WATER EMBEDDED CGE MODEL TO ASSESS THE IMPACTS OF SOUTH TO NORTH WATER TRANSFER TO RECIPIENT REGION

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Abstract: The article reports the social-economic impacts from China's South to North Water Transfer project to recipient region, through a set of outcomes simulated by a water embedded computable general equilibrium model WCGE. Authors modeling efforts devoted focus on the skilful treatment of water in the WCGE framework as a type of factor input of various production functions to reflect its significant effect on the corresponding sector output. Therefore, the WCGE simulation outcomes show water use and adjusted water supply balances in various regions, and draw implications from the results in terms of water use levels by type of uses. The outcomes also interpret how constraining would water resource become under these scenario conditions to the region's sustainable development.

Keywords: Water Transfer Project, CGE modeling and simulations, Water supply and demand, Water SAM, Sustainable development

1 INTRODUCTION

1.1 Background

Among all the natural resources available to mankind, water holds a prominent place particularly because of its importance of human subsistence, an essential element for the sustenance of life on earth. It is equally important for social and economic activities, so necessary for the preservation of modern society. When people enjoy their increasingly prosperous life based on industrialization, they have to pay cost to the related environmental and ecological losses, particularly in developing countries with fast-growing populations. These countries may find dilemmas facing them. Water resource may be constrained due to direct demand by masses of people, and due to the growing water needs of various industries. China, with a population of 1.27 billion in year 2000, is a typical country that need to carry out proper water management policies for available water in the near future, for example, in order to attain its national economic development goal of "Xiaokang or moderate prosperity society", by the year 2020.

1.2 Problematic situation

China is a large continental country with large endowment of water resource of 2800 billion m^3 and per unit continent water resource of 291.7 km^3 per km^2, the level is only slightly lower than the global average water resource level of 315.1 km^3 per km^2. However due to China holds the largest population as 12.65×10^8 in the year 2000, this has led to a water occupation of 2196 m^3 per capita, the data accounts approximately 1/4 of the global average level 8618 m^3 per capita (Chen, 2002a). Therefore, on a per capita basis, China has been grouped as 1 of the 13 countries with severe water scarcity like Kuwait, Saudi Arabia, Israel, and so on. If the factor of geographical distribution of water is further considered, there is another picture of heterogeneity. See table 1 for basic information.

The fact of the lowest water occupation per capita is not to suggest that there would not be sub-regions within China with a relative water surplus. From table 1 which collects some interesting statistics relevant to water resource of the world and China, one can see that the southern China region—south to Yangtze River, is relatively abundant with water resource. It shows that the availability of water resource for every Chinese inhabitant are quite different by their residential location, e.g., in northern China water availability is about 900 m^3 per capita, which is lower than the water stress or severe scarce criterion of less than 1000 m^3 per capita, given by United Nations (refer to table 2).

Table 1 Water resource distribution and socioeconomic situation in China (year 2000)

	Typical City	Area (10^4 km^2)	Population index: Population (10^8person)	Population index: Density (person/ km^2)	Economic Index: GDP (10^8 Yuan)	Economic Index: Average GDP (Yuan/ Person)	Water Resource Index: Total water resource ($10^{12}m^3$)	Water Resource Index: Water resource per capita (m^3/person)	Water Resource Index: Exploitation rate in 1997 (%)
China		960	12.65	131.8	97209	7684.5	2.800	*2196*	25.8
Northern China	Beijing, Tianjin, Shenyang, Xian, Lanzhou, Taiyuan, et, al.	609.6	5.82	95.5	40213	6909.5	0.532	914	62.5
Southern China	Shanghai, Guangzhou, Nanjing, Wuhan, Chendu, et, al.	350.4	6.83	194.9	56996	8344.9	2.268	3321	17.2
Globe		14865	60.36	40.6			46.85	8618	

Source: Chen (2002a) and Chinese water resource gazette (2001).

Table 2 UN criterion for water resource scarcity degree (Unit: m^3/person)

Slightly scarce	Middle scarce	Severe scarce	Most Severe scarce
1700~ 3000	1000~ 1700	500~ 1000	<500

In China, population growth has been rapid, and the progress of industrialization has also grown at a very fast pace. These changes have both direct and indirect strains on water resources, on its quantity and quality. So the water supply-demand balance would come under constant pressure. Some of these trends are already under way. In addition, regional acidification from industrial activity, water pollution (indirectly through air pollution and directly through discharge of pollutants from industrial activity and sewage disposal), desertification and soil erosion may also be major threats to water resources. All of the described changes come together to force an assessment of the carrying capacity of the biosphere of China, and limits may be reached in terms of sustainable level of development.

1.3 South to North water transfer project

South to North (S2N) water transfer project is one of the four China's huge trans-century projects aimed to transfer water from southern China to Northern China to meet the increasing demand for water resource of Northern China, where the storage of water has been a serious constraint to the regional economic development, and consequently, the resultant slower development has become an obstacle to implementation of the country's harmonic and sustainable development plan. How the constraining of water storage would be relaxed through the S2N project? Will water transferring improve the water shortage in Northern China? These are major questions need to be answered.

1.4 Objectives and Scopes of the study

This study was designed to provide a preliminary investigation of China's water resource with a regional disaggregation approach. In section 2, we present a conceptual model of various linkages in social economic and ecological subsystems leading to the problem of regional vulnerability. Based on the qualitative analysis using the conceptual model, then in section 3, a water-embedded CGE model (WCGE) has been constructed to draw a whole picture of economy with a special consideration of water resource. Such that through the behavior of the model WCGE, the water linked problems their causes and consequences can be found and examined. Section 4 illustrates special treatment skills used in this study. And after the model has been verified and validated, in section 5 several meaningful scenario simulations have been carried out which plot out the future development path under different scenario. And finally in section 6, implications for water strategic management are concluded.

2 CONCEPTUAL MODEL FOR THE STUDY

2.1 Concept of regional vulnerability

Refer to the pioneer study on world water resources (Kulshreshtha, 1993) and the economic development strategic planning of China, in this study we define that a region becomes vulnerable to a certain natural resource's availability, if it can not pursue its accepted policy goals at the desired level. Thus, the vulnerability of a region due to water resources is interpreted as the inability of a region to sustain economic and social activity in commensuration with the stated goals of socioeconomic policy.

2.2 Regional water supply level can be raised by policy

The degree of regional vulnerability to water resources can be assessed quantitatively by using the quantity of water deficit as the criterion shown in figure 1.

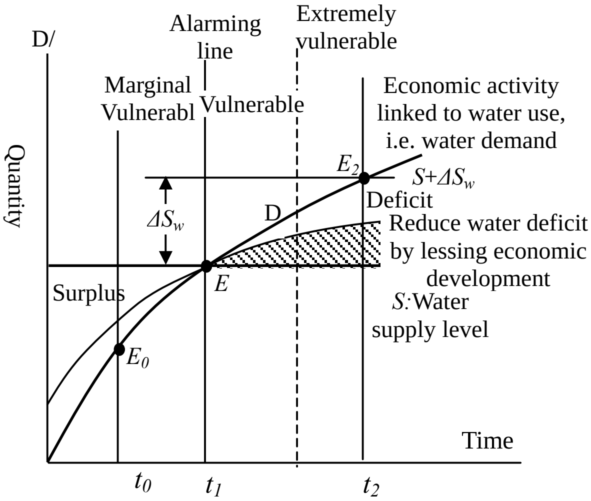

Fig. 1. D-S water balance and the deficit

In this criterion, water availability (supply) and its use (demand) are studied over a period of time. Assume that water supply remains at a constant level but water use increases as a direct result of economic activities in the region, indicated by the demand curve D. We can see the region may change its state from not vulnerable to extremely vulnerable, if the region's water demand moves along the D curve from E_0 (t_0) cross balance point E_1 (t_1) to E_2 (t_2), but if the water deficit can be compensated by additional quantity of water, for instance gained from a water transfer project, then the planning economic development target may well be reached without any water deficit cost e.g. underground water over withdraw or reduce domestic water uses. ΔS_w in figure 1 shows an additional quantity of water supply gained from a project, it raises the total water supply level from S to $S+\Delta S_w$, then E_2 (t_2) becomes a new balance point rather than a water deficit of quantity ΔS that would exist without the water transfer project.

3 DESIGNING THE WATER EMBEDDED CGE MODEL—WCGE

To investigate the water effects reflected in a multi-dimensional social-economic system; authors select a computable general equilibrium model framework, which is one of the best economic quantitative analysis tools and has been successfully used on various topics for many countries around the world. The key problem now faced is how to put water resource into the CGE's mechanism. It is a rational decision to treat water resource equivalent as land resource, due to both are natural resources limited in supply/availability. While water were used as a factor input in various domestic and productive uses, it is necessary to describe the different degree of various sectoral demand for water in different production and consumption processes. Accordingly, economic sectors by water usage intensity should be distinguished, which can be indicated by elasticity of substitution in production functions. Thus, water as an elementary input factor, its behavior can be observed both on input side by its price and output side by its elasticity of substitution in various production function of an economy.

3.1 Representative regional WCGE model

The WCGE stemmed from the Dynamic Recursive Chinese CGE model (DRCCGE[1]) which is developed by the Development Research Center of State Council (Zhai, 1999). The WCGE includes a complete set of 36 production sectors of neoclassical structure, with 3 groups (high, middle and low income) of representative household and 4 primary factors, they are labor, capital, land and water. To cope with regional vulnerability to water resource problem, among those primary factors, water resource has been particularly considered and the special treatment is beyond a standard CGE modeling. For the purpose of investigation the macro impact of S2N project, China's Capital city—Beijing has been chosen as the main water receipt region and the rest part of China ROC has been treated as Beijing's interactive trade partner, while the rest of world ROW is used to specify international trade relationship between China and other part of the world.

3.2 Production, consumption, macro closure and dynamic features of the WCGE

（Omitted）

4 SPECIAL TREATMENTS OF WATER RESOURCES IN WCGE

4.1 Sectoral Water Use

To characterize the different water intensive degrees in various production sectors by elasticity of

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[1] DRCCGE was initially developed as Chinese component of the GREEN model, which was designed by OECD development research center to analyze the impact of the global trade liberalization and environment. (Beghin, John, 1994, Paris).

substitution, the whole economic sectors are grouped into 5 categories by their style of water uses and their elasticity of substitution in production functions, namely: agriculture, high-intensive sector, middle-intensive sector, low-intensive sector and service, with the elasticity value of 0.1, 0.3, 0.5, 0.8 and 0.75 respectively (Shen, 2001).

4.2 Water use and reuse classified by quality
(Omitted)

4.3 Water Price Formation

In this study, the water shadow price in the base year is adopted to represent the water equilibrium price. The following programming problem deriving from Input-Output framework (Chen, 2002b) is used to identify shadow price of water resource:

$$\max z = \sum a_{nj} X_j$$

$$s.t. \begin{cases} AX + Y + U - V \le X \\ X^l \le X \le X^h \\ \sum a_{wj} X_j \le W \\ 0 \le U \le U^h \\ 0 \le V \le V^h \\ Y^l \le Y \\ \sum U_j - \sum V_j \ge c \\ X \ge 0, U \ge 0, V \ge 0 \end{cases}$$

In the above equations, ***X***, ***Y***, ***U***, ***V*** are variables. ***X*** is the total output vector in the Input-Output table; ***Y*** is sector final consumption volumn, ***U*** is export vector; ***V*** is import vector; ***A*** is sector direct consumption coefficient; a_{vj} is sectoral value-added coefficients; a_{wj} are sector water usage coefficients; ***W*** is sectoral water usage vector; $\boldsymbol{X_l}$, $\boldsymbol{X_h}$ are sectoral constraint boundary vector for total output; $\boldsymbol{V_h}$, $\boldsymbol{U_h}$ are the constraint vector for sectors import; ***c*** is sectoral net export bottom boundary. The loose variable corresponding to ***W*** is the shadow price of water resource. The solution of the above maximization problem is given in the following table 3.

Table 3 Water shadow price by types

	Sectoral Classification by water use style	Volume of Water use ($10^8 m^3$)	Shadow price (Yuan/m^3)
1	Agriculture	20.36	1.17
	Industry	9.76	15.32
2	High-intensive	8.24	10.6
3	Middle-intensive	0.98	18.5
4	Low-intensive	0.54	81.5
5	Service	5.05	52.7
	Average		4.7

Actually, the water shadow price represents the extra unit of value added resulting from giving an additional unit of water to the macro economy. In the model, the water shadow price means the GDP generated by the last unit water input. In a complete competitive market, as the marginal cost equals to marginal revenue, the water shadow price equals to the market equilibrium price.

4.4 The Water SAM—WSAM

The base year equilibrium of a CGE model is the starting point of the equilibrium time series created by the CGE model forecasting (Pyatt, 1985). It is a fundamental part of a CGE model system. In the case study, a Social Accounting Matrix SAM (Pyatt, 1985) embedded with water resource was established to provide a consistent macroeconomic database for the calibration of various parameters in the WCGE model.

The essence in constructing WSAM is to capture the links, water resource fee (or water economic value), between the water accounts, which is originally measured in cubic meters (M^3), and the rest of economy, which is denominated in money (Hynd Bouhia, 2001). In WSAM, the water resource fee actually is the transaction cost that the activities should pay to the water resource account for their water usage. In WSAM, Water resource fee are calculated as:

$$\begin{matrix} \textit{Water Resource Fee} \\ \textit{(or Water Economic Value)} \end{matrix} = \begin{matrix} \textit{Water Use Volume} \times \\ \textit{Water shadow price} \end{matrix}$$

In the WSAM, it is assumed that the central government is the water resource possessor, and the payment by the activity for their water resource usage will be collected by central government as water resource taxes or fees (Peter Rogers, 2002). The amount of such income will finally comprise part of the central government revenue. The gap between the shadow price and the current executive price is treated as the government 'implicit subsidy' and this amount of value will be deducted from the net production taxes.

5 SCENARIO SETTING AND THE SIMULATION OUTCOME

5.1 Scenario setting

Four scenarios, classified into two groups are designed to compare the regional economic performance under the assumption of without and with S2N project. The first group designed, B1 and B2, is without S2N project. The second group designed, S1 and S2, is with S2N scenario for the comparison of the B1 and B2. The S2N project expected to be accomplished by 2008. From then on, the scheduled water of 1.021×10^8 m^3 will be replenished to the regional total water supply annually. Table 4 describes the general assumption of each scenario.

Table 4 Scenario description

B1 :Without S2N project

- Without sustainable development strategy
- Keep water use pattern as 1990s;
- With excessive pumping groundwater;
- And keep surface water utilization rate as high as 80%;
- Ecological water use keep zero;
- Household per capita water use increase 2% annually.

B2: Without S2N project

- Adopt sustainable development policy;
- Stop the excessive pumping of groundwater which causes regional total water supply decreased by 0.426billion M^3 consequently;
- Lower surface water utilization rate below 60%;
- Increase the regional ecological water use from 0 in 1997 to 0.92 billion M^3 in 2020 by a linear increment;
- Household per capita water use increase 2% annually.

S1: With S2N project

- From year 2008, the transferred water ΔS_w=1.021* 10^8 M^3 is added to the regional water supply conditional on B1 scenario.
- The transferred water will be first for household use, then allocated for industrial use.

S2: With S2N project

- From year 2008, the transferred water ΔS_w=1.021* 10^8 M^3 is added to the regional water supply conditional on B1 scenario.
- The transferred water will be first for household use, then allocated for industrial use.

5.2 Simulation outcome

The WCGE model has been implemented with package GAMS 20.7 (Brooke, 1998) and the simulations of various scenarios have been carried out through GMAS/PATH solver Version 4.3 (Michael C. Ferris, 2000). The model contains 96 groups of equations and a total number of 8732 endogenous variables. The trajectory of GDP growth rate of each scenario and relevant selected outcome data groups are shown in figure 2 and table 5.

Figure 2 plots the Beijng's GDP growth rate curves from 2006 to 2020 under different scenarios. In water unsustainable utilization pattern B1 scenario, Beijing's GDP growth rate will still keep around 7.5% from 2010 to 2020. While in water sustainable B2 scenario, regional GDP growth rates would sharply decrease to 5.5%. The data indicates there is conflict between regional economic growth speed and ecological preservation within the existing natural water resource supply volume. The high growth rate is always at the cost of the environmental deterioration, which would bring the regional ecological system into the marginal or extremely vulnerability states. While in the S1 and S2 with project's water increment, Beijing's growth rate will increase to 8.5%.

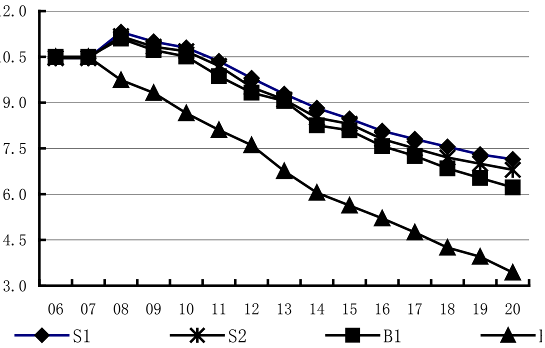

Fig. 2. GDP growth rate in scenarios

Table 5 lists the comparison of main macro index of each simulation. Compare to the scenarios without S2N project, increment of water will contribute to 1~2.3% increase in the GDP growth rate, that will be equal to GDP increase by 89 billion Yuan or almost $10 billion annually. The ripple effect result from the production expansion will increase 700 thousand employments in the year 2010. The project will indirectly increase government revenue by 18 billion Yuan in 2010. The projected benefits may be even larger in the long term as the water usage efficiency of regional water would improve.

Table 5a Main economic comparison index

No. Index	Selected index for comparison
1	Annual GDP growth rate%
2	Real GDP (10^8 Yuan)
3	Total Output (10^8 Yuan)
4	Investment (10^8 Yuan)
5	Household Consumption (10^8 Yuan)
6	Import (10^8 Yuan)
7	Export (10^8 Yuan)
8	Employment (10^4 person)
9	Government Revenue (10^8 Yuan)

Table 5b Main macroeconomic simulation result

No.	Base Year	2010		2020	
Index	(1997)	B1	B2	B1	B2
1		9.21	5.52	7.2	4.52
2	2291	7202	4606	14434	7167
3	6002	19576	13168	40159	20984
4	1197	3675	2349	7283	4655
5	1417	4569	2907	9225	4562
6	257	793	507	1568	778
7	127	392	251	951	385
8	661	672	554	706	575
9	594.0	1006	589	2016	917

No.	Base Year	2010		2020	
Index	(1997)	B1	B2	B1	B2
1		10.2	6.98	9.3	7.05
2	2291	8098	5507	19705	10885
3	6002	21979	14837	53483	29821
4	1197	4046	2795	12598	6647
5	1417	5070	3458	12450	6878
6	257	941	638	2332	1284

No. Index	Base Year (1997)	2010 B1	2010 B2	2020 B1	2020 B2
7	127	428	297	1023	585
8	661	745	600	803	667
9	594.02	1186	770	2885	1594
Project Benefit /Increment(S-B)		2010 S1-B1	2010 S2-B2	2020 S1-B1	2020 S2-B2
1		0.99	1.46	2.1	2.3
2		896	901	5271	3717
3		2404	1670	13324	8837
4		371	447	5315	1992
5		501	551	3225	2316
6		148	131	764	506
7		36	47	72	200
8		73	46	97	92
9		180	181	869	677

Source: Model simulation results

6 IMPLICATIONS OF THE SIMULATION RESULTS AND AREAS OF FUTURE RESEARCH

Implications of the results shown in table 5 and figure 2 can be summarized into four points:

1 In the absence of S2N water transfer project, Beijing would face serious water availability- related problems. Simulation results show a long-term accelerated industrialization process be supported by extracting all of its ground water and wetlands on a over use basis, but may cause the city's natural situation turning to be unmanageable. Simulation B2 shows that if a proper environment and resource protection policy would have been adopted, then the goal of high speeds rate of industrialization may have to be curtailed.

2 Simulation outcomes of B2 and S2 show that in any case a comprehensive consideration of social-economic-environment harmonic development strategy is valuable and oppositely are the B1 and S1 scenarios. These results shown in figure 2 are obviously true.

3 Simulation outcomes show that with S2N project an incremental quantity of additional water supply is definitely beneficial to the receipt region.

4 Although there is a trade-off between the cost of constructing the S2N water transfer project and its benefit derived from the optimized water resource allocation, simulation outcome shows that through an increment of water supply by S2N project and proper economic and other management instruments, e.g., the Beijing government pursues a sustainable development strategy, the gap between water demand and supply can eventually be closed. The outcome form scenario S2 is a proof.

Areas of future research are as following:

(1) *Water use efficiency*. Different types of production technology result in different levels of water use efficiency. There is considerable space to design a water conservation style for water use in China, which is worthwhile of research efforts.

(2) *New topic*. Based on current WCGE model, a further study of the dynamics of the interrelationship among water, food and energy systems under a changing environment (economic and non economic) is a topic that should be given a high priority in future research.

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