Research on the SD Simulation Path of Coal Economic Growth in China under the Perspective of Technological Innovation

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Abstract. This paper discusses the problem of sustainable economic growth under the dual constraint of energy and carbon emission. Using the system dynamics and cobbdouglas production function, the model of sustainable economic growth is constructed to show the relationship between economic growth, energy consumption and carbon emission. Using the system dynamics software, VENSIM simulated the growth path of China's economic growth, energy consumption and carbon emission under the background of considering different technologies. Research shows that it is difficult to achieve sustainable economic growth without the development of technology. China's economy can grow rapidly under the situation of production technology research and development, but it will exert great pressure on the environment. The research and development of carbon emission reduction technology can promote the sustainable development of our economy.

1. Introduction

A series of urgent threats, such as global warming, deterioration of ecological environment, depletion of non-renewable resources and so on, urge the countries all over the world to pay close attention to the reduction of greenhouse gases and the development of low-carbon economy. With the increasing trend of energy resource reserve constraints and greenhouse gas emission reduction constraints, countries around the world have begun to attach great importance to its possible impact in the process of economic development. And try to speed up the pace of technological research and development to solve the process of economic development in the technology lock problem [1]. Therefore, based on the principle of system dynamics, this paper constructs a dynamic model that can reflect the sustainable economic growth under the constraints of energy and carbon emissions, focusing on the energy and carbon emissions constraints. Through technology research and development can find the economic sustainable and optimal growth path, as well as how to achieve economic sustainable development in the optimal growth path [2-5].
2. Model construction

2.1. Causality diagram
Energy consumption, carbon emissions, physical capital, labor and economic growth are closely related to each other. In general, economic development can be viewed as a positive and negative feedback loop composed of three subsystems: energy consumption, economic development and carbon emissions. The causal relationship between them is shown in figure 1: economic growth can ensure the continuous increase of social investment. The second advantage of the increase of social investment is that the investment in research and development is increased, and the investment in research and development can be divided into two aspects. On the one hand, R & D production technology to promote labor productivity and further promote economic growth; on the other hand, R & D emission reduction technology makes carbon emission coefficient per unit of energy reduced, thereby reducing carbon emissions. Economic growth promotes residents' consumption, and then promotes the improvement of residents' living standard, which is beneficial to the growth of population, and then leads to the increase of labor force and promotes economic growth. In addition, the increase of population leads to the increase of per capita living energy consumption. The reduction of energy input will hinder the economic growth to a certain extent.

![Causality Diagram](image)

**Figure 1.** System dynamics causality diagram.

2.2. System flow graph
According to the causality diagram of economic growth and factor input, according to the principle of system dynamics, using Vensim software to build a system dynamics model, as shown in figure 2. Because we only need to understand the trend of the optimal path of economic growth, do not need accurate data, so the simulation accuracy of the model is not very high, there is no need to put some non-key elements into the model to study.

After completing the flow graph design of the model, the relationship between the main variables of the model is set as follows:

(1) \( \text{GDP} = \text{labor productivity} \times \text{physical capital stock} ^ {\text{physical capital elasticity}} \times \text{labor force} ^ {\text{labor elasticity}} \times \text{energy input} ^ {\text{energy elasticity}} \)

(2) \( \text{Material capital investment} = \text{GDP} - \text{R&D investment} - \text{consumption and others} \)
(3) Material capital stock = INTEG (capital formation amount - DELAY1 (depreciation, 1), initial value of physical capital stock)

Note: DELAY represents the material delay function. Since the initial value of the material capital stock is the current value, the depreciation is considered in the next simulation. Therefore, the delay function is needed.

(4) Production staff = labor force - R&D personnel

(5) Number of labor = population * employment rate * (1 - unemployment rate)

(6) Population = INTEG (population growth, initial population value)

(7) Energy input = energy consumption - energy consumption

(8) Living energy consumption = population * per capita living energy consumption (table) (Time) / 1000

Note: Per capita living energy consumption (table) is a table function, and the equation is divided by 1000 in order to keep the unit consistent.

(9) Energy consumption = INTEG (change in energy consumption, initial value of energy consumption)

(10) Rate of change in energy consumption = GDP growth rate * Elasticity coefficient of energy consumption

Note: The elasticity coefficient of energy consumption is an indicator reflecting the proportional relationship between the growth rate of energy consumption and the growth rate of the national economy, and has been widely used [6].

(11) Carbon emissions = unit energy carbon emissions * energy consumption * (1-carbon sink absorption rate)

(12) Carbon emissions per unit of energy = INTEG (-rate of change, initial value of carbon emissions per unit of energy)

Figure 2. Schematic diagram of system dynamics process.
3. Parameter setting

3.1. Parameter setting
At present, regarding the data in China's macroeconomic system, according to the existing economic growth model and data availability, the simulation time is selected from 2012 to 2030, and the simulation step is 1 (unit: year). Since the update of historical statistics requires a certain amount of time, the historical data mainly relates to 2000-2011, so the initial time for selecting the model is 2000 years. The parameters in the system can be obtained in the following ways:

(1) Obtained using historical statistics. The initial value of the physical capital stock, according to the research of Fan Qiao [7], the physical capital stock of 2000 was selected. The depreciation rate was set to 11.48% according to the research of Fan Qiao [7]; the initial population value was 126743 (10,000), data source. In the China Population and Employment Statistics Yearbook (2012); the initial value of energy consumption is 145,531 (ten thousand tons of standard coal), the per capita living energy consumption (the value of 2000-2011), etc., the data comes from the China Energy Statistical Yearbook. (2012).

(2) Arithmetic averaging method is obtained. The acquisition of such data is mainly based on the historical data of each year, and the arithmetic mean is obtained. There are mainly natural population growth rate (0.57%), employment rate (57%), unemployment rate (0.41%), R&D personnel ratio (0.34%), and R&D investment ratio (1.75%).

(3) Obtained by the regression coefficient method. Obtained by multivariate linear regression with parameter constraints by the econometric software Stata. The data are all figures from 2000 to 2011, in which capital formation, GDP, etc. are all converted to constant prices in 1990. The physical capital stock is calculated according to the perpetual inventory method [7]. The production personnel reduce the number of employed people according to the annual labor force, and the energy input reduces the living energy consumption according to the total energy consumption. In order to eliminate the influence of heteroscedasticity, after all the data are logarithmized, the calculation result is: \( Y = 0.4953K^{0.7468}H^{0.0541}E^{0.1991} \), which \( Y \) represents GDP, which \( K \) represents the physical capital stock, which \( L \) represents the number of production people, and \( E \) represents the energy input.

(4) Obtained according to the nature of the parameters. These data are mainly calculated according to different proportions, and some are set to make the running results of the model more accurate. These include carbon sink absorption rate (0.02), emission reduction requirements (0.025), commissioning value (0.2355), consumption ratio (30%), and capital formation ratio (0.6748).

4. Model operation and result analysis

4.1. Validity test
The validity test refers to whether the model can simulate the real system, that is, whether it can pass the historical test. The historical moment is selected as the starting point to start the simulation, and the error is checked by the historical data and the simulated data. After determining the variable parameters and initial values, the simulation was performed by Vensim software, and the GDP (1990 constant price), physical capital stock (1990 constant price), energy consumption and population variables were selected to obtain the simulation from 2000 to 2011. The data is compared with historical data, and the results obtained are shown in Table 1. It can be seen from the results in the table that the relative error between the simulated value of all selected indicators and the historical value is less than 10%. Therefore, it can be considered that the model can basically represent the development status of China's macroeconomic system through historical tests, and can be used to study the development trend of the system.
| Years | GDP (100 million yuan) | Material capital stock (100 million yuan) | Relative error(%) | GDP (100 million yuan) | Material capital stock (100 million yuan) | Relative error(%) |
|-------|------------------------|------------------------------------------|------------------|------------------------|------------------------------------------|------------------|
| 2000  | 50358.73               | 50307.5                                  | -0.1             | 98321.11               | 98321                                    | 0                |
| 2001  | 54538.66               | 55614.8                                  | 1.97             | 106813.71              | 110203                                   | 3.17             |
| 2002  | 59491.9                | 62034.1                                  | 4.27             | 117078.32              | 124529                                   | 6.36             |
| 2003  | 65456.19               | 69050.6                                  | 5.49             | 130607.85              | 140448                                   | 7.53             |
| 2004  | 72057.47               | 76639                                    | 6.36             | 146787.86              | 157953                                   | 7.61             |
| 2005  | 80207.2                | 84878.8                                  | 5.82             | 163703.71              | 177126                                   | 8.2              |
| 2006  | 90374.69               | 93775.2                                  | 3.76             | 183746.58              | 198084                                   | 7.8              |
| 2007  | 103173.91              | 103290                                   | 0.11             | 205715.47              | 220938                                   | 7.4              |
| 2008  | 113114.38              | 113653                                   | 0.48             | 231921.15              | 245768                                   | 5.97             |
| 2009  | 123536.96              | 124690                                   | 0.93             | 264895.52              | 272748                                   | 2.96             |
| 2010  | 136442.86              | 136570                                   | 0.09             | 300276.76              | 301960                                   | 0.56             |
| 2011  | 149124.6               | 149025                                   | -0.07            | 336760.4               | 333546                                   | -0.95            |

| Years | Population (10,000 people) | Energy consumption (10,000 tons of standard coal) |
|-------|-----------------------------|-----------------------------------------------|
|       | actual value                | Simulation value                             | Relative error(%) |
| 2000  | 126743                      | 126743                                       | 0                |
| 2001  | 127627                      | 127465                                       | -0.13            |
| 2002  | 128453                      | 128192                                       | -0.2             |
| 2003  | 129227                      | 128923                                       | -0.24            |
| 2004  | 129988                      | 129658                                       | -0.25            |
| 2005  | 130756                      | 130397                                       | -0.27            |
| 2006  | 131448                      | 131140                                       | -0.23            |
| 2007  | 132129                      | 131887                                       | -0.18            |
| 2008  | 132802                      | 132639                                       | -0.12            |
| 2009  | 133450                      | 133395                                       | -0.04            |
| 2010  | 134091                      | 134156                                       | 0.05             |
| 2011  | 134735                      | 134920                                       | 0.14             |

4.2. Initial operation and result analysis
The system can be simulated by assigning values to the system parameters and passing the model. The model is selected as the initial time of simulation in 2000, and the data has debugging constraints in 2000-2030. The model is simulated and debugged to realize the dynamic simulation and prediction of the optimal growth path of China's economy. Figure 3 shows some of the simulation results of China's economic growth, energy consumption and carbon emissions under natural development conditions.
Figure 3. Unconsider the simulation result graph in the research and development state

As can be seen from the above figure, China's GDP (label 1), energy consumption (label 2) and carbon emissions (label 3) all show an upward state without considering R&D; carbon emissions are consistent with energy consumption. However, because only carbon emissions from energy consumption are considered in the system, carbon emissions from other factors (such as cement production) are not studied; carbon emission intensity (No. 4) shows a downward trend due to China's economic growth. The speed exceeds the carbon emission rate. Although the carbon emission intensity fails to meet China's emission reduction commitments, it is still conducive to China's path of low carbon economy development.

Obviously, without considering R&D, China's economy will grow rapidly, but while the economy is growing rapidly, energy consumption and carbon emissions are also increasing. China's energy reserves and carbon emission capacity are limited. The resource supply capacity and environmental pollution capacity are important limiting factors for the sustainable and stable development of China's economy. According to the research of Xu Shichun et al. [8], the necessary conditions for economic sustainable optimal growth are defined. for \( g_Y > 0, g_E < 0, g_R < 0 \). These are economic growth rate, pollutant emission growth rate, and resource consumption growth rate. Obviously, such a development trend is not the optimal economic growth path and does not meet the requirements of sust.

4.3. System policy regulation and analysis

1. Policy variable parameter settings

According to the principle of determining the control variables, combined with the simulation of system development, select the emission reduction technology research and development efficiency and production technology research and development efficiency as the policy variables, set the time boundary to 2012-2030, 2012 is the simulation base period 2, the time step is 3 years. The regulation test was carried out by adjusting the combination of variables or several variables, and the data of the control parameters are shown in Table 2. It is assumed that the efficiency of the technical research is gradually reduced over time, and is represented by an information smoothing function.
Table 2. Simulation and control variables and schemes

| Plan | R&D investment ratio | R&D staff ratio | Reduced research and development efficiency | Production research and development efficiency |
|------|----------------------|----------------|---------------------------------------------|-----------------------------------------------|
| 1    | 0.0175               | 0.0034         | 0                                           | 0                                             |
| 2    | 0.0175*2             | 0.0034*2       | SMOOTHI(0.03,18,0.05)                       | 0                                             |
| 3    | 0.0175*2             | 0.0034*2       | 0                                           | SMOOTHI(0.03,18,0.05)                         |

Option 1: Do not consider research and development, keep the original situation unchanged;
Option 2: Increase research and development of emission reduction technologies and reduce carbon emissions per unit of energy;
Option 3: Increase research and development of production technology and improve labor productivity.

2. Results and analysis
After the design of the scheme is completed, the simulations are simulated for the three schemes. The simulation results are shown in Figure 4-7.

![Energy consumption curve](image)

**Figure 4**: GDP growth simulation curve.

As can be seen from the simulation results in the above figure, technology research and development has a significant impact on economic growth. Production technology research and development can increase labor productivity and accelerate the pace of economic development; while research and development of emission reduction technology has a slight hindrance to economic development. If only the goal of economic growth is considered, production technology research and development should be carried out.

1SMOOTHI (\{in\}, \{stime\}, \{inival\}) First-order information smoothing function, meaning SMOOTHI (input value, delay time, initial value).
Figure 5 illustrates the energy consumption in different technology development scenarios. It can be seen from the figure that a large amount of energy input is required under the research and development of production technology, and the growth rate of energy consumption is slow under the research and development of emission reduction technology. Moreover, the research and development of emission reduction technologies is very sensitive to energy consumption, and the research and development of emission reduction technologies is intensified, which is conducive to the sustainable supply of energy in China.

Figure 6 reveals the carbon emissions in the case of technology research and development. It can be seen from the figure that different technology research and development will have an impact on China's carbon emissions. Production technology research and development will increase carbon
emissions, while emission reduction technology research and development can effectively reduce carbon emissions. By increasing investment in research and development of emission reduction technologies, it is conducive to China's path of low carbon development.

![Carbon emission intensity simulation curve](image)

Figure 7. Carbon emission intensity simulation curve.

5. Conclusion
This paper mainly simulates the dynamic optimal growth path problem. Using the system dynamics and the Cobb-Douglas production function to construct China's macroeconomic system model, showing the relationship between economic growth, energy consumption, carbon emissions and carbon intensity. The SD model of the macroeconomic system was constructed using the system dynamics software VENSIM. The initial simulation results show that China's economy continues to grow, but energy consumption, carbon emissions are large, and carbon emission intensity is high. This development model does not meet the requirements of sustainable development, and it is necessary to seek better development models through policy regulation.

Through the regulation analysis of the system dynamics model, the following conclusions can be drawn:

1. The technological development can change the relationship between China's economy and the environment, and can promote the sustainable growth of China's economy;
2. By increasing production technology the investment in R&D can effectively increase China's economic growth rate and accelerate the pace of economic growth. However, behind the rapid economic growth, it needs to consume a large amount of energy, emit a large amount of carbon dioxide, and exert tremendous pressure on the environment;
3. The research and development of the platoon technology has reduced the energy input, which has made me economic growth become slower, but the trend of economic growth has not changed. At the same time, China's energy consumption has decreased significantly and the carbon emission intensity has decreased significantly.

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