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Evolution of competition in energy alternative pathway and the influence of energy policy on economic growth

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ABSTRACT

This work is devoted to the evolution of the competition of energy alternative pathway in China, and the influence of energy policy on economic growth by using a dynamical system method. Firstly, the relation between energy and economic growth is taken into account, and a dynamic evolution model is established. It is observed that Hopf bifurcation and chaotic behavior occurs with the varying investment in renewable energy production. Secondly, when there is no policy intervention in energy market, the evolution of competition in energy alternative pathway is also investigated. Thirdly, the system parameters are also identified by using an artificial neural network method on the basis of certain empirical statistical data in China, and the dynamics of the parameters-identified system are studied. Finally, the influences of energy policy on economic growth are empirically analyzed, and some policy recommendations are given based on the results of empirical analysis.

1. Introduction

Energy is a basic condition for human survival and is also an important material for the national economic development. The acute shortage of energy not only affects economic growth directly, but also severely hinders the improvement of people's living conditions. Nowadays, energy consumption is mainly satisfied by non-renewable energy, and this situation may remain for quite a long time. In order to maintain the sustainable development of the economy, it has become an inevitable trend that renewable energy will hold a dominate position in energy resources.

In recent decades, there have been many studies on energy and economic growth. To investigate the REP (renewable energy production) in India, S. Iniyan et al. [1] established a mathematical optimization model to predict different terminal demand of renewable energy. In Ref. [2], by utilizing statistical method, Abanda et al. analyzed the correlation of REP and economic growth of different regions of African continent in the period of 1980–2008. In Ref. [3], to study economic growth of G7 in the period of 1980–2009, Tugcu et al. proposed an auto-regressive distributed lag model by taking advantage of empirical analysis. In 2010, Apergis et al. [4] proposed a panel error correction model of eighty countries, and then analyzed the relationship between energy consumption and economic growth in the period of 1990–2007. In Ref. [5], Silva et al. established a general equilibrium model of non-renewable production and renewable production, and analyzed the interaction and compatibility between economic growth and clean environment. In Ref. [6], by using Brazil's statistical data in the period of 1980–2010, the causality between real GDP (gross domestic product) and four types of energy consumption were discussed. Through establishing a high-tech and bottom-up energy system model, Lind et al. [7] analyzed the approaches of achieving the target of EU Renewable Energy Directive in Norway. In Ref. [8], Gevorgian et al. predicted the short-term energy distribution and consumption with dynamic simulation analysis when energy supply situation was still uncertain.

Regarding to the economic policy analysis in the field of energy, there are general mathematical models, such as CGE (computable general equilibrium) model, SD (system dynamics) model and agent-based model. (a) For the CGE model, Beatriz Gaitan S. et al. [9] studied the optimal exploitation issues of non-renewable resources in a simplified dynamic general equilibrium framework. Hodjat Ghadimi [10] used a dynamic CGE model framework to study the optimal exploitation of Iranian oil, the

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economic optimum savings and the optimal distribution of investment funds. (b)As for the SD model, Fan et al. [11] gave an SD model which included the investment in coal industry, available reserves, mine construction and coal supply capability. Their study found that investment in mining and washing of coal and geological prospecting must be largely increased immediately in order to have coal productions and supplies meet coal requirements caused by rapid economic development of China. Margarita Mediavilla et al. [12] used an SD model to study the exhaustion patterns of world fossil and nuclear fuels and their possible substitutes, namely renewable energy sources. They pointed out that peak oil would be the first restriction and it would not be easily overcome. (c) As to the agent-based model, David Young et al. [13] built the agent-based models to forecast spot prices in the electricity market in New Zealand. They found that agents in SWEM (system wide eutrophication model) were able to manipulate market power when a line outage made them monopolists in the market. Timothy Lee et al. [14] introduced a new agent-based model, which incorporated the actions of individual home-owners in a long-term domestic stock model, and detailed how it was applied in energy policy analysis. The research found that current policies would make it hard to achieve an 80% CO_2 reduction by 2050, and the most favorable conditions are to achieve a reduction of less than 60% from 2008 to 2050.

So far, the commonly used research tools of energy and economic growth are the econometric method and statistical method. But only a few authors considered the method of dynamic evolution in the field of energy. For instance, Sun et al. [15] used the dynamical methods to study relationship among energy demand, energy imports in Jiangsu province and energy supplies from the western part of China. In Ref. [16], Xu et al. used a differential system model with fuzzy coefficients to predict tourism revenue, energy consumption, waste emission and the carbon intensity. In Ref. [17], by establishing a three-dimensional energy-saving and emission-reduction dynamic evolution system, Fang et al. analyzed the complex dynamic behavior from some aspects such as carbon emissions, economic growth, and energy conservation. In Ref. [18], Tian et al. introduced the dynamic evolutionary system on carbon emissions to predict carbon emissions of China in 2020, 2030 and 2050.

From the dynamics point of view, when compared with the CGE model, the SD model and the agent-based model, the dynamic evolution model can not only reflect the coupling relationship among subjects studied but also explain the core factors. So, in this paper, in view of the complex properties of economic system, a dynamic evolution model will be established and studied in order to explore the relationship between energy and economic growth.

In this paper, the ANN (artificial neural network) method will be used to identify the parameters of the evolution system. It is a computational intelligence technique with a good nonlinear fitting capability, and it can be used to identify unknown parameters. For applications of the ANN method in energy systems, one can turn to Ref. [19–22].

The remainder of this paper is organized as follows. In Section 2, we establish a dynamic evolution model for two types of energy production and economic growth, and explain the meaning of this model. Section 3 analyzes the dynamics of the evolution system corresponding to this model. In Section 4, with the assumption that there are no economic policy interventions in the energy market, we study the evolution of competition of energy alternative pathway in China. In Section 5, by applying the ANN method, we identify the parameters and then conduct the empirical analysis. Based on the obtained results, some policy recommendations are given. The last section is for the conclusions.

2. Dynamic evolution model

In this section, a dynamic evolution model will be established to reflect the coupling relationship among NREP non-renewable energy production, REP (renewable energy production), and economic growth in this section.

2.1. Description of the system

It is reported that economic growth relates with energy closely. In Ref. [23], Georgescu-Roegen showed that economic process is neither isolated nor independent, implying the economic growth has tight relation with external factors. Lots of literature manifest that energy is crucial to economic growth. In Ref. [24], Stern and Enflo discovered the nonlinear dependency of economic growth on energy. In Ref. [25], the author concluded that energy play a central role in driving economic growth, and there are strong reasons to treat energy as an essential causal factor in economic growth. In Ref. [26], the authors found that the dynamic economy is strongly dependent on energy, and reducing energy may result in economic decline. In Ref. [27], the authors claimed that energy development is an important component of economic development, and that economic growth is the prerequisite for energy development while rapid economic development makes it possible to gain large-scale development and utilization of energy.

Since GDP (gross domestic product) measures the value of goods and services produced in a country in one year, and it is one of the most primary indexes which estimate macro economy, and also a legitimate measure of economic activities and outputs. Therefore, in this context, economic growth is measured by GDP, and energy is represented by NREP (non-renewable energy production) and REP (renewable energy production).

The main difference between NREP and REP lies in the following aspects: 1) Products and quantity. The main products of NREP include coal, crude oil and natural gas, etc, while of REP are hydropower, nuclear power, wind power and so on. In addition, it is clear that the quantity of the former is larger than the latter. 2) Government support. Considering the fact that non-renewable energy may not be eco-friendly enough and that it may get depleted after high-volume production, the government is reducing the share of non-renewable energy in the market and giving stronger support to renewable one.

Our dynamic evolution model includes three subsystems, i.e. NREP subsystem, REP subsystem, and GDP subsystem (denoted with the three variables,x,y, and z, respectively). In order to study the relationship among them, the factors influencing these variables need to be ascertained. In Ref. [28], due to the strong positive correlation between energy and economic growth, any negative shocks to energy, such as a rise in energy prices or the impact of energy conservation policies, will have a negative impact on GDP. In Ref. [29], economic growth is both central and fundamental for improving social welfare, and economic growth had a positive role to play in enhancing social welfare, at this point (the threshold point), further economic growth reduces social welfare. In Ref. [30], the growth rate of energy price has a negative effect on real GDP. In light of [31,32], the effect of technology investments on REP is positive. Other common influencing factors include risk of production technology, loss rate of NREP, impact of NREP and REP on GDP, and rate of GDP growth, etc.

To facilitate the study, these influencing factors will be represented as certain coefficients of the three variables x, y, and z. Fig. 1