Management tool of urban sustainable development: establishment of an economy-resources-environment system dynamics model

X Feng and G H Cao*

School of Economics and Business Administration, Chongqing University, No.174 of Sha Zhengjie Street, Shapingba District, Chongqing, China

*E-mail: caoguohua@cqu.edu.cn

Abstract: Economy-Resources-Environment (ERE) system is considered as a complex component for sustaining the urban development. System dynamics (SD) is a method to explain the behavior of complex component. According to the conceptual framework of urban sustainable development, this paper takes Chongqing of China as case study to develop an ERE-SD model for simulating the feedback process of economic development with resource restriction and environmental degradation. Firstly, conceptual framework and structure of ERE-SD model is established, and model test is carried out. Secondly, five scenarios, named natural growth, resource restriction, environment protection, smart development and economy, are selected to forecast the future results. Finally, the optimization scenario is selected for improving urban sustainable development. The results illustrate that the GDP level in five scenarios decreases in the following sequence: economy −, economy +, smart development, environment protection, resource restriction, economy −, natural growth; the net GDP level in five scenarios decreases in the following sequence: economy +, resource restriction, smart development, environment protection, economy −, natural growth. The adjustment of the economic development path is necessary to access sustainable development in Chongqing.

Keywords: Sustainable Development; ERE-SD Model; Cobb-Douglas Production Function; Scenarios Simulation; Chongqing

1. Introduction

In the recent past, environmental pollution and degradation associated with rapid industrial development and population growth have attracted critical concerns of government department and environmental protection administration [1]. Urban economic growth and human environment is a complex system that is affected with natural, economy and society drivers, resource management, land degradation and ecological environment. How to characterize, evaluate and forecast the complicated system is an important issue of urban sustainable development.

Most of evaluation methods focus on indicators selection [2]. Although these indicators cover a wide range of content, the intrinsic feedback relationships among themselves are usually ignored so that these indicators are independent of each other. As a consequence, these evaluation indicators can't reflect the running regime of the entire system. Facing with a nonlinear giant system which contains numerous factors and variables that cover various fields and have complex coupling relationship, modeling is a valuable method. At present, many methods were employed to simulate a dynamic

process of urban sustainable development [3-5]. The approaches include potential models, IPAT model and quantitative economics method, system optimization, quantitative method, spatial logistic regression, as so on. The main research methods can be summarized into two aspects: (1) model analysis: artificial neural network model, the GIS-RS model, grey model; (2) evaluation method: fuzzy comprehensive evaluation method, index evaluation method, comprehensive index assessment method of sustainable development, ecological footprint method. These models can not only effectively trace the past urban development, but also forecast the future growth scenarios. Therefore, they are useful to examine the reasonability of urban planning policies.

System dynamics (SD) is an interdisciplinary discipline that recognizes system problems and solves system problems. SD is widely applied to evaluate urban sustainable development [6]. This paper employs the system dynamics method to establish a model of urban economy, resource and environmental development, which is named an ERE–SD model. The established ERE-SD model can be used to provide technical support and scientific guidance for the other similar regions. It is anticipated that the deterioration of ecological environment will be effectively curbed, and an economic - resources - coupled environmental development system will be established, which can provide technical support and scientific guidance for the sustainable development of Chongqing

2. Methodology

2.1. Study area

Chongqing city in China is picked as a case to simulate ERE system, as seen in Figure 1. By the end of 2019, the population in Chongqing reached to 30.75 million, GDP researched to 2360 billion Yuan. The altitude of the main urban area of Chongqing ranges from 140 m to 1327 m, with an average altitude of approximately 425 m. The karst geomorphology of Chongqing is developed and widely distributed, covering 24 districts and counties. Although Chongqing is rich in rainfall, due to its special geological background and environmental characteristics, the occurrence and distribution of water resources is very complicated, and it is difficult to develop and use. Water developing is severe. In this paper, five types of data sources are used: Chongqing Statistical Yearbook, China City Statistical Yearbook, Chongqing Environment Bulletin, Chongqing Water Resources Bulletin, and China Statistical Yearbook.

2.2. ERE-SD model establishment

In the ERE-SD model, GDP will be consumed while fixing essential input of labor force, fixed assets, technology development, and pollution control; resources stock will be reduced for keeping GDP growth; as the resource gap becomes greater, restriction effect of economic development is more obvious; the increase of GDP growth and population are accompanied with the increased pollutants; resource consumption speed is increasing with the growth of economic output (Figure 2). Conceptual framework of the ERE-SD model establishment in the following aspects: (1) concept and characteristic of sustainable development are injected into the ERE-SD model when the feedback relationships of urban population, economy, resource and environment are constructed; (2) in order to accord with the running rule of the real system, the ERE-SD model and quantitative geography are deliberately combined to amend the environmental system; (3) a modified Cobb-Douglas production function by historic data and least square method is used to establish main function relationship between economy system and other systems; (4) water resource and coal consumption are separately selected as representative variables to simulate renewable and nonrenewable resource dynamic change in the future; (5) macro-scale economic growth (GDP) and micro-scale sustainable planning measures (net-GDP) are adequately considered into the ERE-SD model for illustrating dynamic change and sustainable development of urban complex system; (6) according to the actual situation and regional characteristics of Chongqing city, the system structure and the relationship between the variables are adjusted to modify the model, and to continuously capture the changes in the urban sustainable development.

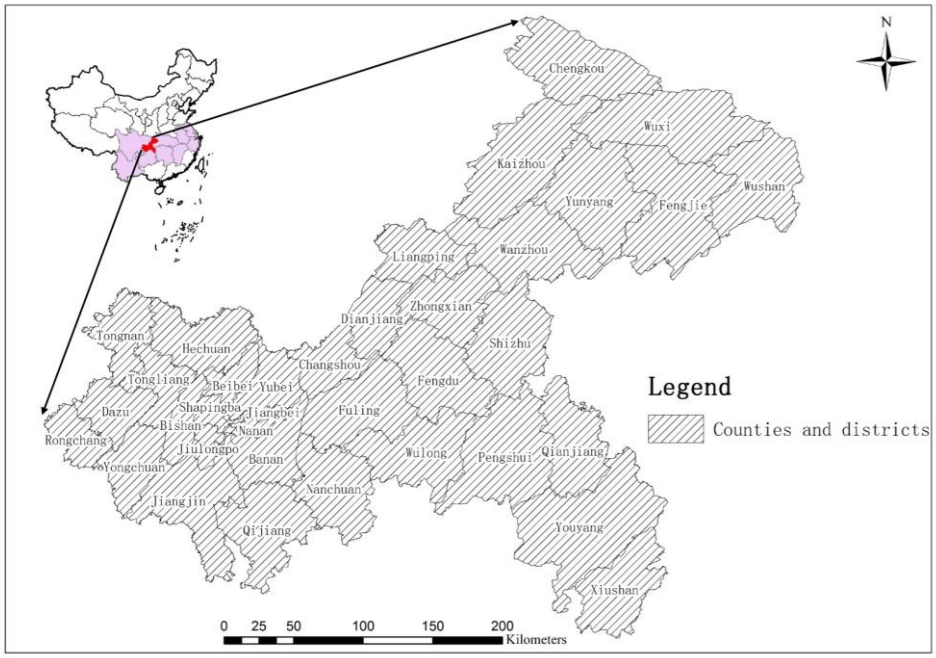

Figure 1. Location of the study area.

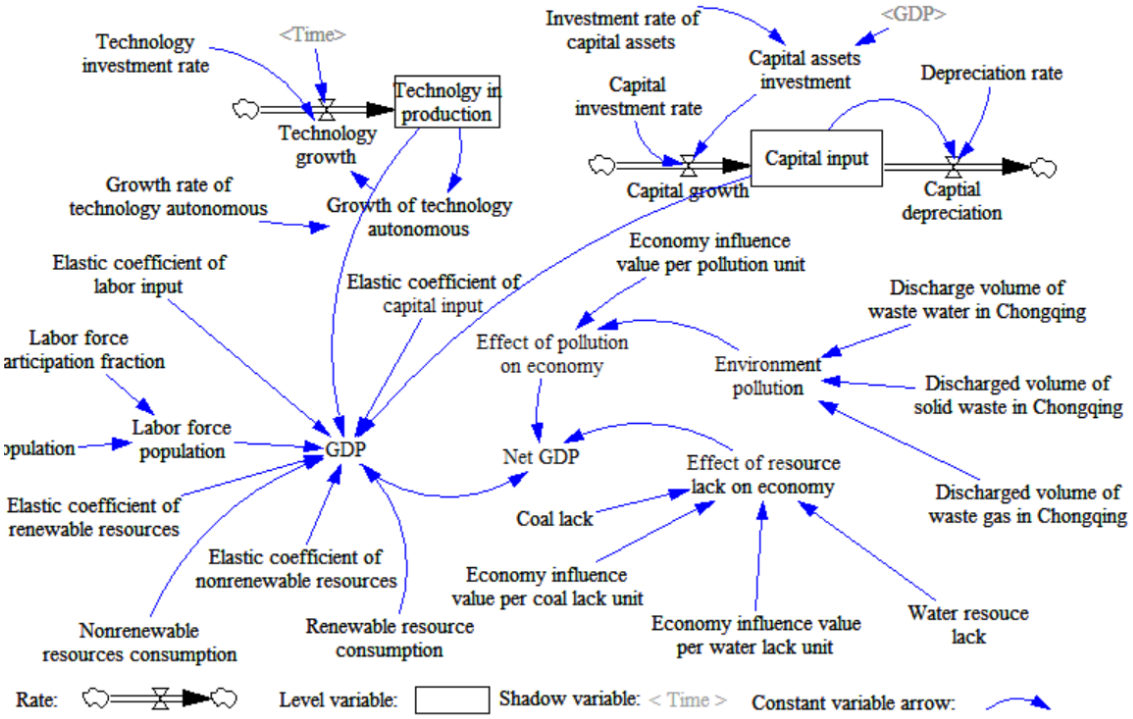

Figure 2. Conceptual framework of ERE-SD model in Chongqing.

2.3. ERE-SD Model Test

This study picks up the data of a period of 2000-2009 to perform the historical test by using Vensim software. The ERE-SD model testing results are seen in Figure 3. The results show that error of the

simulation value against historical value is less than 10%, and the fitting relative errors for most of major indicators are between 0.1% ~ 6.0%. Therefore, fitting degree is high, applicability is strong, and replication ability is good. On this basis, the model can monitor the relationship between economy, resources and environment of Chongqing, and can be used for simulating future changes. Therefore, the established ERE-SD model can be used the other areas by adjusting the relevant parameters.

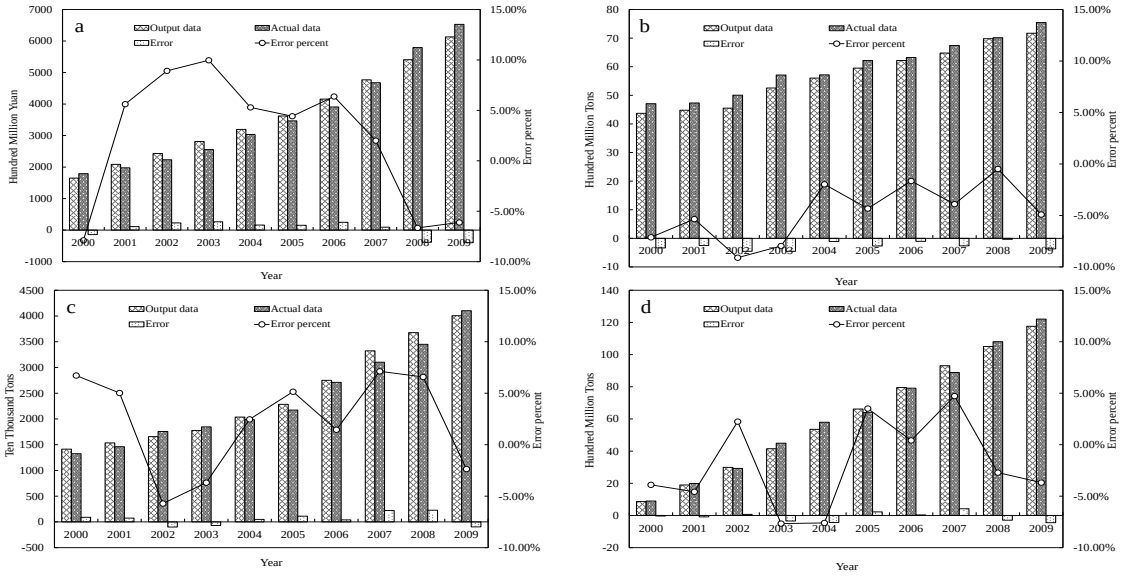

Figure 3. Comparison results of actual data with the output data.

Note: *a* is GDP; *b* is water resource lack; *c* is coal lack; *d* is environment pollution.

3. Results

Five different scenarios are set, which include natural growth, resource restriction, environment protection, smart development, and economy in this paper. In the natural growth scenario, GDP will experience an exponential increase till 2050, as seen in Figure 4a. Environment pollution have an effect on the economy growth; subsequently, the Net GDP is enhanced with the same tendency as the increase of GDP. The above natural growth scenario results show that Chongqing's development is closely dependent on the resources. Comparing the natural growth scenario with the resource restriction scenario as seen in Figure 4b, the increase of GDP is slower in the resource restriction scenario in the initial period of model run, and later becomes faster. Before 2025, the increase of GDP in the resource restriction scenario is evidently slower because the resource input is reduced. As for the environment indicator in the natural growth scenario, the effect of pollution on economy in the future decades keeps a continuously increasing tendency, leading to the further deterioration of environment, as seen in Figure 4c. Therefore, a smart development scenario is set according to increasing technology investment, as seen in Figure 4d. The Net GDP grows more rapidly in smart development scenario than in the other three scenarios. In the smart development scenario, improving the technology level gives rise to the pronounced increase of GDP production value. And, the net production value of GDP is increased obviously. The results reveal that the improvement of technology level is favorable for the rapid economy development, denoting that the technology index is a decisive factor during the economy growth process. Therefore, it's important to enhance the technology advance for increasing GDP and improving production quality. Under the smart development scenario, innovation activities, as the headspring of technology advance, can impulse the persistent economic growth in the endogenous economic growth theory.

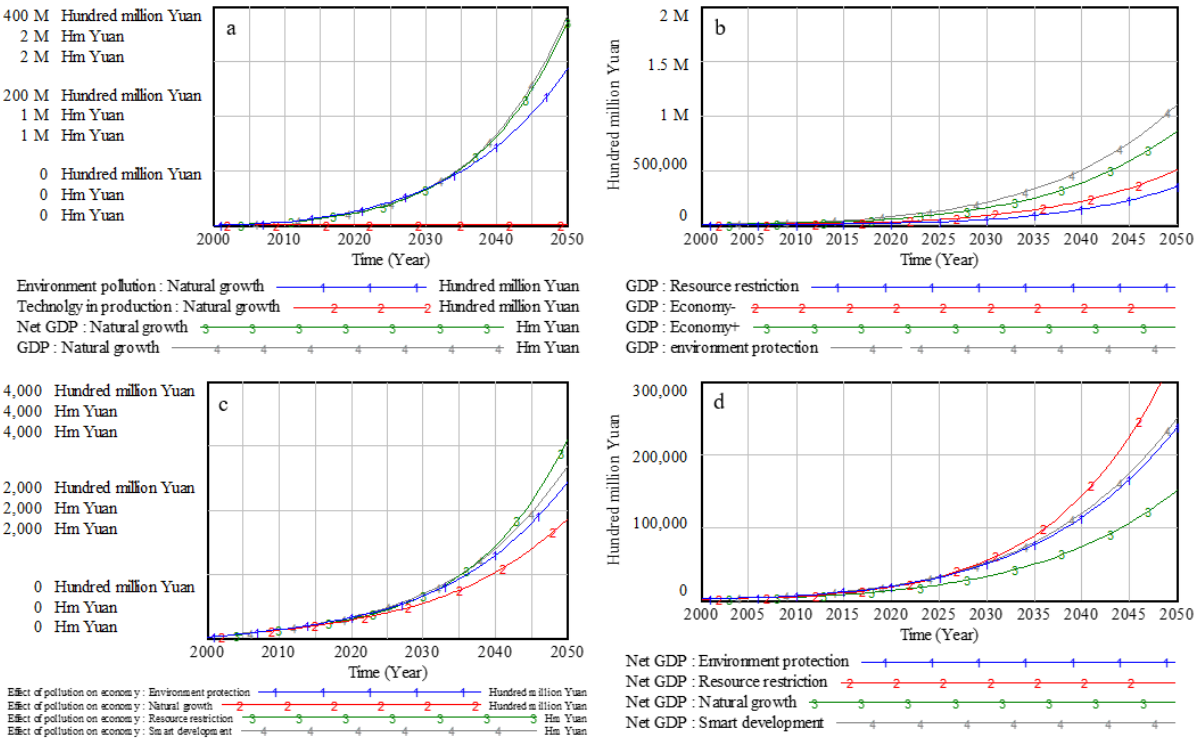

Figure 4 The simulation result comparison under different scenarios

Note: *a* is the simulation result of economic index in natural growth scenario; *b* is the simulation result of GDP under different scenarios; *c* is the effect of pollution on economy under different scenarios; *d* is the result of Net GDP under different scenarios.

Chongqing's economic development is confirmed to be unsustainable due to severe environmental pollution and excessive resource consumption. As a sequence, economic system will collapse after a long period. This can be ascribed to poor industrial structure and lagging economic level, which suggests that the economic development is mainly attributed to the expansion of industrial scale, but lacks the optimization of industrial structure. According to analysis results of five development scenarios, either reducing dependence of economic system on natural resource, or increasing investment of environmental protection, or increasing investment of technology, or enhancing speed of capital circulation, cannot bring the economic development of Chongqing back to sustainable development. Facing at the problems of resource constraints in Chongqing, several effective measures are suggested to be taken for keeping the GDP growth. Firstly, resources and energies should be not much allocated into excessive industry, but into those emerging industries and real economy such as automobile, electronic core parts, IOT, high-end equipment, and new materials. Expectedly, the rapid growth of the emerging industries will be one of the leading industries contributing to the economic growth. Secondly, numerous enterprises should be systematically organized by local government to invest overseas for promoting the transformation and upgrading of Chongqing's industries. Overseas investment in Chongqing should not be the extracorporeal circulation, but should direct the Chongqing market and dock the international excess resources with the Chongqing's demand for shortage resource. Presently, the overseas investment of Chongqing basically focuses on the shortage resource projects in China, typically such as, 3 billion tons of iron ore project for Australia's investment, leasing 3 million acres of planting soybeans in Brazil. Thirdly, large-scale processing trade should be continued to extend the industrial chain and form industry agglomeration, especially in terms of producer services and manufacturing cluster. A large proportion of the "smiling curve" of processing

trade should be left in Chongqing to form a world-class processing industry base. Therefore, Chongqing, as a developing city with a big resource gap, should improve the manufacture industries and further move steps to high-end industrial chains, for the leapfrog development in Chongqing.

4. Conclusion

In this study, resources, environment, technology subsystems and GDP subsystem are integrated by Douglas production function, and then a dynamic model of ERE system is established. Five scenarios of natural evolution, resource dependence, environmental protection, technological innovation and economic investment are designed to simulate future change tendency. According to the five scenarios comparative analysis, current economic development in Chongqing is not sustainable because of large resource consumption and serious pollution. Therefore, the current economic development model need be modified to accelerate the transformation and upgrading of industry which need the support of national policy for the purpose of escaping the plight of current development.

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