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Impacts of water pollution and shortage on the economic development of the Haihe River basin

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Abstract The Haihe River basin is one of the seven major river basins, which are of great ecological importance to China. On one hand, the Haihe River basin's economy is developing rapidly, but on the other hand, the ecological environment in this region is increasingly worse, and its ecosystem is becoming extremely fragile, which is not harmonious with its rapid economic development. Coming from the general equilibrium theory of Walrus, the CGE model (Computable General Equilibrium) can be applied to analyse the impact of government policy on economic development. Environmental policies taken to reduce pollutant disposal and water consumption directly influence product price, production cost, and even economic structure. In this paper, by building a CGE model, we will analyse the impact of water pollution and water shortage on economic development in the basin region. By viewing water resource as one of the production factors and water pollution treatment as an independent entity, we will also analyse the relationship between input and output of water resource, and between water pollution control and other economic activities. The analysis comes to the following points. First, through water pollution control the traditional GDP decreases, but the green GDP increases. Second, compared to water shortage, the water pollution crisis is more urgent. Through the water diversion project from the south to the north of China and technique index promotion, water shortage is alleviated, but water pollution needs further effort.

Key words CGE Model; Haihe River basin; water pollution; water shortage

INTRODUCTION

The Haihe River basin is one of seven major basins in China. Due to its location as the country's political and cultural centre, the region plays an essential role in the development of China's economy. Over the past three decades, the ecology and environment has suffered great deterioration, while the area has seen rapid economic development. Serious water pollution, the drying-up of rivers, and over-exploitation of groundwater have affected the weakening of river function, deterioration of estuarine ecology, a large decrease of the quantity of water entering into the sea, the area of wetland, and bio-diversity. Consequentially, sewage irrigation has a strong impact on people's health, and thus water security in north China has become the focus of the country (Xia, 2001, 2007).

CGE (Computable General Equilibrium) model, originating from the general equilibrium theory of Walrus in western economics, is applied to analyse the influence of government policy over economic development, and can take environment and resource elements into a numerical model of the general economic equilibrium, and thus show how the general mechanism of key elements determine resource distribution and income distribution in the market economy. The key point in setting up the CGE model is to actualize the abstract form of Walrus's general equilibrium theory into a concrete model (Shoven & Whally, 1984). An important characteristic of the CGE model is that it contains all the factors in economic activity—the government's budget, tax policy, foreign trade, the labour, capital, natural resources and the influence of environmental policy in consideration of environment (air and water quality, etc.). Therefore, the economy can comprehensively be taken into account, together with resources and the ecological environment.

The CGE model has been applied in environmental policies research, such as PRCGEM, developed by the Development and Research Centre of State Department and the Chinese Academy of Social Sciences (CASS), which has been applied by CASS to analyse the impact of the carbon tax and CO_2 emission control policies on the economic development of China. There are also some cases of using the CGE model to analyse the relationship between water and economy. The Chinese Academy of Water Conservancy and Hydropower adopts the CGE model to calculate the marginal price of water in Handan City (Shen Dajun, 1999). There are many approaches in modelling CGE with respect to water resource and environment factors. The key lies in how to relate water resource and water environmental factors to the economic system, like bringing labour, capital and water into production function (Berck, 1991), or regarding water resource development and environmental factors as an independent economic branch and taking them as middle input into the production function (Dixon, 1990).

In this paper, we will analyse the input of resource and environmental factors in the whole economic activity by building a simple CGE model, and studying the advantages of modulating the economy by analysing environmental policy such as the policies of water shortage alleviation, and pollution control in the Haihe River basin through an extended model, in order to analyse the impacts of water resource shortage and water pollution on economic development in the basin. Here, water resource is brought into production function as a factor of production in the modelling, and water pollution control is regarded as an independent economic section.

MODEL CONSTRUCTION AND PARAMETER SELECTION

The Chinese national economy can be divided into eight sectors: agriculture; industry; construction industry; transportation and post and telecommunication industry; commerce and catering; government utility and citizen service industry; financial insurance; and other service industries. By using the CGE Model, we will analyse the total GDP and green GDP, and also study the increase of different sectors in economic development under water pollution control of different degrees and with water resource supply of different amounts.

Supply module

Assuming that each department of the eight sectors only produces one kind of product, and production elements are capital, labour, water resource and intermediate input, then the commonly used Cobb-Douglas (C-D) production function is adopted, and three factors are included: the labour, the capital and water resource.

Our modelling first sets up independent pollution water disposal departments, supposing that *WP* is the sum of pollutant water disposal, it is 54×10^8t year^{-1} in Haihe River basin in 2000, the charge for pollutant water disposal of each individual department is tp_i (the tax rate of department no. *i*, assumed to be regulated by government), and the disposal tax rate of domestic water use is assessed upon the quantity of water consumption and sewage disposal.

The total pollutant water emission of national economy is *WP*, and then the emission of each individual industry is assumed to be $\alpha_i WP$. The domestic water pollutant emission is $\alpha_9 WP$. Supposing the coefficient of water pollution emission corresponding to industry unit production and intermediate input is e_i, then there is:

$$X_i - e_i = \alpha_i WP \qquad (1)$$

and then we get

$$\sum_{i=1}^{8} \alpha_i WP_i - d_i = X_9 - \alpha_9 WP_9 - f \qquad (2)$$

In the formula, $\alpha_i WP_i\ d_i$ stands for department expense on pollution elimination, and d_i for pollutant rate, *f* is the pollutant rate of consumption.

The total available water resource of Haihe River basin is the summation of water diverted from Yangtze River and the local water resource. Ecological water use is calculated according to water use of the ecological rehabilitation plan of the basin.

The net output (*GDP*) of every industry is:

$$GDP_i = P(1 - td_i)X_i - \sum \mathrm{P}_j a_{ji} X_j - \sum_s W_s L_{is} - \alpha_i WP_i - d_i \qquad (3)$$

The P_i in the equation stands for product price, and *L* and *W* stand for labour and wages, respectively.

Demand module

Citizen income is their wages, and their net income is minus tax and banking. The net income of enterprises is their net profit, and the government income is just taxes. Consumer purchase ability is limited by price level and net income level, and citizen consumer activities are described as follows in the CGE model.

$$X_{i,citizen} = b_i \frac{Y_s(1 - S_s)(1 - t)}{P_i} \qquad (4)$$

b_i is the proportion of citizen consumption in each industry, Y_s is citizen income, S_s is the proportion of banking, *t* is the tax rate, and P_i is the product price of each industry. Government consumption is mainly on public utilities and other service industry.

We get the intermediate consumption directly from the input–output table:

$$X_v = \sum_i a_{ij} X_j \qquad (5)$$

The a_{ij} in the equation is the input–output coefficient. We evaluate the range of annual regulation of a_{ij} according to the American input–output table of 1992 (the process will not be elaborated on).

As for investment consumption, supposing all deposits are totally applied to investment (*TS*), the sum of investment (equal to the total deposits) includes the industry and the construction department. Their proportion is selected by an investment ratio of Beijing in the year 2000.

Then we consider water pollution elimination as an independent department and its products can be bought by each department to eliminate their water pollution. The output of the each department is $X_i d_i e_i$. Its investment proportion in total investment is (1 – k), β is the proportion of each industry.

Therefore, investment consumption is:

Industry $$IND = TS\beta_1 p_1 + TS\beta_2 p_2 + ... + TS\beta_8 p_8 + TS(1-k)0.5 \quad (6)$$

Construction $$CON = TS\beta_1 q_1 + TS\beta_2 q_2 + ... + TS\beta_8 q_8 + TS(1-k)0.5 \quad (7)$$

Total consumption:

$$X_d = \sum_{i=1}^{9} x_i + V_i + \sum_{i=1}^{9} g_i + Inv \quad (8)$$

The items in the equation above are gross consumption, citizen consumption, intermediate input consumption, government consumption and investment consumption, respectively.

Green GDP

Compared to the conventional GDP, the green GDP takes into account environmental factors, which includes two parts—natural resource consumption and the deterioration of environmental quality. Supposing λ is the marginal damage resulting from pollutants emission, or in other words the marginal benefit brought by the decrease of pollutants emission, $X_i e_i$ is emission quantity of each industry, and $X_i e_{i0}$ is the quantity of water pollution emission that will not bring harm to environment, then we get:

$$gGDP = GDP - C = GDP - [\lambda X_i (e_{i0} - e_i) - X_i - d_i] \quad (9)$$

C is the economic loss caused by environmental pollution, $X_i d_i$ is the cost of pollution prevention and control, equal to pollution charge.

The parameters X_i, d_i and e_i has been given above (we just confirm λ and e_0. e_0 is the percentage of water pollution emission that has been treated and will not do harm to environment (in most developed countries, it is higher than 90%, but in the Haihe River Basin, it is only 15%). If it is increased to 90% the quantity of water pollution emission that will do no harm to the environment is 6.6×10^8 m^3 $year^{-1}$. λ is the damage resulting from one ton pollution emission, including production damage and consumption damage. The production damage caused by the industry in the Haihe River basin is 23.4×10^8 \$ $year^{-1}$ in 2000, and that of agriculture is 14.1×10^8 \$ $year^{-1}$. Consumption damage, which includes family antipollution expenses and health loss expenses, are 0.84×10^8 \$ $year^{-1}$ and 14.7×10^8 \$ $year^{-1}$. Thus, the total damage is 54.6

$\times 10^8$ \$ year^{-1}, 4.7% of the total GDP, and \$1.102 losses result from one ton pollution water.

Equilibrium of the models

The CGE model reaches general equilibrium through the following equations, i.e. the supply equals consumption.

$$X^S = X^D \text{ (supply and consumption are equal)} \tag{10}$$

Besides general equilibrium, we also get restraints in terms of total water resources and total water pollution emissions:

$$\sum_{i=1}^{9} Q_i + W_{ecology} + W_{domestic} \le Q \tag{11}$$

$$\sum_{i=1}^{8} \alpha_i WP_i \cdot d_i + \alpha_9 WP_9 - f \le WP \tag{12}$$

The goal of the economic activities is to seek maximum green GDP.

$$Max \quad gGDP = GDP + X_i \cdot d_i + \lambda e_i \tag{13}$$

Scenarios analysis

Total water resource change includes annual average water resource change (available water resource except reused sewage) and water resource from the water diversion project from the south to the north. The local average annual water resource in Haihe River basin is 354.0×10^8 m^3 year^{-1}, water diverted from Yellow River is 51.0×10^8 m^3 year^{-1}, deep ground water overexploitation is 63.7×10^8 m^3 year^{-1}, the ecology water use and reservoir change is 36.7×10^8 m^3 year^{-1}, and thus the current total water consumption is 432.0×10^8 m^3 year^{-1} in the basin, and in the year 2010 the gross will be 492.6×10^8 m^3 year^{-1} owing to the water diversion project from the south to north. There are two kinds of situation: when ecology rehabilitation is carried out, ecological water use would be 100×10^8 m^3 year^{-1}; and secondly if the ecology condition continues worsening, ecological water use would be at the present level of 24×10^8 m^3 year^{-1}. What is above is only the constraint of total water use, and in that calculation, the water use would be determined by the requirements of industries. Based on the change of water resource, we may model the relationship between water shortage, water pollution charge and economic development.

RESULTS OF SIMULATION AND DISCUSSIONS

Table 1 shows the change of GDP and green GDP caused by different controls of total water pollutant emission brought by the charge of water pollution. Table 2 shows the change of the output of different industries caused by that charge.

Table 1 Results of different control of water pollution emission.

Emission of total amount (10^8 t year^{-1})	40	35	30	25
Total output (10^8 \$ year^{-1})	8398.6	8388.2	8353.5	8301.5
Traditional GDP (10^8 \$ year^{-1})	3260.0	3258.3	3248.3	3243.1
Green GDP (10^8 \$ year^{-1})	3220.6	3221.3	3223.6	3224.0
Total water consumption (10^8 m^3 year^{-1})	360.0	358.9	356.9	355.3
Pollution loss (10^8 \$ year^{-1})	36.8	31.3	25.8	20.3
Pollution charge (10^8 \$ year^{-1})	1.1220	1.1268	1.1012	1.1341

Table 2 Output of different industries caused by different controls of pollution emission.

Total amount of emission	output (10^8 \$ year^{-1}) 30 (10^8 t year^{-1})	40 (10^8 t year^{-1})	Rate of change (%)	Water consumption (10^8 m^3 year^{-1}) 30 (10^8 t year^{-1})	40 (10^8 t year^{-1})	Rate of change (%)
Agriculture	1050.6	1051.7	0.11	314.9	314.7	–0.05
Mining industry	318.3	320.3	0.63	2.1	2.2	3.36
Light industry	1342.7	1352.8	0.75	13.1	13.9	6.09
Energy	325.1	328.0	0.87	6.1	6.6	7.88
Heavy industry	2586.2	2607.9	0.83	16.3	17.9	8.96
Construction	652.5	653.5	0.15	0.8	0.8	0.70
Transport & telecommunications	253.9	254.2	0.13	0.8	0.8	0.59
Service	1824.1	1830.2	0.33	2.9	3.1	5.52

From these results we know that economic development will be influenced when controls for water pollution are implemented. If we increase water pollution charge by 31%, water pollution emission will decrease by 25%, from 40×10^8 t year^{-1} to 30×10^8 t year^{-1}, and the total output will decrease by 0.53%; if total water pollution emission reduces from 40×10^8 t year^{-1} to 35×10^8 t year^{-1}, the total output will decrease by 0.123%; if total water pollution emission reduces from 35×10^8 t year^{-1} to 30×10^8 t year^{-1}, the total output will decrease by 0.414%; and if water pollution emission is cut from 35×10^8 t year^{-1} to 30×10^8 t year^{-1}, the total economic output will be greatly influenced, reducing by 0.622%. Although the change of the total water pollution emission remains constant, it will bring different influences to the total outputs. When the control of water pollution emission is strengthened, economic development will greatly accelerate. The decision-makers should make appropriate policies through water pollution emission control on economic development and ecological rehabilitation.

From Table 1 we come to this conclusion: first, through water pollution control, the conventional GDP decreases, but the green GDP shows a tendency to increase, and the economy grows sustainably; second, through the water diversion project from the south to the north and the promotion of a technique index, water shortage is alleviated. Compared to the water resource shortage in the river basin, the water pollution problem seems more urgent and needs further effort.

Through the analysis of impacts of water pollution control and water resource alleviation on different industrial outputs (Table 2), we know that the energy industry is most sensitive to water pollution control, the loss caused by water pollution is most serious, and heavy industry is most sensitive to water shortage. When the degree of water pollutant control changes from 40×10^8 t year^{-1} to 30×10^8 t year^{-1}, the production output of all the industries will decrease, among which the energy and heavy industries suffer the greatest loss. Therefore, the industries that need urgent adjustment are the energy industry and the heavy industry. Table 2 shows that the economic development of the Haihe River basin needs adjustment of industrial structure to encourage low pollution emission and low water consumption.

This paper analyses the impacts of water pollution and water resource shortage on the economic development of the Haihe River basin. Further analysis and discussion should be given to the input and output coefficient, the technological progress coefficient, and the quota of water use in the future. We hope this study could serve as applicable suggestions to the decision makers of the Haihe River basin.

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