System Dynamic Modeling of National Policy: Case of Environment Conservation Input in China

Qingrui Xu, Jin Chen, Shaoxia Chen and Jie Han
School of Management, Zhejiang University,
Hangzhou, 310027, China

Abstract

The underpinning factor for one nation's sustainable development is the proper investment on environment conservation, advanced countries spend 24% GNP on national environment conservation, but China's spend is only around 0.60.7% of GNP. Increasing the input on environment conservation is emphasized by Chinese Government and many scholars. In this paper, based on the situation of environment conservation input in some countries, the mechanism analysis on the relationship between environment, economy, science & technology, education, population, we introduce a system dynamics model to forecasting China's environment conservation input in near 50 years and try to help China's sustainable development through synchronization of economic growth and environment conservation. The relationship between model structure and model behavior in a mathematical framework of system isomorphism as well as the senario of different economic growth rate and different ratio of environment conservation input over GNP are studied.

System Dynamic Modeling of National Policy: Case of Environment Conservation Input in China

I Introduction

Since human society developed into the era of industrialization, especially in the 1950'-60's, the environmental pollution caused by economic growth has become more and more severe. The continuous deterioration of the surroundings which we live in has been threatening human survival and development and the awareness of environmental issues has gone through a tortuous process. After World War II, the economic depression turned into prosperity in the west. "Economic development determinism" and the viewpoint concerning "pollution first and clean-up later" prevailed for a time and the environmental pollution rised to a peak in the west at the end of 1960s and western countries paid a high price for it. The pessimistic view of "zero growth theory" came into being. However, human beings also learned many experience and lessons from this and were gradually receptive to the new idea of continued development. Every country pursues to achieve the coordinate development between economy and environment.

Since foundation of the People's Republic of China, especially the economic reform, China's national economy has achieved a fairly rapid development but followed by serious environmental pollution.

There are two characteristics in China's environmental pollution:

- The first is the advance of pollution. The environmental pollution is an outcome of rapid industrialization and abnormal industrial structure in China. There is a large industrial pollution group and it brings about fairly serious pollution. According to statistics, the amount of waste gas, waste water and waste residue caused by industry is respectively 24.9 billion ton, 149.5 billion ton and 76.7 billion ton in 1990 and it is reported a large quantity of waste gas, waste water and waste residue is continually discharged, the environment is increasingly polluted, some researchers show that the present degree of environmental pollution in China has reached to that of western industrial countries in the 1970s.

- The second is that vast areas have been polluted. Since the 1980s, the township enterprises have been developed rapidly and the economic growth is full of new vigour. However, because the technology which township enterprises apply is fairly backward and the benefit from economic scale is so few, they become one of the main sources of pollution. Furthermore, the irrational distribution of township enterprises bring about a large scale of pollution, especially in the regions where township enterprises are flourishing.

Thus severe environmental pollution results in tremendous harm to people's health and national economic development. By rough estimation, China's economic loss caused by environmental pollution is high to 37.9 billion yuan every year.

Since the environmental pollution overwhelms the economic growth, China is facing up to not only the arduous task to control environmental pollution but also the task of large-scale economic construction. It also needs a large quantity of financial and material resources to control the new pollution resulted from economic development. All of these are very difficult problems to such a developing country as China. It has profound practical significance to study how to coordinate the confliction between environmental harnesses and economic growth and how to unify the environmental, economic and social benefit.

In view of the complexity and other effects on environment - economy system, the method of system dynamic simulation is fairly ideal. The guiding ideology of this paper is to probe into general principles concerning the investment in environment conservation in the light of specific conditions in China through researching the mechanism of coordinative development between

environment and economy and the effect which the investment in environmental conservation acts on the coordinate development with quantitative analysis. Based on this, a system dynamic model is built up to analyze the pattern of the investment in environmental conservation in future 50 years in China.

II Environment Conservation Input: Aspects in China and Western Countries

The investment in environmental conservation is one of the important component parts of the whole social investment and closely relations to every aspect of society and economy. On the one hand, it is essential to the social reproduction, to control the environmental pollution and to promote the sustainable development of the society and economy; on the other hand, because the national income is fixed during a given period, when the investment in a very field is more, the ones in other fields are less. If the investment in environmental conservation and economic growth is increased, the investment in policy and various consumption fund will be decreased. Therefore, determining the proper ratio that the investment in environmental conservation to the total capital invested in the national economic and social development is important to ensure the coordination between the environmental conservation and economic growth.

It can draw a conclusion that the investment in environmental conservation is not only one of the important component parts of fixed assets invested in the national economy and social development, but also a kind of independent investment with its own characters unlike the common fixed assets.

Studying the process of environment conservation input in some countries (see fig 1), there are several patterns including:

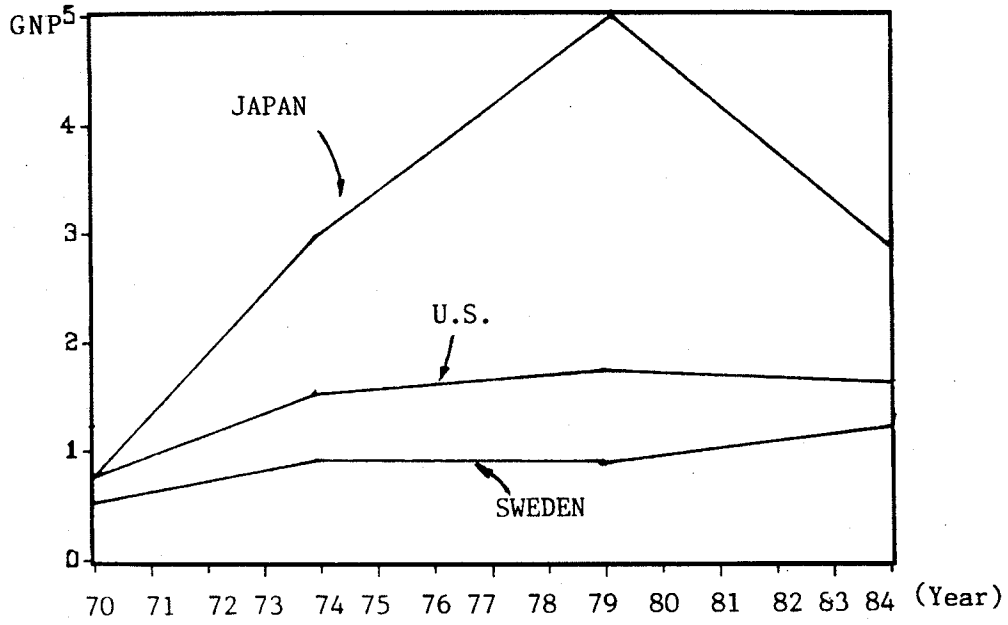


Fig. 1 Patterns of Environment Conservation Input

1 High starting point and low increase path (as US, German and so on);
2 High starting point and high increase path (as Japan);
3 Low starting point and low increase path (as some developing countries);
4 Low starting point and high increase path (as some developing industrial countries).

Since the 1970s, the investment in environmental conservation in developed countries is great because of some historic backgrounds. First, the environmental pollution has been accumulated for a long period of time. Second, the tremendous economic strength and advanced technology make it possible to invest more capital in the environmental conservation. Third, citizens with strong awareness of environmental conservation make high claims to the environment. This prompts the continuing improvement of environmental laws and regulations and the effective implement of them.

In China, the investment in environment conservation is gradually increased in recent years and plays more and more important role in protecting the environment against pollution. Nevertheless, compared with the reality of serious pollution and destruction of the environment, the investment in environment conservation is on the few side: compared with many countries in the world, the investment ratio is on the low side. At present, the ratio of the environment conservation to GNP is 0.6 to 0.7%.

According to the comparative research, the conclusion is that under present conditions, 1 to 15 percent of GNP invested in the environmental conservation can control a great part of pollution; and 2 percent of GNP invested in environmental conservation can prevent the further deterioration of environment and can preliminarily improve the environment. Since the 1980s, the investment in environmental conservation has been increased, but it has not reached to 0.7 percent of GNP yet. To settle the environmental issues in China, the essential way is to increase the investment in environmental conservation appropriately. Furthermore, every aspect such as economy, environment, society, and so on must be taken into account and these basic principles must be followed:

- The ratio of investment in environmental conservation should coordinate with the level of economic development and should not be too high;
- To determine the ratio of investment in environmental conservation should take the present conditions that the environment is seriously polluted in China into account and should not be too low.

To sum up the above analysis, it can be concluded that to settle the environmental issues in China is a giant systematic project and is confronted with many unfavourable factors. First, the level of economic development is low and the economy can not afford more capital to protect the environment. Second, a large population, especially the surplus labour force in the countryside is a heavy burden on the environment. Third, the low level of Science and Technology and culture limits to make the investment yield well to a certain extent. Fourth, the low level of management and the unperferct laws and regulations also affect to make the investment yield well.

III System Dynamics Model Building & Preliminary Qualitative Analysis

There are many factors to affect the environment, mainly including the degree of economic development, the level of science & technology, the quantity of population and the quality of population which depends on the level of education. Therefore, in order to study the problem how to invest in environment conservation, the total system should be divided into such subsystems as the population subsystem, the economy subsystem, the environment subsystem, the science&technolgoy subsystem and the education subsystem. These subsystems influence each other and condition each other. They determine the behaviour of the whole system jointly.

There are many factors to affect the economic growth in a country. The effects on economic growth mainly include:

- The environmental pollution causes various diseases and does harm to the people's health. On the one hand, it reduces the productivity of labours; on the other hand, it increases the medical and health cost;

- The environmental pollution causes the reduction of output in agriculture and injuries animal husbandry as well as breeding poultries;

- The environmental pollution, especially the acid rain, speeds up the deterioration of some materials and buildings and shortens their service lives;

- Because the economic growth requires more and more natural resources and some resources which can not be regenerated is now becoming more and more rare, the using costs increase. Meanwhile, more and more capital is used to deepen exploiting natural resources and it affects the investment in promoting economic growth.

In this paper, how science and technology acts on the environmental conservation is also the focus.

The indirect effects of science and technology on the environment is that the progressive science and technology promotes the economic growth. This offers more investment to protect the environment.

The direct effects of science and technology on the environment are mainly shown in the following respects:

- Either the innovations of tools of production or the adoption of new technology, new equipment, and new material improves the utilization ratio of energy and resources. On the one hand, the consumption of energy and resources is cut down; on the other hand, it reduces the production of pollutant and is beneficial to improve the quality of the environment.

- The comprehensive utilization of pollutant and the development of technology offer the environmental sound technology to control the environmental pollution ar) improve the quality of the environment. It effectively reduces the releas of pollutant and fully utilize the resources;

- The scale economy is developed. In general, large enterprises have advanced technology and benefit from the large scale production. Thus, the consumption of energy and resources is lower than that of small enterprises as well as township enterprises;

- The technical level determines the effect that a country controls the environment. Here, the technology is in a board sense and includes the general technology and the managerial technology of the environment. The former is indicated by the number of the achievements in science & technology every year in a country and the latter is indicated by the influence coefficient of education on the environment that means the quality of population.

The main causal-effect of environment-economy-population-science & technology is shown as figure 2.

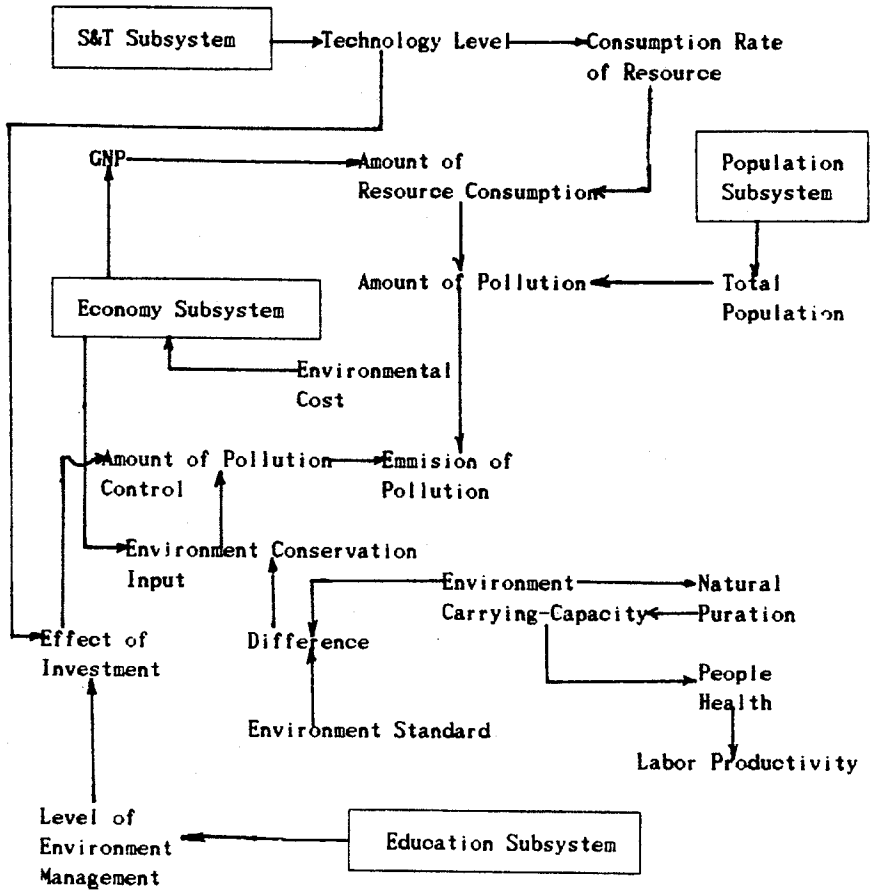


Fig 2 Simple Illustration of Causal-effect Relations on Environment Conservation Input in China.

As any social and economic model is not perfect, System Dynamics modeling usually lacks of a more formalized procedures of mathematical analysis, and trial and error approach was always used to the realising acceptable policies, the number of policy alternatives is limited by the analyst's own experiences and judgement rather than the attainment of objective criteria (Toyoda, 1991) as well as the cost of policy test and simulation is relatively high. The simulation of environment conservation input is better based on our study of mathematical analysis of system behaviour and system structure.

In our system thinking, the input of environment, conservation must be coordinated with the development of economy, education, as well as science and technology. There are 5 subsystems: environment subsystem, economy subsystem, population subsystem, education subsystem and science and technology subsystem and the actual System Dynamics model of environment conservation input consists of around 260 variables and 60 feedback loops, so the evolving rule of system is more complicated, and traditionally a parameter and feedback loop on the system behaviour. The focus of isomorphism analysis is trying to change the structural analysis to the topological analysis of graph, then find out the functional loop of the total system so as to the effectiveness of policy test and simulation of this environment conservation input model could be highly raised.

The algorithm of isomorphism analysis is shown as follows:

Let system is X, x,y, ... are the elements of system, the structural relationship is x→y . Assume the mapping from X to the directed graph is F, then we have:

$$F(x)=\text{apex } x,\ \forall\ x\in X$$

$$F(x\to y)=\text{apex } x\to\text{apex } y=F(x)\to F(y).$$

For each loop C in the directed graph, define

$$C_i=\begin{cases}1 & \text{if are i is in } C_r \text{ and direction is the sameas the loop direction;}\\ -1 & \text{if are i is in } C_r \text{and arc direction is reserved to to the loop direction;}\\ 0 & \text{if arc i is not in } C_r.\end{cases}$$

Based on above difinations, the algorithm of finding the functional loops is done as follows:

(1) Symbolizing the system X with its equivalent directed graph D, evaluating out the total related matrix R_e and related matrix R.

Here, D is the directed & connected graph with n apexes and l arcs,

$$\text{then: } R=(r_{ij})_{n\times l},\ r_{ij}=\begin{cases}1 & \text{if apex i is the starting apex of arc i;}\\ -1 & \text{if apex i is the finishing apex of arc i;}\\ 0 & \text{if apex i is not in arc i,}\end{cases}$$

(2) Finding the non—singular sub—matrix, and assuming it is R_{12}, then $R=(R_{11}, R_{12})$;

(3) Calculating the basic loop matrix C_f, C_f is defined as:

$$C_f=(C^{1T},C^{2T},\dots,C^{(l-n+1)T})^T=[I-R_{11}^{T}(R_{12}^{T})^{-1}]$$

(4) For every loop C_r^s, C_r the corresponding vector of C^s and C^r, verifying whether the direction number of common arc in these two arcs is the same or not, continuing step (5) when it is true, or turning to step (7);

(5) Calculating $g(C^s,C^r)$, and checking up whether the its non—vanishing vector has the same sign, if it is true then $C_r^s\oplus C_r$ is the functional loop of the system;

(6) Returning to step(4);

(7) Calculating $R_e(D,C_r^s)$ and $R_e(D,C_r)$, where

$$R_e(D,C_r)=\delta[C_1E_e,C_2E_e,\dots C_nE_e]\otimes R_e(D)$$

$$E_e^T=(1,1,\dots,1)_{e\times l}$$

(8) Finding the adjacent matrix $P(D, C_r^s)$,

$$P(D,C_r)=R_e^{+}(D,C_r)\cdot R_e^{-T}(D,C_r);$$

(9) Checking up the whether there exist non—zero element in every row and column of $P(D,C_r^s)\oplus P(D,C_r)$, if it is true then $C_r^s\oplus C_r$ is the functional loop of the system;

(10) Returning to step (4).

According to the isomorphism analysis, to get high simulation efficiency, the range of some important policy tests are shown as Table 1.

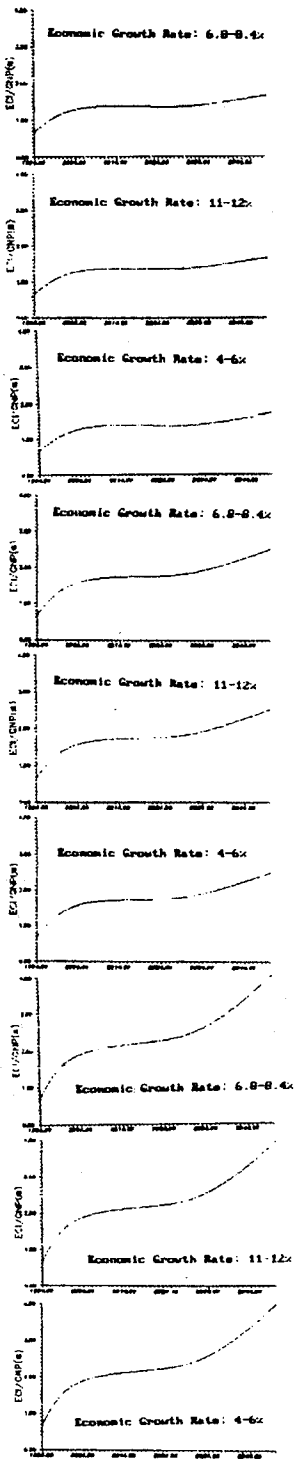
Table 1 The Varying Range of Some Important Policies

POLICY	VARYING RANGE
Environment Conservation Input over GNP	0.5% - 8%
Economic Growth Rate	2% - 15%
Science & Technology Input over GNP	0.5% - 4%
Population Growth Rate	3% - 8%

IV Simulation and Policy Analysis of Environment Conservation Input in China

According to China's economic basis and the low starting point of the investment in environment conservation in China, the increasing path is inevitable to spend a long period of time, so the time of policy design is taken as year 2050.

The required time to reach the final scale determines the rate of increase of environment conservation input. In this model, the increase rate of environment conservation input is taken as 2%, 2.5% and 4% from 1994 to 2050 correspondingly.



Time	2000	2030	2050
EL	767.9	2450.6	2830.5
GNP	18.41e3	211.5e3	759.4e3
EL	2301.7	5212.3	48379.4
GNP	24.9e3	570.0e3	4595.5e3
EL	103.6	940.7	2837.6
GNP	15.96e3	91.67e3	200.85e3
EL	777.3	1977.8	1721.5
GNP	18.41e3	211.5e3	759.4e3
EL	777.3	2977.8	2110.5
GNP	24.9e3	570.0e3	4595.5e3
EL	687.3	1736.3	1853.2
GNP	15.96e3	91.67e3	200.85e3
EL	685.3	1628.4	1873.4
GNP	15.96e3	91.67e3	200.85e3
EL	872.4	1902.3	2093.1
GNP	18.41e3	211.5e3	759.4e3
EL	872.4	1602.3	2353.1
GNP	24.9e3	589.4e3	2293e3

Fig.3 Simulation Results

Notes: EL: Environmental Loss (Unit: billion yuan)
GNP:Gross National Products (Unit: 100 billion yuan)
ECI/GNP: Environment Conservation Input over GNP

In order to provide the scenario of different economic growth rate and different ratio of environment conservation input over GNP, the economic growth rate in future China is taken around 4%, 8% and 11%. And the performance of policy tests are measured by GNP and Environmental Loss (EL).

According to the above analysis, 9 portfolio patterns of the environmental conservation input and economic growth rate are selected to analyze how the policies affect the environment and economic development comprehensively and integredly (See Fig 3).

According to the Fig 3, there are several useful conclusions:

1 Overspeeding economic growth rate (around 11%) and ignoring the sufficient environment conservation input will induce huge environmental loss (48379.4 billion yuan in 2050); the quality of environment is worse and will confine the economic development in China, this kind of policy design for economic growth and environment conservation is the worst one;

2 Overspeed both economic growth rate (around 11%) and environment conservation input will beyond the carrying-capacity of national economic, from Fig 3, the GNP will be reduced to around 189300 billion yuan, the actual economic growth rate is 5.8%, so this kind policy design is not the best one;

3 Putting the moderate economic growth rate (6.8 - 8.4%) and increasing the environment conservation input in medium rate (around 2.5%, and in year 2050 the ratio between environment conservation input over GNP is 2.5), will bring the synchronization of economic growth and environment conservation (less environment loss).

V Concluding Remarks

The input on the environment conservation is a strategic issue for China, in the meantime, it must be coordinated with one nation's economy as well as its science and technology, education, population, this is the principle of system dynamic modelling of national policy.

According to this principle of system modelling, the relations among economic growth, population growth, environment conservation, technical change and economic development et al are tentatively studied.

The system modelling on national policy often involves lots of variables and feedbacks, and the number of policy tests is large, the knowledge of system isomorphism could be used to change the structural analysis to the topological analysis of graph and to find the main functional loops in this model, then the effectiveness of policy test and simulation could be highly raised.

As a case, the environment conservation input China is studied by using the coordinative principle and isomorphism analysis, the scenario of simulation tests show that China's economic growth and environment conservation input over GNP might be 6.8%-8.4% and 2.5% correspondingly in 2050.

References:

(1) C A Tisdell, Natural Resources, Growth and Development: Economics, Ecology and Resource Scarcity, Praeger, New York, 1990.

(2) A M Freeman et al, The Economics of Environmental Policy, New York, 1973.

(3) Qingrui Xu, Chen Jin, Towards a Decision Support System of Environment Conservation Input in China, Working Paper, 940023, Institute of Management Science, Zhejiang University, 1994