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Predicting the capital intensity of the new energy industry in China using a new hybrid grey model

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A B S T R A C T

Capital intensity is an important indicator for reflecting the relative changes of production factors of an industry. The facilitating effect of capital deepening, i.e., the positive impact of the augment of capital intensity, towards the structural transformation of the industry is definite. Therefore, the accurate prediction of capital intensity of the new energy industry is of great significance in facilitating the structural transformation and upgrading of the industry. Based on the Cobb-Douglas production function, an industry-level capital-labour ratio (KLR) model is established to describe the dynamic characteristics of the capital intensity. Then, by combining the estimation and prediction method of the nonlinear grey Bernoulli model (NGBM(1, 1)) with the KLR model, a new hybrid grey model, i.e., NGBM(1, 1)-KLR model is proposed. In this way, the economic meaning of the KLR and the advantage of the NGBM(1, 1) model in solving small-sample and nonlinear problems are complemented with each other, which enables one to more favourably predict the capital intensity of the industry. To verify the effectiveness and superiority of the proposed model, the NGBM (1, 1)-KLR model is used to predict the capital intensity of the new energy industry in China, and the model is compared with the GM(1, 1) and the NGBM(1, 1) models in the prediction performance. The empirical results show that the NGBM(1, 1)-KLR model can more accurately predict the capital intensity of the industry in China than the GM(1, 1) and the NGBM(1, 1) models. Moreover, the new hybrid grey model is used to carry out the out-of-sample prediction for the capital intensity of the new energy industry in China in the period of 2017–2020. The predicted results demonstrate that the structure of the industry in China will further transform and upgrade towards the capital deepening.

1. Introduction

In recent years, China's new energy industry[1] has developed rapidly under the background of relevant subsidy policies by the government. However, as the cost of labour increases and the aging of the population becomes increasingly prominent (Ota, Kakinaka, & Kotani, 2018; Tonn & Eisenberg, 2007), the relative prices of production factors such as capital (K) and labour (L) in the manufacturing industry, including new energy industry, gradually change. This also, to some extent, forces competitive enterprises to transform and upgrade their substitution forms of capital for labour (Zhang, Zheng, & Zhai, 2016). Capital intensity, also known as capital-labour ratio (KLR) and measured using K/L (Acemoglu & Guerrieri, 2008; Hasan, Mitra, & Sundaram, 2013; Judzik & Sala, 2015; Krasker, 1984; Lim, 1981; Sosin & Fairchild, 1987; Takahashi, Mashiyama, & Sakagami, 2012), shows the relative speeds of capital accumulation and labour accumulation.

As the improvement of the KLR and also known as capital deepening, the substitution of capital for labour presents significant facilitating effects on the energy consumption and economic growth (Desai, 1986; Grandville, 1989; Madsen, 2010; Palivos & Karagiannis, 2010; Takahashi et al., 2012). Under the effect of the capital deepening, industrial sectors have unbalanced increases in the output due to different proportions of the production factors, thus facilitating the transformation of the industrial structure (Acemoglu & Guerrieri, 2008). At the same time, the substitution of capital for labour factor inevitably exerts the crowding-out effect on the employment. While, in another aspect, the capital deepening also promotes the improvement of the labour productivity (Leung & Yuen, 2015), and thus increases the income of labourers.

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[1] The new energy industry is the part of the energy industry focusing on new energy technologies, which refers to a series of processes involved in the development and application of new energies by organizations and enterprises, including four sub-industries, i.e., nuclear, wind, solar, and biomass energies (Wang, Li, & Pei, 2017; Wang, Zheng, Pei, & Jin, 2017).

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It can be seen that capital intensity, or KLR, has profound economic meaning and therefore shows practical significance to guide the rational transformation and upgrading of the industrial structure. Therefore, accurately predicting the capital intensity of the new energy industry in China, on the one hand, provides a perspective different from previous research for deeply understanding the internal mechanism of the industry. On the other hand, it also offers a new starting point for studying the structural transformation of the industry.

Current research scarcely directly predicts the capital intensity while intensively empirically analyses the factors influencing the capital intensity. For example, Madsen (2010) pointed out that capital deepening results from technological advancement after conducting Granger causality on KLR and total factor productivity. Hasan et al. (2013) showed that the imperfection of labour market caused by the regulation of labour force exerts a great positive influence on capital intensity. By investigating the determinants of capital intensity from supply and demand sides, Judzik and Sala (2015) suggested that the relative cost of production factors is one of the major driving forces of capital intensity. As a strategic emerging industry, the new energy industry has rapidly developed in recent years due to being concerned by governments of various countries (Richards, Noble, & Belcher, 2012; Sen & Ganguly, 2017). However, the industry develops late, and therefore available data length is limited. Thus, it is inevitable to be confronted with some obstacles when predicting the capital intensity of new energy industry by using traditional methods.

The grey prediction model is widely used owing to it can scientifically and quantitatively predict uncertain problems with small samples and poor information and also acquire a favourable effect (Deng, 1982). The superiority of the model in small-sample prediction compensates for the deficiency of traditional models in this aspect to some extent. There are lots of literature about the grey prediction model. Numerous studies expand traditional grey model (GM) to thus broaden its application fields. Based on traditional GM(1, 1) model, Chen, Chen, and Chen (2008) introduced Bernoulli differential equation and further established nonlinear grey Bernoulli model (NGBM(1, 1)) in order to solve nonlinear prediction problems. Furthermore, Chen, Hsin, and Wu (2010) constructed improved Nash NGBM(1, 1) by introducing the Nash equilibrium into NGBM(1, 1). On this basis, by optimizing initial conditions, Wang (2013) constructed the optimized Nash NGBM(1, 1) model and applied it to predict the major economic indexes of high-tech enterprises in China. The optimized Nash NGBM(1, 1) model shows excellent prediction performance in empirical research. Hsin and Chen (2015) put forward two-stage NNGBM model. After conducting iterative computations on parameters p and n in the model, they further established NNGBM(1,1) model, which exhibited excellent performance in predicting gross domestic product (GDP) of Taiwan. Shaikh, Ji, Shaikh, Mirjat, and Uqaili (2017) applied the optimization principle of Levenberge Marquardt (LM) into estimating the parameters of NGBM (1,1) model. By empirically comparing the optimized model with the regression model, traditional GM(1,1) model and grey Verhulst model, it can be speculated that NGBM(1,1) model shows the highest prediction accuracy.

Some researches established the grey hybrid model by integrating GM into the whole modelling process of general models in order to improve the prediction accuracy of models. By using the trend and potency tracking method (TPTM), Li, Yeh, and Chang (2009) extracted hidden information from small-sample series and constructed adaptive grey model (AGM)(1,1) based on grey theory. The empirical results showed that the method significantly improves the prediction accuracy of small-sample data. On this basis, considering the difference of increasing trend of data, Chang, Li, Chen, and Chen (2014) established an adaptive non-equigap grey prediction model, i.e., ANGM(1, 1). By utilizing the optimized TPTM values as the parameters of background value, the new model shows higher prediction accuracy on unequal-interval series with small samples. Yuan, Liu, and Fang (2016) predicted the consumption of primary energies in China after integrating ARIMA (the autoregressive integrated moving average) model and GM (1, 1) into a hybrid model, i.e., GM-ARIMA model. Wang and Hao (2016) proposed an improved grey multivariable model GMC(1, n) based on conventional GM(1,n) model by introducing a control parameter μ to predict China's industrial energy consumption. Wang, Li, et al. (2017) and Wang, Zheng, et al. (2017) established the DGGM(1, 1) which combined the data grouping method and GM(1, 1) in order to predict the seasonal time series with seasonal fluctuant characteristics. By combining kernel method and GM, Ma and Liu (2018) constructed kernel-based GM(1, n) model to thus realize the mutual advantages between GM(1,1) (the ability to address small-sample problems) and kernel method (the ability to address nonlinear problems). The kernel-based GM(1,1) model shows superior performance compared with the current linear multivariable grey model. To be specific, Table 1 distinctly indicates the main features, achievements, and shortcomings, of the above-mentioned prediction models. Additionally, studies also proposed a large number of valuable optimization methods, such as the application of various intelligent algorithms (Ding, Hipel, & Dang, 2018; Zhao & Guo, 2016), which all increase the prediction accuracy or efficiency of GM (1,1) to some extent. Therefore, this study utilizes the particle swarm optimization (PSO) to optimize the unknown parameters by its advantages such as simple rule, rapid convergence rate and few adjustable parameters and so on (Ding et al., 2018; Zhou, Fang, Li, Zhang, & Peng, 2009).

In this study, the KLR model is combined with NGBM(1, 1) so that the economic significance of the KLR is complemented with the superiorities of NGBM(1, 1) in addressing small-sample and nonlinear problems. It is worth noting that there are two aspects of the economic meaning of the KLR. One is the profound economic significance of capital intensity, or capital-labour ratio, itself, which shows the relative speeds of capital accumulation and labour accumulation. On the other hand, the specific construction and deduction process of the KLR model also has important economic meaning, namely, by solving the KLR model we can acquire the analytical solution of capital intensity. On this basis, a new hybrid grey model–NGBM(1, 1)-KLR is established, which is used for predicting the capital intensity of new energy industry in China. Additionally, NGBM(1, 1)-KLR model is compared with other prediction models (including traditional GM(1,1) and NGBM(1, 1)) in the prediction performance in order to show its superiority in predicting the capital intensity.

It is worth noting that using the traditional models such as time series analysis or regression equation to predict the capital intensity is confronted with significant limitations. Specifically, they both require a large data size to obtain reliable regressions while the available data length of the new energy industry is limited because of its short course of development, and their out-of-sample prediction performance is also relatively weak. By contrast, the NGBM(1,1)-KLR model has the characteristics of grey prediction models which can reliably predict uncertain problems with small samples and inadequate information, acquiring a favourable prediction performance, and resolving the weakness of massive data size demand when using traditional methods to predict the capital intensity.

The main contributions of the study are as follows:

(1) A new hybrid grey model–NGBM(1, 1)-KLR is established to analyse and predict the dynamic path of capital intensity of industry. In this way, the economic meaning of KLR is complemented with the superiorities of NGBM(1, 1) in addressing small-sample and nonlinear problems.
(2) The new energy industry in China develops late and therefore acquired data are finite. For the reason, the capital intensity of the new energy industry in China is empirically investigated by separately using GM(1, 1), NGBM(1, 1) and NGBM(1, 1)-KLR models. The result shows that the hybrid model–NGBM(1, 1)-KLR has the most superior prediction performance than the other two models.
(3) The NGBM(1, 1)-KLR model is used to carry out the out-of-sample