OIL DEMAND UNDER A CARBON DIOXIDE EMISSION CONSTRAINT

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Overview

An optimization dynamic internal ecological variation model is introduced for illustrating the oil supply and demand balance. The main consideration is given to the utility maximization of oil demand and the degree of social (human) satisfaction with the environment. Moreover, a primary energy consumption model is established based on the Markov process, with a carbon dioxide emission constraint introduced. We use oil reserves, production, environment changes and investment to formulate a general internal ecological model. Production can be expressed as a function of capital, labour, science and technology. Reserves and investment can be changed dynamically. The relationship can be described by differential equations. The change of investment is affected by the change of oil price and supply-demand balance, as well as a time variant ordinary differential equation(ODE). Finally, the above model is used to forecasting the world and the main region's oil demand from now to 2030, including North America, Latin America, Africa, Europe, Central Asia, Russia and the Asia Pacific region.

Methods

From the macro level, the supply of petroleum can be expressed as

$$Y = A_0 K^{\alpha} L^{\beta} R^{\gamma}\ , R := R(t) = R_0 e^{\lambda t}$$

The amount of reserves *S,* Changes of investment *K* and Changes in environmental quality include the ability to purify and deteriorate *Q* are as follows

$$S(t+1) - S(t) = \mu S(t) - Y\ , K(t+1) - K(t) = f(Y, C, Pr)\ ,\ Q(t+1) - Q(t) = \alpha g(C) - \lambda P(t)$$

Simplified to society (human) for environmental satisfaction, the definition of health index-h is the degree of environmental pollution *Q* function. Generally, *h* and *Q* have the inverse direction relationship. Some utility functions are used to evaluate the utility of social welfare h, which can be expressed in the form of additive equal elasticity utility function.

$$h = \frac{1}{Q}\ ,\ U(h) = \frac{h^{1-\theta} - 1}{1-\theta}$$

Supposing the primary energy consumption to be a Markov chain model, according to the Markov's theory, and setting p_{ij} as the probability of preceding consumption element *i* to next consumption element *j*, a transition matrix is built as follows:

$$P = \left\{ \begin{array}{ccccc} & \text{Oil} & \text{Gas} & \text{Coal} & \text{Renewable} \\ \text{Oil} & p_{11} & p_{12} & p_{13} & p_{14} \\ \text{Gas} & p_{21} & p_{22} & p_{23} & p_{23} \\ \text{Coal} & p_{31} & p_{32} & p_{33} & p_{34} \\ \text{Renewable} & p_{41} & p_{42} & p_{43} & p_{44} \end{array} \right\}$$

The weight process of the primary energy resources can be expressed with a state vector corresponding to *t*

$$\theta(t) = \left[S_1(t), S_2(t), S_3(t), S_4(4)\right]$$

where $S_1(t), S_2(t), S_3(t), S_4(4)$ are The weight of oil, gas, coal and other energy respectively.

The maximization of social welfare and the general balance of supply and demand

$$\text{Min} \sum_{t=1}^{T} \left| \tilde{Y} - \tilde{C} \right| \text{ and } \text{Max} \sum_{t=1}^{T} \frac{\text{U(h)}}{(1\text{-}\rho)^t}$$

In order to obtain the more accurate one-step transition probability matrix, the quadratic sum of error must be minimal. Then, we need to minimize the following equation,

$$\min\ f(P) = \sum_{t=0}^{m-1} \left\| \alpha(t+1) - \alpha(t) P \right\|^2$$

Global energy-related carbon dioxide (CO_2) emission reached a high level. Suppose that the carbon dioxide emissions CD(t) in the time t. If the carbon dioxide emission target is cut by at least λ regarding to the initial CD(0), the following restriction can be hold,

$$CD(T) = S_1(T)PRD(T)C_1 + S_2(T)PRD(T)C_2 + S_3(T)PRD(T)C_3 + S_4(T)PRD(T)C_4 \le (1-\lambda)CD(0)$$

where C_1, C_2, C_3 and C_4 are carbon dioxide emission conversion corresponding to oil, gas, coal and renewables respectively.

By considering the continuous (not discontinuous) decreasing which happens in reality, the boundary of CD(t) should be added as follows with a small positive real number ε,

$$1 - \varepsilon \le \frac{CD(t)}{CD(t-1)} \le 1 + \varepsilon$$

we formulate the oil demand optimization model with a carbon dioxide emission constraint as follows,

$$\text{Min} \sum_{t=1}^{T} \left|\tilde{Y} - \tilde{C}\right|, \quad \text{Max} \sum_{t=1}^{T} \frac{\text{U(h)}}{(1-\rho)^t} \text{ and } \min\ f(P) = \sum_{t=0}^{m-1} \left\|\alpha(t+1) - \alpha(t)P\right\|^2$$

$$s.t. \begin{cases} \sum_{j=1}^{4} p_{ij} = 1,\ i = 1,2,3,4 \\ p_{ij} \ge 0,\ j = 1,2,3,4 \\ \frac{CD(T)}{CD(0)} \le 1 - \lambda \\ 1 - \varepsilon \le \frac{CD(t)}{CD(t-1)} \le 1 + \varepsilon \\ Y(t) = A_0 K^{\alpha} L^{\beta} R^{\gamma} \\ S(t+1) - S(t) = \mu S(t) - Y \\ K(t+1) - K(t) = f(Y, C, Pr) \\ P(t+1) - P(t) = \alpha g(C) - \lambda P(t) \end{cases}$$

Results

In this section, the model is used to forecast the primary energy consumption from 2018 to 2030. Supposing that the carbon dioxide emission target is cut by at least 10% regarding to that in 2016, that is to say, $\lambda = 10\%$. The data from 2010 to 2016 are used to solve the model. All data can be obtained from BP Statistical Review of World Energy, 2017. Then, the future primary energy consumption is predicted from aspects of the world, North America, Asian-Pacific and Europe&Eurasia.

World oil demand will reach about 4452 million tons/year by 2030.Asia Pacific region's oil demand increase, taking into account the slowdown in economic growth, will reach 1607 million tons. North America's demand is also huge, basically maintained at around 1000 million tons.

Conclusions

In this paper, an optimization dynamic internal ecological variation model is introduced for illustrating the oil supply and demand balance. The main consideration is given to the utility maximization of oil demand and the degree of social (human) satisfaction with the environment. Moreover a primary energy consumption model is established based on the Markov process, with a carbon dioxide emission constraint introduced. The model is used for predicting the primary energy consumption from 2018 to 2030. In the future primary energy consumption, gas and renewables which have low carbon dioxide emissions will take a higher share, while oil demand need to be reduced.

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