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Forecasting Chinese carbon emissions from fossil energy consumption using non-linear grey multivariable models

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ABSTRACT

Much theoretical and empirical research has verified the non-linear and uncertain relationships between carbon emissions and economic growth. To forecast the carbon emissions from fossil energy consumption, this paper introduces the power exponential term of the relevant variables as exogenous variables into a multivariable grey model. Under the target of minimisation of the mean absolute percentage error, two non-linear programming models are constructed to solve the unknown parameters of the non-linear grey multivariable model. In addition, to enhance the adaptability of the grey model to large sample sizes, we divide the data of Chinese gross domestic product and carbon emissions from fossil energy consumption of 1953–2013 into 15 stages. The empirical results show that the non-linear grey multivariable model can reflect the mechanism of the non-linear effects of gross domestic product on carbon emissions from fossil energy consumption, and has higher forecast accuracy than the traditional grey model and the autoregressive integrated moving average models. In three schemes – economic growth at low, medium, and high, speeds – we use the non-linear grey model to quantify future Chinese carbon emissions from fossil energy consumption from 2014 to 2020, and the predicted results can provide the basis for energy planning and the formulation of environmental policy.

1. Introduction

Along with continuous economic development, energy consumption is increasing, and the problem of global warming is becoming more serious. It has gradually become the common concern and focus for all countries to address climate change, reduce carbon emissions, and develop their low-carbon economies. Since Chinese reform and opening of her economy, the Chinese economy has exhibited rapid growth, however, it has been accompanied by the uncontrolled consumption of energy and the indiscriminate discharge of carbon dioxide and other pollutants that have triggered a series of environmental and ecological problems, especially, the problem of high carbon emissions from fossil energy consumption which is increasingly prominent. High carbon emissions have resulted in multi-scale, all-round, multi-level influences and damage. It is a direct factor causing global warming, the greenhouse effect, and extreme weather including frequent hurricanes, flood disasters, and high temperatures. As global warming accelerates, glaciers melt more rapidly, which gives rise to an annual increase in sea level. The environment is thus severely damaged. In addition, tense international relationships and local conflicts will become more frequent. Moreover, the greenhouse gases emitted by high carbon emissions tend to harm human health and quality of life. To deal with the increasingly serious environmental problems, at the UN Climate Change Summit in 2009, the Chinese Government proposed the goal that the carbon emissions per unit GDP in 2020 would be 40%–45% lower than that in 2005, and the government also proposed the goal by which carbon emissions per unit GDP should decrease by 17% compared with 2010 during the "12th Five-Year" for the first time: this formed a constraining index on the long-term planning for national economic development. To achieve the goal by which Chinese carbon emissions should peak in 2030, the government set another constraining index such that the carbon emissions per unit GDP should decrease by 18% during the "13th Five-Year Plan", and also proposed that energy consumption per unit GDP should decrease by 15% in the 13th Five-Year Plan. As the problem of global warming is increasingly serious, China is facing great pressure to

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reduce emissions.

The use of energy, especially fossil energy consumption, is the main reason for rapidly increasing carbon dioxide emissions. According to the IPCC's findings, the carbon dioxide emissions from fossil fuels discharged into the atmosphere have been more than 95% of global carbon dioxide emissions since the period of industrialisation. Hence, to analyse the relationship between carbon emissions and economic growth, and forecast Chinese carbon emissions from the fossil energy consumption forms a significant reference for the relevant government departments as they formulate medium-, and long-term development strategies and adjust current policy: these can also provide the basis for the realisation of the 2020 emission reduction targets.

The main purpose of this paper is to forecast the trend of Chinese carbon emissions from fossil energy consumption on the basis of estimating the non-linear influence of Chinese economic growth on the carbon emissions from fossil energy consumption. The rest of this paper is organised as follows: the second part is a review of the literature related to this research; the non-linear grey multivariable models and its solution are presented in the third part; in the fourth part, the efficacy of the new method is verified by a classic case; the predictive analysis of carbon emissions from fossil fuel in China is presented in the fifth part; finally, the conclusions from the research are summarised.

2. Literature review

As climate change has become a topic of universal global concern, scholars, in various countries have proposed different theories and mathematical models to research carbon emissions from different perspectives. Now, we will review the relevant literature from three aspects: the relationship between carbon emissions and economic growth, the forecasting of Chinese carbon emissions, and the grey forecasting method.

2.1. Relationship between carbon emissions and economic growth

The relationship between carbon emissions and economic growth is actually a special case of environmental quality and economic development. Research into the relationship between carbon emissions and economic growth is mainly based on the hypothesis of the Environmental Kuznets Curve (EKC).

Panayotou (1993) proposed the Environmental Kuznets Curve (EKC) for the first time, and the relationship between environmental quality and per capita income was called an EKC. Schmalesee et al. (1998) researched the relationship between carbon dioxide emissions and per capita income in developed countries, and they thought that carbon dioxide emissions and per capita income did cause an inverted U-type of EKC. According to the hypothesis of the EKC, He and Richard (2009) used the methods of half parametric and non-linear parametric modelling and they found that economic growth was actually profitable and beneficial to environmental quality beyond a certain point, which could be conducive to supporting the hypothesis of an EKC. On the other hand, some scholars found that there is an inverted U-type EKC between economic growth and carbon dioxide emissions (Arouri et al., 2012; Hamit-Haggar, 2012; Saboori et al., 2012). In addition, Galeotti et al. (2006) and Wang et al. (2011) found there is evidence of an N-shaped model. A monotonically increasing model is verified by Haghnejad and Dehnavi (2012), and Alkhathlan and Javid (2013).

Besides, some scholars used a co-integration test, the Granger causality test, to research the relationship between carbon emissions and economic growth. Fodha and Zaghdoud (2010) used time series data and co-integration analysis to verify the EKC. Wu et al. (2013) thought that fossil energy consumption is the main source of carbon dioxide emissions, by calculating carbon dioxide emissions from fossil energy and using a co-integration test and a Granger causality test, it was concluded that there was a long-term stable co-integration relationship between them and there was a one-way causal relationship between Chinese carbon dioxide emissions and economic growth in the short-term. In addition, the cause and effect relationship between environmental efficiency and economic growth was also verified (Song et al., 2015; Song and Zhou, 2015; Song and Zheng, 2016).

In the aforementioned research, the EKC hypothesis, a co-integration test, and the Granger causality test are widely used in the study of carbon emissions and economic growth. The general conclusion of these studies is that there is a close relationship between carbon emissions and economic growth in the long, or short-term, and there is a non-linear relationship between carbon emissions and economic growth.

2.2. Forecasting Chinese carbon emissions

As a developing country, Chinese energy consumption, especially fossil energy consumption is constantly growing with the acceleration industrialisation and urbanisation, hence, the future changing trend in carbon emissions is a concern: to that end, many scholars have forecast Chinese carbon emissions from different perspectives.

For the prediction of Chinese future carbon emissions, the most widely used model is the IPTA, which is also known as the Kaya model. Du et al. (2015) improved the IPTA model and used it to predict and analyse China's per capita carbon emissions in three assumed scenarios up to 2050.

In addition, many scholars have used other methods to forecast Chinese carbon emissions. Zhou et al. (2013) evaluated the efficiency of Chinese energy consumption and thought that Chinese carbon emissions would reach a peak in 2030. Gambhir et al. (2013) used the hybrid modelling method to forecast Chinese carbon emissions in 2050. Liu et al. (2015) forecast the gross carbon dioxide emissions and their intensity in China from 2013 to 2020 using a system dynamics simulation. Sun and Liu (2016) applied the least squares support vector machine (LSSVM) to predict different types of carbon dioxide emissions in China.

From the above forecasting results, we know that the traditional EKC method and other forecasting methods have been widely used. As economic growth has a prominent non-linear impact on carbon emissions, if the prediction of carbon emissions were based on the non-linear relationship between carbon emissions and economic growth, it would not only have theoretical support but also could result in more direct policy suggestions for economic growth and environmental quality. In fact, few scholars make such an attempt at present.

2.3. Grey forecasting method

To solve the problem of analysis, modelling, prediction and control of uncertain system, Deng (2002) proposed the use of a grey system. As this theory had obtained ideal effects of application in practice, the grey theory has been recognised by many scholars at home and abroad in recent years, and its application fields have been extended from control science to many fields such as industry, agriculture, energy, economy, management, and so on (Liu and Lin, 2006; Wang et al., 2008).

Deng (2002) first proposed a multivariable grey model GM(1,N), and it was used in the coordination and development of the planning of the economy, technology, and society of a city in Hubei Province. The GM(1,N) is a first-order multivariable grey model, the model contains a system behaviour variable and $N-1$ influencing

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