A dynamic computable general equilibrium model to calculate shadow prices of water resources: implications for China *

Jing He and Xikang Chen

Institute of Systems Science, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing, P.R. China.

May 16, 2004

Abstract. Although the use of shadow prices (SP) calculation approach has been widely appreciated in public macroeconomics calculation way, discussions of SP have been confined to static settings. This paper develops a dynamic SP approach based on multi-periods Input-Output (I-O) optimizing model. Unlike previous approaches it is based on the dynamic computable general equilibrium(DCGE) model to solve the problem on marginal long-term prices of water resources. Firstly, basic concepts of dynamic I-O analysis and Turnpike theory are reviewed. Secondly, definition and algorithm of DCGE is elaborated. Lastly result of SP for1949-2050 in China as well as the sensitivity analysis by using the national water conservancy Input-Occupancy-Output table of China for 1999 in 19 sectors is listed out. A lesson from this paper is that the SP of water resources is largely based on the scarcity extent. Selling prices of water resources should be rewritten with the use of parameters representing SP.

Keywords: water development, shadow prices, dynamic, computable general equilibrium, input-output analysis

* This research has been partially supported by grant a National Nature Foundation of China (NO.70131002).

1. Introduction

China is poor in water resources with the average annual water resources of 2812.4 billion m^3. Per capita annual water resources of China in 1999 was 2230 m^3, which is less than one-third the global average of 7,800 m^3. Regional distribution of water resources in China is unbalanced(Chen et al., 2003). Water prices policy has the potential to mitigate water scarcity. Because of its key role in managing water demand and supply, water prices is an important policy instrument for creating incentives to conserve and allocate water efficiently. Shadow prices (SP) can be calculated for those goods and services set by government. The government still controls the prices of water resources so the result of SP can give the useful decision support. As water moves from least productive to most productive uses, places, and time points for efficient allocation, there will be a convergence of the scarcity value, opportunity cost, and longterm marginal cost of the resources. Unfortunately, such a convergence is rarely seen in practice. Unrealized longterm marginal cost still exists and selling water prices can be estimated much lower. For this to occur, technology to dynamic computable general equilibrium for calculation of SP is required, as are institutions to govern the development, allocation, and utilization of the water resources(Liu, 2003). There are brief four approaches to calculate the Chinese SP of water resources: (1) static computable general equilibrium (CGE) model. It regards the prices of water resources for the output of the water resource sector and the input of the non-water resource sector as the equilibrium prices between the supply and the demand(Shen, 2003). (2)Equilibrium prices in I-O table(Zhong, 1984). The supplying water sector is putted into the I-O table as a sector or a commodity and then theoretical prices of the sector is regarded as the SP. The difficulty of this way is to construct the value type I-O table of water resources and it is the most basic work in the water conservancy economics in China.(3)Marginal prices(Chen et al., 2003). This way is most popular to use and equal to the derivative prices of the production function. (4) Linear programming (LP) model(Liu, 2003). We can use optimal solution of the resources allocation and get the resources SP from the optimal solution of dual problem according to the water resources constraint line in the LP .In the non linear programming the SP is equal to the Lagrange multipliers and in the dynamic programming the SP is equal to the vector in the Hamilton matrices(Zhao, 1995). In a word, the four above models show the different process of resources allocation and economics theory and ideas directing them.

On the other hand, when we applied the real-time data to the above models we always face the same difficulty of collecting the required interdependent data. So we try to solve this problem by constructing the I-O table of water resources. So far there are some expertise have use the I-O analysis to the water resources, such as research on Colorado River developed by California and Arizona state in USA (H. O. Carter, 1985) on which the paper list the water resources sector alone (Hynd Bounhia, 1998); the water resources I-O table in Beijing of China. (MeiXie, 1991); the water resources I-O table of Shanxi Province (Chen ,1994); the water resources I-O table in Huabei and Xinjiang regional of China (Chen, 1997). All above constructed water Input-Output tables are water resource Input-Output table. They only discuss and study how to use and allocate water resource, and do not study water conservancy construction.For example, construction of duke, reservoir, floodgate, flood discharge and flood diversion project, water ecological construction and water conservancy management, etc. In our model we will study all water conservancy activities.

This paper will proceed as follows. Section 2 will review the basic concepts of dynamics I-O analysis and Turnpike theory. Section 3 and Section 4 will elaborate the definition and algorithm of the proposed dynamic model for Chinese SP calculation. Section 5 we bring forward the result of SP for 1949-2050 in China as well as the sensitivity analysis by using the national water conservancy Input-Occupancy-Output table of China for 1999 in 19 sectors. The further research problems and the lesson will be outlined in Section 6.

2. Extended dynamics I-O model and Turnpike Model

In order to understand the dynamic computable general equilibrium (DCGE) model for SP, the extended dynamics I-O model and Turnpike model are crucial .We also develop the above two models for the calculation based on the separation of the amount and the structure.

2.1. Dynamics I-O Model (DI-O)

The linear static and dynamic I-O models are well known in economic theory and practice(Leontief, 1951). The dynamic extended Input Occupancy Output (I-O-O)model (Liu, 1995)is as follows:

$$\sum_{j=1}^{n} X_{ij}(t) + \sum_{j=1}^{n} Z_{ij}(t) + Yc_i(t) = X_i(t) \quad (1)$$

$$K_{ij}(t+1) = K_{ij}(t) + Z_{ij}(t) - D_{ij}(t+1) \tag{2}$$
$$i, j = 1, 2, ..., n$$

Where,$X(t)$is output in t year,$K_{ij}(t)$ is sector i th use of input j th available capital goods in t year,$Z_{ij}(t)$ is sector i th use of input j th capital investment in t year,$D_{ij}(t)$ is sector i th use of input j th depreciate in t year.

Define 1. Direct input coefficient in t year

$$a_{ij}(t) = \frac{X_{ij}(t)}{X_j(t)} \tag{3}$$

Define 2. Added investment coefficient in t year

$$b_{ij}(t) = \frac{K_{ij}(t) - K_{ij}(t-1)}{X_j(t) - X_j(t-1)} \tag{4}$$

Define 3. Depreciate coefficient in t year

$$\beta_{ij}(t) = \frac{D_{ij}(t)}{X_j(t)} \tag{5}$$

Thus,

$$\sum_{j=1}^{n} a_{ij}(t)X_j(t) + \sum_{j=1}^{n}[b_{ij}(t+1)(X_j(t+1) - X_j(t)) + \beta_{ij}(t+1)X_j(t+1)] \tag{6}$$
$$+Yc_i(t) + X_i(t)Yc_i(t) = X_i(t)$$
$$i, j = 1, 2, ..., n$$

(6) can be written in matrix form:

$$[I - A(t) + B(t+1)]X(t) - [B(t+1) + \beta(t)]X(t+1) = Yc(t) \tag{7}$$

Where, I is the unitary matrix.

2.2. Turnpike Model(TM)

Turnpike model (Dorfman, 1958)is based on the linear programming with the objective function of the maximum of the accumulating capital at the end of the objective term.When we calculate the balanced growth solution of TM, the dynamic I-O model is used to extend the original structure of TM in order to avoid the constraint of occluding hypothesis in the Neumann model(Neumann,1937)of Turnpike model and then the model can accord the real status in China. Recall the dynamic I-O model in section 2.1:

$$[I - A(t) + B(t+1)]X(t) - [B(t+1) + \beta(t)]X(t+1) = Yc(t)$$

Define 4. Final demand coefficient depreciate coefficient in t year

$$C(t) = \frac{Yc(t)}{X(t)} \tag{8}$$

Then, (7) can written as follows:

$$X(t) = A(t)X(t) + B(t+1)(X(t+1) - X(t)) + \beta(t)X(t) + C(t)X(t) \tag{9}$$

Suppose the equilibrium growth rate is the same in different sectors:

$$X(t+1) = (1+\alpha)X(t) \tag{10}$$

Then,

$$\frac{1}{\alpha}X(t) = [I - A(t)\beta(t) - C(t)]^{-1}[B(t+1) + \beta(t)]X(t) \tag{11}$$

Thus,

$$\frac{1}{\alpha}X(t) = [I - A - \beta - C]^{-1}[B(t+1) + \beta]X \tag{12}$$

We discuss the existence of balanced growth solutions in the extended model (12).Before discussing the existence of a balanced growth path (BGP) for(12),we need to recall some basic issues related to nonnegative systems. If a square matrix is non negative i.e.all of whose elements are nonnegative, then its spectral radius is an eigenvalue, and incorrespondence of this eigenvalue there exists a non negative eigenvector(Berman and Plemmons, 1979). Moreover, an irreducible matrix is characterized by exactly one (up to scalar multiplication) nonnegative eigenvector and this eigenvector is positive. Based on the hypothesis in I-O model(Leontief, 1951) ,Hawkins Simon condition, Solow condition in I-O analysis,we can safely draw that the modulus of eigenvalue of the matrix $[I - A - \beta - C]$is below 1 and $[I - A - \beta - C]^{-1}$is nonnegative matrix, then$[I - A - \beta - C]^{-1}[B(t+1) + \beta] = H$ is nonnegative matrix according to the theorem of Perron-Frobenius .So the balanced growth rate is equal to the reciprocal of the Perron-Frobenius solution, the eigenvector is equal to the output structure on the balanced growth path.

Proof 1. This is an application of Perron-Frobenius's result to economic model.

2.3. Separating amount and structure of output

The basic style of I-O analysis is:

$$X = AX + Y \tag{13}$$

Where,X is output and Y is final demand.
In order to impress the structure of the economic system, we change the (13)as follows:

$$\dot{X}\tilde{X} = (I - A)^{-1}\dot{Y}\tilde{Y} \tag{14}$$

Where$\dot{X}$,$\dot{Y}$ is amount vector, $\tilde{X}$,$\tilde{Y}$is structure vector which is the output ratio vector of the every sector occupying in the gross output vector.

3. Dynamic computable general equilibrium (DCGE) model for calculation of SP

The dynamics of change in SP of water resources in China are consequently a project with a long time span, distinctive character and complex structure. The conception of DCGE assumed that the level of production and resources control the structures of economic system on the BGP .The BGP are instrumental to the maintenance and improvement of SP. It also assumed that the increased input coefficient and the decreased gross amount of the water resources are synonymous with the increased SP.

3.1. Basic structure of DCGE

The advantage of our model can be shown as: (1) SP is accord to the dynamic global optimal solution reflecting the dynamic order of the resources optimal allocation. (2) The model can be modified to calculate the SP of the certain year easily. Those solution sets of SP are useful to analysis the balanced developing of an economic system. The model shows as follows:

$$MaxZ = (I - A(T))X(T)$$

$$
s.t. \begin{cases} A(t)X(t) + B(t+1)(X(t+1) - X(t)) + \beta(t)X(t) \\ +C(t)X(t) \leq X(t) \\ t = 1, 2, ..., T-1 \\ A(T)X(T) + B(T+1)(\tilde{X}(T+1)\dot{X}(T+1) - X(T)) + \beta(T)X(T) \\ +C(T)X(T) \leq X(T) \\ A_w(T)X(T) \leq W(T) \\ H(t)X(t) \leq h(t) \\ L(t)X(t) \leq l(t) \\ X(t) \geq 0, \dot{X}(T+1) \geq 0 \\ t = 1, 2, ..., T \end{cases} \tag{15}
$$

Where, $X(t)$ is output in t year, $A(t)$ is direct input coefficients in t year, $\dot{X}(t)$ is the amount vector in t year, $\tilde{X}(t)$ is the structure vector in t year, $C(t)$ is final consuming demand coefficient in t year, $A_w(t)$ is direct water input coefficient in t year, $W(t)$ is total water input in t year, $B(t)$ is investment coefficient in t year , $\beta(t)$ is depreciate coefficient in t year.$H(t)$,$h(t)$,$L(t)$,$l(t)$ are other constraints and parameters .

3.2. Notes for DCGE

3.2.1. *Basic constraint*

DCGE is to suggest a new method that can be used to overcome the difficulties static SP in water conservancy projects evaluation. The model proposed is different to traditional analysis and has been based on a large linear programming in discrete-time including efforts to achieve a balance during the whole developing period. The time factor has been put into in order to reflect relationship between the changing. Stagnant of time has been selected as one year. The constraint is compounded the dynamic I-O model and Turnpike theorem, together with the separating of the amount and the structure. The objective function is the maximum of the Gross Demotic Product (GDP) in the objective year of the plan. Data of I-O table used in this analysis will demonstrate a practical approach to balance the economic developing. Beyond the I-O equilibrium relations, it is not limited in the fixed technical coefficient and can have the nonlinear character. Multiplying the gross amount with the structure vector is the vector of the output .The separation can make the practical work exact. The shadow prices of the water resources in BDP are the dual solution according to the water resources constraint line in the objective year.

3.2.2. *Other constraint*

The above constraint note is the basic in DCGE model. If we want to establish the general equilibrium model we should add some other constraint in order to construct large-scale systems avoiding the limit of the assumption of the I-O analysis. The follow is the other equilibrium and resources constraint which is shorten as $H(t) \leq X(t) \leq h(t)$ and $L(t) \leq X(t) \leq l(t)$:

(1)Constraint of production capacity:

$$X_i \leq \varphi_i \tag{16}$$

Where, $\varphi_i$is the maximum production capacity in sector i .

(2)Constraint of labor capacity:

$$\frac{\sum_{i=1}^{n} X_i}{T_i} \leq L \tag{17}$$

Where, T_i is the labor-working rate in sector i , L is the available labor amount in the economic system.

(3)Other constraint of resources

$$\sum_{i=1}^{n} g_{ki} X_i \leq h_k \tag{18}$$

Where, g_{ki} is the input coefficient of the kth resources in sector i . h_k is the available resources amount of the k th resources in sector i .

(4)Constraint of the equilibrium between the import and export.

$$\sum_{i=1}^{n} e_i X_i = \sum_{i=1}^{n} F_i \tag{19}$$

Where, e_i is input of the import commodity in sector i , F_i is export of the ith commodity.

(5)Constraint of the equilibrium between the reward of the income and the consumable.

$$\sum_{j=1}^{n} a_{vj} X_j + V^* - U \leq Y_w + W \tag{20}$$

Where, $\sum_{j=1}^{n} a_{vj} X_j$ is income of dwellers in the property sector, V^* is income of non-property sector, U is non-commercial payout of dwellers, Y_w is supply of consumable, W is import consumable.

(6)Equilibrium in supply and demand of the main consumable:A example in the food supplies.

$$\alpha\beta + F + \sum_{j \neq k} a_{kj} X_j \tag{21}$$

Where, α is average input of the food supplies in non-food supplies sector per person, β is sustain coefficient of the labor in non-food supplies sector, F is population in non-food supplies sector, $\sum_{j \neq k} a_{kj} X_j$ is direct input in non-food supplies sector, γ is commodity rate in non-food supplies sector, X_k is output in food supplies sector, E_k is net export of the food supplies.

(7)Equilibrium between accumulation and consumption.

$$\sum_{j=1}^{n} Y_{iw} + \mu \geq Y_w \tag{22}$$

Where, Y_{iw} is consumption amount in sector i in the previous term, Y_w is consumption amount in sector i in the present term, μ is other factors in the previous term.

$$\sum_{i=1}^{n} Y_k \geq \sum_{i=1}^{n} \tilde{k}_i (\hat{L}_i - L_i) \tag{23}$$

Where, Y_k is capital forming amount in the previous term, $\tilde{k}_i$ is average fund occupying amount per person in sector i , $\hat{L}_i$ is number of the employee in the previous term, L_i is number of the employee in the present term.

3.3. Notes for the long-term marginal cost in the DCGE

The Lagrange Multipliers are given the names "*shadow prices*" and "*dual activity*" in linear programming where these changes are analyzed by sensitivity analysis. Why are SP of the water resources in BDP the dual solution according to constraint line of the water resources in T year? The testify is as follows:

Proof 2. (13)can be shortened as:

$$MaxZ = CX$$
$$s.t. \begin{cases} AX \leq b \\ A_w X \leq b_w \\ X \geq 0 \end{cases} \tag{24}$$

$A_w X \leq b_w$ is the water resources constraint in the original linear programming , give the optimal basis is B ,the optimal solution of the dual problem is $Y^* = (y_1^*, ..., y_k^*) = C_B B^{-1}$,The input water resources of b_i is equal to the optimal solution of the dual problem y_i^* ,then $Z^* = y^* b$,and $Z^* = \sum_{i=1}^{m} y_i^m b_i$,thus:

$$y_i^* = \frac{\partial Z^*}{\partial b_i} \tag{25}$$

$$i = 1, 2, ..., m$$

$$Y_m^* = \frac{\partial Z^*}{\partial b_w} \tag{26}$$

In a word, the shadow prices of water resources y_m^* are the changed amount of the objective function when the resources b_w are changed, as well as the marginal long-term value. If the water resources increase one m^3, the objective function (GDP) will increase one Yuan. So the unit of shadow prices for water resources is $Yuan/m^3$.

4. Computer-Based Algorithm of DCGE

A heuristic DCGE algorithm can be outlined as:

Algorithm 1. DCGE

Step 1 : Use the Turnpike model (12)to calculate the structure of the output in T+1 year $\tilde{X}(T+1)$.
Step 2 : Solve the LP beginning with $\tilde{X}(T+1)$. During the process of calculation, perhaps there is no feasible solution in the model in some time. Then we can adjust the upper and the lower limit again and again and add or reduce the constraint and balance conditions.
Step 3 : Get the SP along with the structure and the amount of the each year .The process of calculation can be divided into short term. For example if we get the result SP of 2005 by using the 1999-2005 model, the SP denote the equilibrium SP during the five years in BDP. Based on the National Water Conservancy Economy Input-Occupancy-Output Tables for 1999, we can get the 1949-1999 prices backwards and calculate the 1999-2050 prices forward as a whole system. When we face the long-time span, the stagnant of the time can be prolonged to 2 years or more to reduce the complexity of algorithm.
Step 4 : Sensitivity analysis for the DCGE.

4.1. Notes for the data and the parameter

4.1.1. *Input-Occupancy-Output(I-O-O) Tables*

Many appraisal presented in Section 1 for calculation of SP is tentative and has suffered from data inadequacies.To solve this question, we will describe the design and implementation of a National Water Conservancy Economy Input-Occupancy- Output Tables (NWIO table).The research group leaded by Xikang Chen, consisted of about 22 researchers and professors, spent more one and half year to construct water conservancy economy Input-Occupancy-Output tables of China for 1999(Chen et al., 2003).The table is shorted to 19 sectors is the main data resource for our calculation.The style of the NWIO table can be showed as the graph in Figure 1 on Page 12:

4.1.2. *Other parameters*

Some parameter for DCGE should be estimated and emended for each year, such as input coefficient, added value coefficient, final demand, water input coefficient, added capital coefficient, depreciate capital coefficient by using the nonlinear and the key emendation way in Statistics and Economics. A study in the computational efficiency and complexity through a series of empirical tests is also important in DCGE.

5. Computer-Based result of the DCGE model for calculation of SP

5.1. Result and analysis for SP of water resources in 1949-2050

During calculation of DCGE, the basic variable of output is $19 * 19 * 100 = 36100$, not including the slack variable and the others. The scale of calculation is so enormous that much common software can't work out, such as Matlab and Excel. We use the "Lingo" software (see http://www.lindo.com) to do and get the fitful result.The following shadow prices shows as the graph in Figure 2 on Page 13 which is based on the unchanged prices index in 1999 and don't reflect the inflation of average market prices, the exchange rate etc.

				Intermediate Demands		Final Demands	Total output And Total water
				Non-water conservancy Sectors	Water conservancy sectors		
				1,2,……, S	S+1,S+2, ……, n	1,2, ……, t	
INPUT	Non-water conservancy Sectors		1 : S	X_{ij}		Y_{ij}	X_i
INPUT	Water Conservancy Sectors		S+1 : n				
INPUT	WATER	Fresh Water	1 : k	F_{ij}		Z_{ij}	W_i
INPUT	WATER	Recycle Water	K+1 : m				
INPUT	WATER	Waste water Emission		P_j		R	W_w
INPUT	Primary Input		1 : S	V_j			
INPUT	Total Input			X_j			
OCCUPANCY	Fixed Assets		1 : n	D_{ij}			
OCCUPANCY	Circulating Capital		1 : n	C_{ij}			
OCCUPANCY	Labour Force		1 : g	L_{ij}			

Figure 1. Water Conservancy Economy Input-Occupancy-Output Table.

5.2. Sensitivity analysis result for 1999 shadow prices of water resources in China

SP is the important accounting not only in decision-making but also in sensitivity analysis. Another advantage of using the“Lingo” is that it has a special package to calculate the sensitivity analysis result. The important lesson you can get from the sensitivity analysis of overall variable is that the total available water resources and the direct input water coefficient is the key factor that can impact the SP greatly. As

Years	Shadow prices of water resources
1949	0.48
1959	0.11
1965	2.01
1980	2.89
1993	3.46
1994	3.57
1995	3.69
1996	3.80
1997	3.92
1998	3.79
1999	3.85
2000	3.86
2005	3.99
2008	4.10
2010	4.29
2015	4.47
2020	4.58
2025	4.77
2030	4.93
2040	5.11
2050	5.39

Figure 2. Shadow prices of water resources for 1949- 2050 in China(Unit: Yuan/M^3)

the following graph in Figure 3 on Page 14 we give the limit of the two parameters when the shadow prices for 1999 keep fixed.

6. Conclusions and Recommendation

These conclusions suggest that the directed prices by government were far lower than the SP the paper has assumed, and that in several cases should not have been made if decisions on water conservancy project evaluation were to be based on directed prices by China government criteria alone. Based on these empirical findings, there is an alternative perspective, which support the hypothesis that the present economic efficiency alone in estimate the value of the water resources is incomplete. The main objective of this paper is to propose a new method that can be used as a sustainability indicator in evaluating the prices. The government still controls the prices of water resources so the result of SP

	Sector	Output	Consumption of the water resources	Water Consumption coefficient	Upper limit	Lower limit
	Unit	Ten thousand Yuan	M^3	M^3/ Ten thousand Yuan		
1	Agriculture	2.46E+08	381796	1554.09	1557.939	1552.95
2	Heavy industry	76131051	3646.917	47.903	47.906	47.902
3	Food & tobacco	1.5E+08	6795.831	45.417	45.420	45.416
4	Costume	70275852	590.282	51.088	51.092	51.087
5	Lumber & furniture	25704102	1323.06	51.472	51.476	51.471
6	Heavy Mach	35131121	1077.528	30.67162	30.673	30.671
7	Other Machines	1.03E+08	6527.708	63.07298	63.079	63.071
8	Non-ferrous Metals	1.04E+08	3675.273	35.180	35.182	35.180
9	Ferrous Metals	57959302	2462.91	42.493	42.496	42.492
10	Transport	64995880	2075.316	31.929	31.931	31.929
11	Electricity	72589754	3165.297	43.605	43.608	43.604
12	Communications	67051215	1715.172	25.580	25.581	25.579
13	Apparatus	11034049	680.532	61.675	61.681	61.673
14	Reparation	7390588	177.0689	23.958	23.959	23.958
15	Other industry	32932604	1992.707	60.508	60.514	60.506
16	Culture & education	54123930	15375.14	284.072	284.201	284.034
17	Chemistry	4.46E+08	43118.77	96.640	96.655	96.635
18	Electric power	42049767	34066.96	810.158	811.204	809.848
19	Other sectors	7.43E+08	21234.08	28.596	28.597	28.596
	Gross water consumption		534496.5		537382.8	533641.4

Figure 3. The limit of the total available water resources and the input water coefficient of China for 1999

can give the useful decision support. In recent years, the prices of water resources has been elevated many times by government .In the mind of the author the reason of the marketing prices of water resources below the real prices is due to the Marxism prices theory which is applied by China government .The prices theory of the Marxism can reflect the society need labor time and the input and output during the process of the production but it ignore the real society benefit of the labor and the material. On a very general level, it seems to be widely accepted by now that the SP should be viewed as reflecting at least three dimensions: an economic, a social-cultural and an ecological one .China government should speed up Water Prices Reform.

Appendix

A. List of variables

Name	Description
$X(t)$	Output in t year.
$A(t)$	Direct input coefficients in t year
$\dot{X}(t)$	Amount vector in t year.
$\tilde{X}(t)$	Structure vector in t year.
$C(t)$	Final consuming demand coefficient in t year.
$A_w(t)$	Direct water input coefficient in t year.
$W(t)$	Total water input in t year.
$B(t)$	Investment coefficient in t year.
$\beta(t)$	Depreciate coefficient t year.
$Y_c(t)$	Final demand coefficient in t year.
$K_{ij}(t)$	is sector i th use of input j th available in t year.
$Z_{ij}(t)$	is sector i th use of input j th capital in t year.
$D_{ij}(t)$	is sector i th use of input j th depreciate in t year.

B. The syntax of DCGE

```
MODEL: ! Dynamic computable general equilibrium  model(DCGE) !
Data based on Jing He, Study(2003); \\
! Find dynamic shadow prices for water resources in  China;\\
sets: Year/1..50/; Year1/1..49/; cc/1/:x0(51)
row/1..19/;XJ(51),bb(51) col/1..19/; axs(row,col);i\\
@for (year(T):axs(T)(row,col):a(T),b(T);bxs(T)
```

```
(row):bb(T),c(T),X(T),AW(T),H(T),L(T); cxs(T)(cc):w(T),h(T),l(T);
); endsets: ! Define variable for model; data: \\
i=@OLE ('C:\Documents and Settings\administrator\data.xls','i');
b(51)=@OLE ('C:\Documents and
Settings\administrator\data.xls','i'); xj(51)=@OLE('C:\Documents
and Settings\administrator\data.xls','i');
@for(year(T):a(T)=@OLE('C:\Documents and
Settings\administrator\data.xls','a(T)'); \\
b(T)=@OLE ('C:\Documents and
Settings\administrator\data.xls','b(T)'); c(T)=@OLE ('C:\Documents
and Settings\administrator\data.xls','c(T)'); \\
aw(T)=@OLE ('C:\Documents and
Settings\administrator\data.xls','aw(T)');\\
 w(T)=@OLE
('C:\Documents and Settings\administrator\data.xls','w(T)');\\
bb(T)=@OLE ('C:\Documents and
Settings\administrator\data.xls','bb(T)'); ); \\
! Demand parameter for sector and year;
max=@sum(row(r):@sum(col(c):(I(r,c)-A(T)(r,c))*X(T)(r));\\
@for(year1(t): @for(row(r):
@sum(col(c):a(t)(r,c)*x(t)(r))+@sum(col(c):B(t+1)
(r,c)*(x(t+1)(r)-x(t)(r))
+@sum(col(c)):bb(t)(r)*x(t)(r)+c(t)(r)*x(t)(r)<=x(t)(r) ); );\\
@for(row(r):
@sum(col(c):a(T)(r,c)*x(T)(r))+@sum(col(c):B(51)(r,c)*(x0(51)
(r)xJ(51)-x(T)(r))
+@sum(col(c)):bb(T)(r)*x(t)(r)+c(T)(r)*x(T)(r)<=x(T)(r) );\\
```

```
@sum(row(r):Aw(T)(r)*X(T)(r))<=W(T);
@sum(row(r):H(T)(r)*X(T)(r))<=h(T);
@sum(row(r):L(T)(r)*X(T)(r))>=l(T); @for(year(T):x(T)>=0 );
x0(51)>=0 \\
! Linear programming for the DCGE;\\
end
```

References

Xikang Chen and Cuihong Yang and Jian Xu. Water Conservancy Economy Input-Occupancy-Output Table of China and Its Application. *International Journal of Development Planning Literature*, 2(2):48–54, 2003.

Xiuli Liu and Xikang Chen. Input-Output Analysis Applied in the Caculation of Chinese Shadow Price of Water Resourde. *Management Review*, 15(3):49–54, 2003.

Zhile Zhang . The Caculation Theory for the Shadow Water Price As the Output of the Supplying Water Project. *Technology and economic of water power*, 5(3):8–12, 1999.

Qifu Zhong . *Input-Output Analysis.* Zhongguo Caijing Press,Beijing, 64–70,1984.

Jing-wen Zhao. Analysis of the Shadow Price. *Economics and education of the leader*, 2(3):6–11, 1995.

Xinjian Liu . *Input-Occupancy-Output Models for National Economy and Others.* PhD thesis, Chinese Academy of Science, 1995.

Jin-shui Zhang. Nonlinear Computable Dynamic Input Output Model. Qinghua University Press,Beijing, 24–44,2000

Dajun Shen and Ruiju Liang and Hao Wang and Xiaoliu Yang. Theory and Caculation on the Price of Water. Science Press,Beijing, 33–35,2001

H.B.Chenery and P.G.Clark . Interindustry Economics. John Wiley Sons.Inc,New York, 1959

Dorfman and Samuelson and Solow. Linear Programming and Economic Analysis. Mc Graw-Hihi,1958.

W.W.Leontief et.al. Studies in the Structure of the American Economy,1919-1939. Oxford University Press,1951.