Journal of Environmental Sciences, Vol. 6, No. 4, pp. 412—421, 1994 ISSN 1001-0742

Population growth, economic growth, technology changes in relation to environmental changes
——A theoretical modelling analysis of environmental changes

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Abstract— This paper mainly deals with the impact of three major factors, namely population growth, economic growth and technology changes, on the changes of environmental quality. It presents a curve of environmental changes in relation to demographic transition and process of industrialization. It concludes that a major way of improving environmental quality is to intensify pollution decreasing technical factors and that control of population growth will also reduce the pressure on the environment.

Keywords: population growth; economic growth; environmental changes; technology change.

1 Introduction

Modern economic growth is a historical theme of human development in the contemporary world. It mainly features a simultaneous high-speed development of population and per capita output value and an industrial revolution brought about by technology progress (Kuznets, 1966). According to statistics, during the more than 200 years from 1770, the annual per capita output growth in developed countries averaged 2% while population growth averaged 1% so that the total output growth reached 3% (Todaro, 1985). Whereas in China, the population growth and economic growth have far exceeded the level of developed countries. In the 38 years from 1952 to 1990, China's population grew at an average annual rate of 1.83% while the national income grew at an average annual rate of 6.7% and the average per capita national income grew by 4.9% (Chinese Statistical Bureau, 1991).

However, population and economy have grown at the expense of ecology and environment. Being the most populous country in the world, China vigorously pushed the process of industrialization starting from the 1950s, resulting inevitably in a large scale industrial pollution. The current state of the environment in China can be described as deteriorating in general, with some local improvements (Hu, 1989).

2 Economic analysis of impacts on environmental quality

Factors affecting changes in environmental quality vary and are complicated. One of major subjects of study in environmental economics is to determine the environmental quality of a country or a region, pinpointing the factors contributing to the changes in environmental quality and make a quantitative analysis of different factors affecting environmental quality.

Commoner uses environmental stress as a concept of environmental quality, and regards the amount of pollutants discharged into the environment to reflect the degradation of environmental quality. He divides factors affecting environmental quality into three kinds: population factor, such as total population, economic factor, such as per capita output or per capita consumption, and technology factor, such as the amount of pollutants discharged for per unit output. This can be expressed in the following formula:

$$\text{pollutants} = \text{population} \cdot \frac{\text{output}}{\text{population}} \cdot \frac{\text{pollutants}}{\text{output}}$$

$$\text{i.e. } P_{ol} = P_{op} \cdot \frac{Good}{P_{op}} \cdot \frac{P_{ol}}{Good}. \tag{1}$$

In the formula, P_{ol} denotes the amount of pollutant charge; P_{op} denotes total population; *Good* represents output value. The formula reflects the relations between pollutants and population, per capita output and production technology level (Commoner, 1972). We may call Formula (1) environmental quality factor equation or Commoner equation. In a given period of time, Formula (1) may be rewritten as follows:

$$1 + \Delta P_{ol} = 1 + \Delta P_{op} \cdot \frac{1 + \Delta Good}{1 + \Delta P_{op}} \cdot \frac{1 + \Delta P_{ol}}{1 + \Delta Good}. \tag{2}$$

In this formula, ΔP_{ol}, ΔP_{op}, $\Delta Good$ denote the variables of the discharge of pollutants, population and output at a given period of time or the changes per-unit time (Commoner, 1991).

The Commoner equation provides a basis for analyzing environmental quality in view of economics.

On the basis of Commoner equation, this paper introduces an environmental quality increment equation and technology factor types, first taking logarithm from both sides of the Equation (1). Then, solve the figures on both sides of the equation and take differential form:

$$lnP_{ol} = lnP_{op} + ln\left(\frac{Good}{P_{op}}\right) + ln\left(\frac{P_{ol}}{Good}\right). \tag{3}$$

$$\frac{\Delta P_{ol}}{P_{ol}} = \frac{\Delta P_{op}}{P_{op}} + \frac{\Delta\left(\frac{Good}{P_{op}}\right)}{\left(\frac{Good}{P_{op}}\right)} + \frac{\Delta\left(\frac{P_{ol}}{Good}\right)}{\left(\frac{P_{ol}}{Good}\right)}. \tag{4}$$

To express the formula above in the following letters:

$$P = P_\alpha + P_\beta + P_\gamma. \tag{5}$$

In the formula, P denotes the growth rate of pollutants discharge; P_α denotes the growth of the population; P_β denotes the growth of production or per capita output value; and P_γ denotes the technology co-efficient, i. e. the annual growth rate of pollutants discharge per-unit output or output value. This indicator reflects the type of production technology and level. We call Formula (5) the increment equation of environmental quality, showing that the growth of pollutants discharge is determined by the growth of per capita output value and technology coefficient. In order to compare quantitatively the impacts of various factors on the environment quality, we define the contribution of various variable in the following formula:

$$E_\alpha = \frac{P_\alpha}{P} \cdot 100\%, \tag{6}$$

$$E_\beta = \frac{P_\beta}{P} \cdot 100\%, \tag{7}$$

$$E_\gamma = \frac{P_\gamma}{P} \cdot 100\%. \tag{8}$$

In the formulas, E_α, E_β, E_γ are contributions of, respectively, population factor, economy factor and technology factor to the environmental quality. For aparticular factor, when $E_i>0$, it increases the pressure on the environment, thus contributing to the deterioration of the environmental quality. The larger the value of E_i, the larger its contribution; when $E_i<0$, pressure on the environment is reduced, making negative contributions to the deterioration of the environmental quality, i. e. contributing to the improvement of the environment quality; when $E_i=0$, the factor does not have any pressure on the environment and it therefore has no impact on the changes of the environmental quality.

No matter what the contributions of various factors, they should satisfy the following condition:

$$E_\alpha + E_\beta + E_\gamma = 100\%. \tag{9}$$

The environmental quality factor equation (1), the increment equation (5) and the contribution equation (6), (7), (8) form the basic methods for analyzing the changes of the environmental quality and its contributing factors. Here we do not regard the changes in the environmental quality as a technical process, but as an economic development process, and investigate the process of the changes of environmental quality against the background of the growth of the population, economy and technology, and analyze the real dynamic factors causing changes in the environment.

3 Roles, types and significance of technical factors

From Formula (5), we can see that the pollutants discharge grows in proportion to the growth of the population. The growth of the per capita output value (a variable reflecting the economic development level and the living standard of the people) also stimulates the growth of the discharge of pollutants. However, we have to make a specific analysis of technology factor, examining its types and characteristics. Few people have studied this factor in the past ignored the differentiation of different types and nature of technology factor. Here we shall make a specific analysis of the roles and significance of this factor.

First of all, we define the technology co-efficient P_γ as the difference between P and $(P_\alpha+P_\beta)$. From Formula (5), we can arrive at the following formula:

$$P_\gamma = P - (P_\alpha + P_\beta). \tag{10}$$

In the formula, the economic implication of P_γ includes technology progress and changes in the industrial structure.

As the increase of output $P_y=P_\alpha+P_\beta$, Formula (10) may be rewritten as:

$$P_y = P - Py. \tag{11}$$

Formula (11) shows that the technology co-efficient is related to the growth of the discharge of pollutants and the growth of output.

We have taken note of the fact that technology level has developed rapidly since the industrial revolution in industry, communication, construction and public utilities in the 18th century, and technologies developed before the 1960s and 1970s all belong to the pollution increasing type. After that, with the rise of the living standard of the people, there was a demand for better environmental quality, thus stimulation the development of pollution reducing type of technology. This shows that the technology factor is not a hard and fast one. On the contrary, it has its diversity and changeability.

We have divided the technology factor into three types:

(1) Pollution increasing type. It refers to the index of pollutants discharge exceeding the index of the growth of output (Fig. 1—A curve), $P_\gamma>0$, i.e. $P-Py>0$, and so $P>Py$.

(2) Pollution reducing type. It refers to the index of pollutant discharge lower than

the index of output growth (Fig. 1—B curve), $P_\gamma<0$, i.e. $P-P_\gamma<0$, and so $P<Py$.

(3) Neutral technology. It refers to the index of pollutants discharge increase equalling the index of output growth index (Fig. 1—C curve), $P_\gamma=0$, i.e. $P-Py=0$; and so $P=Py$.

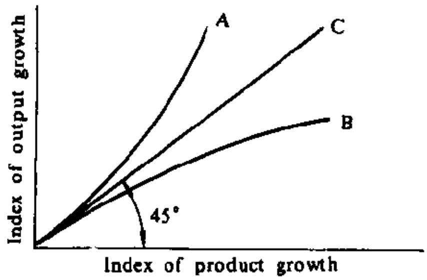

Fig. 1 Classification of technology factor
A—Pollution increasing type;
B—Pollution reducing type;
C—Neutral technology

From the contributions technology factors to the deterioration of the environmental quality, the pollution increasing type of technology is $E_\gamma>0$; pollution reducing type of technology is $E_\gamma<0$; and neutral technology is $E_\gamma=0$.

To introduce technology factor into the environmental quality equation and to classify them is of great significance in studying the changes of the environmental quality. This is because: (1) Technology factors are not identical but diversified, with different technologies having different impacts on environmental quality. With the growth of output, it may increase or reduce pollution. In the process of industrialization, it is of major importance to select the proper technical line that will help reduce pollution but increase output. (2) Technical factors is not static or hard and fast. It is dynamic and has stages. The choice of technology is closely related to the industrial structure and the stage of development. When a country is at a low come stage of initial stage of industrialization, the demand for environment quality by residents is not high and the state lacks the ability of developing pollution-reducing technology. When a country is at a stage of high income or a post industrialization period, the demand for environmental quality by residents is higher and the state has the ability (funds and technology) of developing pollution-reducing technology. From a dynamic view of long-term development, the technology factor develops from pollution increasing type into neutral type and onto the stage of pollution reducing type. These are the stages of human progress and so is the evolution of technology factor. (3) Technology factor is not a single concept in a narrow sense, but a comprehensive concept in a broad sense. It includes levels of both technology and industrial structure, at microscopic as well as macroscopic levels. It provides a simple but effective way of analyzing the status of environmental quality, trend of changes and their causes of a factory (microanalysis), a region (mesoanalysis) and a country (macroanalysis). Microanalysis stresses the type of technology such as hydroelectric power technology which is of the pollution-free type, oil-fired electric power technology which is a type causing light pollution and coal-fired electric power technology which is a heavy pollution type. Macroanalysis stresses the type of industry for development, such as tourism which is a pollution-free industry, electronic industry which is light-pollution or pollution-free type and metallurgy and petroleum which are heavy pollution type. Misoanalysis stresses both the type of technology and industrial structure. Technology factor includes not only production technology and industrial structure but also consumption technology and mode, such as energy for daily use. The use of electricity causes light pollution; the use of coal causes heavy pollution; the use of public transportation means (buses and subways) causes light pollution and the use of a lot private cars causes heavy pollution. The pollutants discharge is in direct proportion to the energy consumption but inversely proportional to the consumption technology and mode. (4) Technology factor is not an ordinary and minor factor, but a special and important one and the most active and changeable one. As a source of discharge of pollutants, it is an important factor contributing to the deterioration of the environment quality; as a way of controlling and preventing pollution, it is a decisive factor in improving the environmental quality. This dual character determines that it is a key factor to the changes in the environment.

4 Environment change curve

The environment change curve is dynamic, showing the changes in environmental quality. Environmental pollution is a by-product of industrialization. Process of changes of environmental quality is closely associated with process of industrialization. Different levels of industrialization determine stages of changes in environmental quality.

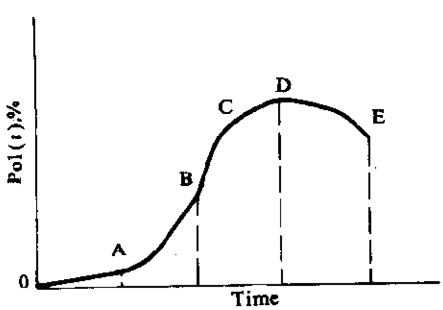

Fig. 2 Curve of pollutants discharge

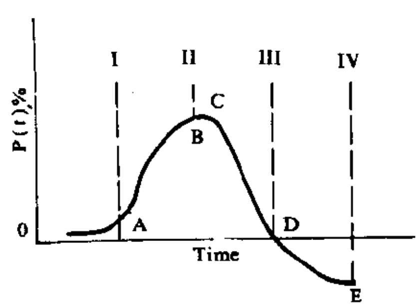

Fig. 3 Curve of speed of pollutants discharge

We use the discharge of pollutants and its growth rate to describe the curve of environmental quality or environmental changes and obtain the following dynamic equation:

$$\frac{\mathrm{d}P_{oi}(t)}{\mathrm{d}t} = P^{(t)} = P_{\alpha}^{(t)} + P_{\beta}^{(t)} + P_{\gamma}^{(t)} = P_{y}^{(t)} + P_{\gamma}^{(t)}. \tag{12}$$

For features of the above dynamic equation, see Fig. 2 and Fig. 3. We call Equation (12) environment change equation and the curves in Fig. 2 and Fig. 3 environment change curves.

The process of environmental quality changes is governed by its intrinsic law, which is reflected theoretically in the environment change curve. The process of environment changes can roughly be divided into four periods in relation to the demographic transition curve (Fig. 4) and the curve of the ratio of industry or manufactural industry to GNP (Fig. 5)

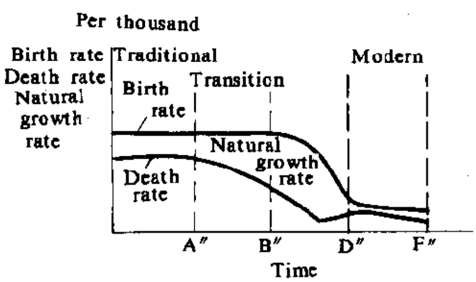

Fig. 4 Demographic transition curve

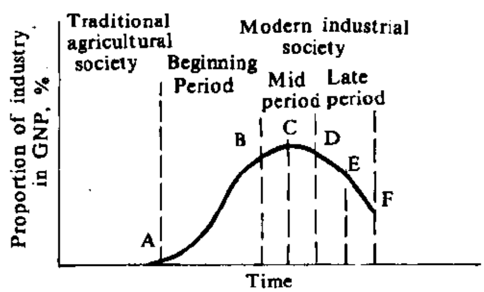

Fig. 5 Proportion of industry or manufacturing to GNP

Period Ⅰ: there is no or low industrial pollution and the environmental quality is good. This happens in a traditional agricultural society. As there is no industry, there is no industrial pollution. But this does not mean that there is no discharge of pollutants. The pollutants are discharged mainly by human and animal, which are quite small, so much so that it was negligible as compared with a modern industrialized society. In that society, there is no modern economic growth in its real sense and the growth rate of per capita output value nears zero. Population is the main factor affecting the environmental quality. Suppose the amount of pollutants discharge is equal to the growth rate of population, then we get:

$$P^{(t)} = P\alpha^{(t)}. \tag{13}$$

As it is a traditional society, which features high birth rate, high death rate and low natural growth rate, the population growth $P\alpha^{(t)}$ is considerably small, hence the low growth of the discharge of pollutants.

Period Ⅱ: Industrial pollution increase and environmental quality is degraded. This is a stage in the initial period or middle period of industrialization. The population enter the transitional stage, with high birth rate, rapidly declining death rate and rapidly raising natural growth rate (Fig. 4 A—B section). The high growth of population exerts much pressure on the environment. Economically, the growth of per capita output value breaks the 1% level, revealing the features of modern economic growth. Many countries are in the stage of transition from low income to middle income, showing signs of economic take off and rapid growth of per capita output value. Technologically, this is a period in which countries begin to establish industrial systems and lay foundations, with the proportion of industry or manufactural industry to the GNP rising rapidly (Fig. 5, A—B section). At the same time, pollution increasing industries, such as coal, iron and steel, chemicals and building materials are founded. Pollution increasing technology is extensively adopted such as the massive application of chemical fertilizers and pesticides and the use of dirty energy source of coal in industry. In that period, the growth of pollutants discharge rose rapidly to reach a peak (B) and the environmental quality of a country or a region drastically deteriorated. While humanity enters the era of industrialization, it enters the era of environmental pollution.

Period Ⅲ: Industrial pollution grows slowly, but environmental quality continues to decline. This happens in the middle or later period of industrialization. In terms of population factor, death rate continues to decline and so is birth rate and natural growth rate (Fig. 4, B—D section). Economically, the average per capita income begins to move from middle income to high income, with the per capita output value growth slightly declining. Technologically, with the establishment of industrial systems, there is not much change in the proportion of industry or the manufacturing to the GNP. The tertiary industry rises steadily, resulting in the decline of the pollution increasing industries and the rise of pollution reducing industries. Pollution reducing technology and processes begin to be adopted and the public demand better environment. These factors have helped reduce the discharge of pollutants. Suppose the technical co efficient $P_T^{(t)}=0$ on the C' point, then the growth of pollutants discharge is equal to the growth of output. When $P_T^{(t)}<0$ after point C', then $P^{(t)}<P_T^{(t)}$, showing that the pollutants discharge is lower than the growth of output. When it reaches D' point, with the pollutants discharge growth nearing zero, and the pollutants discharge reaches the peak (Fig. 3-D), it has entered a stage of improvement of the environmental quality.

Period Ⅳ: Industrial pollution has been reduces steadily and environmental quality begins to improve continuously. This happens in the late period of industrialization or in the post-industrialization period. The population growth is marked by low birth rate, low death rate and low natural growth rate, with many countries recording zero growth. Economically, the per capita income is at a high level. As the economy enters a period of maturity, the economic aggregate is big and the consumption residents enters a period satuation. Though the growth of per capita output is low, the demand for better environment by the public exceeds that in any other periods, constituting a tremendous pressure for improving the environmental quality. Technologically, with the completion of industrialization, the proportion of industry or the manufactural industry to the GNP begins to drop; the traditional industry begins to decline; emergening industries gradually becomes the leading sector, with the tertiary industry accounting for a large proportion in GNP, far exceeding the proportion of the manufactural industry. The technologies adopted feature low pollution, low energy consumption and low material consumption. The pollution reducing technology factor has grown, overtaking the role of other factors. The growth of the discharge of pollutants is negative and the amount of pollutants decreases steadily. It is only at this period that the growths of population and economy and environment protection are well coordinated, and mankind and nature have returned to their harmonious relationship.

As the conditions of various countries vary, the environment change curve is not universally applicable. There might be differences with regard to the demographic transition curve and the curve of the proportion of industry to the GNP. The various periods shown in the curves do not strictly correspond with each other. They provide a framework for analyzing the environmental problems and the stage of the development, and need to be substantiated by practical materials.

5 Summary

Main work and conclusions of this paper:

(1) This paper has constructed an environmental quality economics equation on the basis of the Commoner equation and has used this equation to analyze the effects of population growth, economic growth and changes in technology on the quality of the environment. The method is clear and computation to easy.

(2) This paper has given special emphasis on the technology factor which is decisive in the changes of the environmental quality, and is divided into three types: pollution increasing type, pollution reducing type and neutral type. Technology factor not only includes production technology but also industrial structure, technology and mode of consumption.

(3) This paper has draw an environmental change curve, and has associated it with demographic transition and the process of industrialization and has divided it into four periods: period I, which is the pre-industrialized society featuring no or low industrial pollution and good environmental quality; period II, which is the initial or middle period of industrialization featuring rapidly growing industrial pollution and drastic deterioration of the environmental quality; period III, which is the middle or later period of

industrialization featuring slower growth of industrial pollution but continued deterioration of the environmental quality; and period Ⅳ, which is the post-industrialization or post-industrialized society featuring diminishing industrial pollution and constant improvement in the environmental quality. This is the theoretical framework for knowing the relationship between the changes of the environment and development stages.

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(Received April 5, 1994)

Journal of Environmental Sciences, Vol. 6, No. 4, pp. 422—431, 1994 ISSN 1001—0742

Yellow River Valley flood and drought disaster: spatial-temporal distribution prediction and early-warning

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Abstract——By means of analysing the historical data of flood-drought grade series in the past 2000 years (A. D. 0—1900), especially in the last 5000 years (1470—1900), this paper revealed the spatial-temporal distribution features of severe flood and drought in Yellow River Valley. Statistical methods of variance analysis, probability transition and the principles of scale correspondence were employed to comprehensively predicate 90's tendency of severe flood and drought in the Yellow River Valley. In addition, this paper pointed out the possible breaching dikes, sectors and the flooding ranges by future's severe flood, meanwhile estimating the associated economic losses and impact to environment.

Keywords: Yellow River Valley; flood and drought disaster; spatial-temporal distribution; prediction and early-warning.

1 Introduction

China will be entering a new developing era from now to the year 2000. By 2020, the mid-term targets of China's industrialization project will be accomplished. In the initial and mid stages of this industrialization process, economy is being developed rapidly and those industries consuming numerous resources and discharging large amounts of wastes are bringing about a series of environmental problems, for example, the urban scope and urban infrastructure can not meet the increasing demand caused by rapid population growth; the degradation of urban environmental quality caused by housing shortage, traffic jam and environmental pollution; the excessive resources exploitation and the aggravation of environmental pollution hastened by the development of rural and township industries; soil erosion, land quality degradation and desertification; drought and flood disasters; shortage of water resources decrease of biological species and so on. All these environmental problems have been turned into severe obstacles for social and economic development. The major points of ecological environment early warning research include how to deal with the relationship between resources exploitation and envi-