one to date [1,2]. As of 2013, ETS policy has been followed by 31 countries being applied to more than 11,000 factories, power stations, and other installations with a net heat excess of 20 MV. These installations are collectively responsible for close to half of EU's CO_2 emissions and 45% of its total greenhouse gas emissions [3].

Corporations and their directors and officers are at increasing environmental risk of facing serious financial cost for not properly addressing EU environmental issues. Policies outlined by EU affect costs incurred by those companies to which the policies are applied. For example, the price of carbon emissions represents a new asset class called 'carbon emission allowances'. Like any other commodity, carbon emission allowances may be bought and sold in international markets. Companies that generate carbon emissions through their production activities can reduce costs by strategically buying or selling emission allowances and their futures. As such, carbon prices as well as predictions thereof are of critical importance to certain companies, brokers, traders, and investors. Thus, market investors with knowledge of and access to accurate carbon price forecasting models could benefit, in principle, by following efficient trading strategies with reduced risk leading to potentially better investment decisions [4].

Given the utility of an effective forecasting tool, researchers have developed several methods for forecasting outcomes associated with complex, real-world, nonlinear problems. For example, new data-driven models that incorporate bio-inspired computational algorithms have been developed. These new models are commonly referred to as computational intelligence (CI) based models and methods [5,6].

In this paper, three CI based techniques, a hybrid neuro-fuzzy controller system (PATSOS), an ANFIS and an ANN, are used to forecast the short-term carbon future prices. Using well-established measures of statistical error, the accuracy of each technique is evaluated and compared to the accuracy of other researchers' models.

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Further, the trading results of the PATSOS model are used to offer effective Buy and Hold strategies.

The contributions of this research may be summarized as follows: (i) Development and implementation of fuzzy logic and neuro-fuzzy controllers applicable to price carbon forecasting. (ii) Development and implementation of closed-loop feedback control to account for uncertainties associated with forecasting carbon prices (dynamic behavior). (iii) Although forecasting of carbon prices has become an increasingly popular subject for practitioners and academics, there has been little empirical work to investigate the most effective models. Moreover, there has been limited research using hybrid models. This paper uses and implements such models to forecast carbon prices. (iv) This research represents a first attempt to use a hybrid ANFIS to forecast carbon prices. (v) The paper includes (for the first time) a carbon forecasting model that is evaluated by comparing the results of a simulating trading period with a Buy and Hold strategy. (vi) Reported research fundamentally extends and supplements the growing empirical literature on carbon price forecasting. Overall, this paper presents a novel tool to manage and evaluate environmental risk companies face because of EU legislation related to carbon emissions. The use of the proposed model contributes to managing the cost of carbon emissions. The proposed model is a computational model that may be tuned and used in diverse disciplines to support decision making in similar problems.

The rest of the paper is organized as follows: Section 2 focuses on literature review closely related to carbon price forecasting. Section 3 describes the proposed techniques. Section 4 centers on describing the used dataset and on reporting obtained results. Sections 5 and 6 discuss and concludes the paper.

2. Literature review

Although many academic researchers and business practitioners have recently begun to show great interest in carbon emissions price forecasting, there exists limited literature on the topic. Zhu and Wei [7] used root mean square error (RMSE) and Dstat as criteria to evaluate and compare the hybrid ARIMALSSVM2 model with the single ARIMA, ANN and LSSVM models, as well as the hybrid ARIMALSSVM1, ARIMALSSVM3, ARIMASVM and ARIMA ANN models. Byun and Cho [8] explored the specification of different GARCH-type models to forecast the volatility of carbon futures. Garcia-Martos et al. [9] sought to develop a joint model which incorporates fuel price, CO_2 emission allowances, and electricity prices. They used a VARIMA approach to forecast the prices and the univariate modeling of each series. Following this, they compared the results they generated in terms of forecasting error. Similarly, Chevallier [10] developed a forecasting model to gauge the volatility of futures carbon prices using two dynamic factors as exogenous regressors. Benz and Truck [4] analyzed the short-term spot price behavior of CO_2 emission allowances under the new CO_2 emissions trading system implemented by the EU. Pastorekova and Zapletal [11] have developed a GARGH model to predict the prices of emissions allowances. Still other models have been developed and described by Chevallier [12–16] where he has proposed a future carbon price forecasting model based on macroeconomic and energy dynamics. Feng et al. [17] use random walk models and methods derived from physics and mechanical research, such as chaos theory, to examine the nonlinear dynamic behavior of the carbon price. Fezzi and Bunn [18] illustrate that energy prices and the EUA price can mutually influence each other. Hintermann [19] presented a structural model of the allowance price under the assumption of efficient markets; he examined the extent to which this variation in price can be explained by marginal abatement costs. Wei et al. [20] contend that it was an over-allocation of emission permits as well as the inability to bank and carry these permits into Phase II, which led to the significant downward pressure on price. Daskalakis et al. [21,22] provide evidence that the prohibition on banking EUAs between Phase I and II had a significant impact on derivative pricings in their study of the Powernext, the Nord Pool and the European Climate Exchange (ECX). They argue that the prohibition on banking permits between phases resulted in additional uncertainty and hedging costs for market participants. This additional uncertainty runs counter to that of the primary goals of emissions trading; that emission reductions are achieved at the lowest possible cost. Mansanet-Bataller et al. [23] presented a model to forecast daily carbon emissions price changes in an attempt to examine the underlying rationality of pricing behavior based on weather and non-weather variables. Paolella and Taschini [24] claim that the differences in carbon intensity for coal and gas could potentially change the way companies run their power plants. Moreover, knowledge of the statistical distribution of emission trading allowances, and its forecastability, becomes crucial in constructing optimal hedging and purchasing strategies in the carbon market. This paper provides an in-depth analysis of available data addressing the unconditional tail behavior and the inherent heteroskedastic dynamics in the returns on the emissions allowances. Alberola et al. [25] prove that higher EUA prices can lead power generators to switch from coal to natural gas installations. This in turn leads to an increase in demand and price for natural gas. This relationship is determined by the dispatch order power companies employ to minimize their costs. Viteva et al. [26] analyze the forecasting accuracy of the implied volatility of options on futures contracts for the delivery of CO_2. They demonstrated that option-applied volatility is highly informative about the variance of the returns and the accuracy predicting the directionality of the prices. Perez-Suarez and Lopez-Menendez [27] present a model based on the Extended Environmental Kuznets Curve and the Environmental Logistic Curve to forecast and explain the CO_2 emissions in different countries. Wu et al. [28] examine the relationship between energy consumption, urban population, economic growth and CO_2 emissions in the BRICS countries by using a multi-variable gray model.

Although there has been limited research related to forecasting the price of carbon emissions, a number of scholars have developed forecasting models and applied them to other commodities (see Azadeh et al. [29]; Hu et al. [30]; Jammazi and Aloui [31]; Kaboudan [32]; Kohzadi et al. [33]; Li et al. [34]; Malik and Nasereddin [35]; Pang et al. [36]; Parisi et al. [37]; Yu et al. [38]; Atsalakis et al. [39]).

The above studies illustrate various attempts to model and forecast the price changes of carbon emission prices. They examine the carbon prices from a risk management or econometric perspective to find out the relationships between the prices and related economic variables like the cost of energy prices, weather events, temperature etc. Here we extend the carbon market literature with an investigation of applying a computational intelligence hybrid model named PATSOS, based on historical prices, to forecast carbon prices, and correspondingly whether profitable strategies can be identified by trading carbon emissions according to the proposed model forecasts.

3. Experimental methods

Fuzzy logic is considered one of the most important CI methods being capable of handling inexact and uncertain information [40]. A fuzzy inference system that employs “if-then” rules can model qualitative aspects of human knowledge and reasoning processes without using quantitative data or analysis. Ruan and Kerre have presented a detailed overview of if-then rules in computational intelligence [41]. Thus, fuzzy logic is applicable to diverse practical