MITIGATING CHINA'S WATER SCARCITY AND POLLUTION: ENVIRONMENTAL AND ECONOMIC ACCOUNTING, MODELLING AND POLICY ANALYSIS

Changbo Qin

Examining committee:

Prof.dr. J.C. Lovett	University of Twente
Prof.dr. A. van der Veen	University of Twente
Prof.dr. P. van der Zaag	UNESCO-IHE
Prof.dr. H. Wang	IWHR

ITC dissertation number 196
ITC, P.O. Box 217, 7500 AE Enschede, The Netherlands

ISBN 978-90-6164-321-0
Cover designed by Job Duim
Printed by ITC Printing Department

ITC UNIVERSITY OF TWENTE.
FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

MITIGATING CHINA'S WATER SCARCITY AND POLLUTION: ENVIRONMENTAL AND ECONOMIC ACCOUNTING, MODELLING AND POLICY ANALYSIS

DISSERTATION

to obtain
the degree of doctor at the University of Twente,
on the authority of the Rector Magnificus,
prof.dr. H. Brinksma,
on account of the decision of the graduation committee,
to be publicly defended
on Friday 18 November 2011 at 14:45 hrs

by

Changbo Qin

born on 24 February 1981

in Shandong, China

This thesis is approved by
Prof. dr. Z. (Bob) Su, promoter
Prof. dr. Hans J.A. Bressers, promoter
Prof. dr. Yangwen Jia, assistant promoter

Acknowledgements

I have received tremendous assistance and encouragement from several people during my PhD studies in both the Netherlands and China. The work reported in this thesis was made possible in the present shape with the support and contribution from many organizations and individuals who have helped me in some ways or the other. It is difficult for me to use the words to fully express my appreciation to them, but I want to take this opportunity to use simple words to describe my deepest gratitude.

Firstly, I would like to express my great gratitude to my promotors Prof. dr. Z. (Bob) Su, Prof. dr. Hans Bressers and Prof. dr. Jia Yangwen for their guidance, innovative ideas, expert advices, encouragement and valuable comments as well as scientific attitude. Without their support none of this was possible.

Special gratitude goes to Prof. Wang Hao, Academician of Chinese Academy of Engineering for his invaluable guidance towards my research and the support of my academic career. I also express my profound gratitude Prof. Qin Dayong. I am indebted for his assistance during my stay in China.

I would like to gratefully acknowledge University of Twente/ITC, for its financial support, which allowed me to peruse my research in the Netherlands. I also thank University of Twente/CSTM and IWHR (China Institute of Hydro-power and Water Resources) for their support of my study.

I am grateful to Prof. Martin Hale, Dr Paul van Dijk and Ms. Loes Colenbrander, Ms. Anke de Koning, Ms. Tina Butt-Castro who ensured that I had excellent research administration. I also express my gratitude to the financial department, education affairs department, library, information technology department and ITC international hotel for their dynamic support.

I would like to express my thankfulness to Tian Xin, Li Longhui, Zeng Yijian, Zhong Lei, Mustafa Gokmen, Enrico Balugani, Mireia Romaguera, Joris Timmermans, Christiaan van der Tol, Rogier van der Velde, Alain Pascal Frances, Laura Dente, Zheng Donghai, Chen Xuelong, Wang Guangyi, Ou Yangwei, Cheng Fangfang, Zhang Qiuju, Zhang Tangtang, Tina Tian, Hao Pu, Yang Zhenshan, Ma Xiaogang, Xiao Jing, Pu Shi, Bai Lei for their kind help during my stay in the Netherlands.

I also wish to express my appreciations to Niu Cunwen, Zhou Zuhao, Qiu Yaqin, Yang Guiyu, You Jinjun, Li Juan, Han Chunmiao, Ding Xiangyi, Gong Jiaguo, Shen Suhui, Gao Hui, Hao Chunfeng, Penghui, Wang Xifeng, Lv Caixia, Zhang Zhixia, Zhou Na for their kind support during my stay at IWHR.

I am most grateful for the support and encouragement throughout my education from my parents and grandma. I also express my thankfulness to my sister for taking care of my mother when she was in hospital during my stay in the Netherlands. I wish to express my gratitude to my girlfriend Xu Xinrong, thank you.

List of abbreviations

AGR	Agriculture
BJ	Beijing
CAEP	Chinese Academy for Environmental Planning
C-D	Cobb-Douglas
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
CNY	Currency Unit: Chinese Yuan
COD	Chemical Oxygen Demand
DEAN	Dynamic Applied General Equilibrium
DFWF	Domestic Freshwater Footprint
DWWF	Domestic Wastewater Footprint
EESAM	Environmentally Extended Social Accounting Matrix
ESAM	Environmental Social Accounting Matrix
EV	Equivalent Variation
FWF	Freshwater Footprint
GAC	General Administration of Customs
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GTAP-W	Global Trade Analysis Project for Water
HB	Heibei
HO	Heckscher-Ohlin
IND	Industry
IO	Input-Output
Jing-Jin-Ji	Beijing-Tianjin-Hebei
LES	Linear Expenditure System
MCP	Mixed Complementarity Problem
MEP	Ministry of Environmental Protection
MOF	Ministry of Finance
MPSGE	Mathematical Program System for General Equilibrium
MWR	Ministry of Water Resources
NAMEA	National Accounting Matrix including Environmental Accounts
NBS	National Bureau of Statistics
NFWF	Net Imported Freshwater Footprint
NH3-N	Ammonia Nitrogen
NNI	Net National Income
NWWF	Net Imported Wastewater Footprint

OHP	Other Pollutants
PAS	Pollution–Abatement Substitution
PE	Pollution Equivalent
PLEI	Pull Effect Index
PSEI	Push Effect Index
ROC	the Rest of China
ROW	the Rest of the World
SAM	Social Accounting Matrix
SAT	State Administration of Taxation
SCCG	State Council of the Chinese Government
SEEA	System of Integrated Environmental and Economic Accounts
SEEAW	System of Environmental and Economic Accounting for Water
SEPA	State Environmental Protection Agency
SER	Service
S-I	Savings-Investment
SIC	State Information Centre
SNWT	South-to-North Water Transfer
SPSS	Statistical Product and Service Solutions
TEV	Total Economic Value
TFWF	Total Freshwater Footprint
TJ	Tianjin
TWWF	Total Wastewater Footprint
UK	United Kingdom
UN	United Nations
US	United States
WF	Water Footprint
WHO	World Health Organization
WSAM	Water embedded Social Accounting Matrix
WWF	Wastewater Footprint

Table of Contents

Acknowledgements i
List of abbreviations...iii
Table of Contents v
List of figures viii
List of tables ix
Chapter 1. General Introduction 1
1.1 Overview of water issues in China 2
1.2 Ongoing mitigating strategies for water issues in China 4
1.3 Problem statement..6
1.4 Objectives of the study 8
1.5 Overview of the study 8
Chapter 2. An Analysis of Water Consumption and Pollution with an Input-output Model in the Haihe River Basin, China 11
2.1.1 Emerging water and development issues in the Haihe River Basin 13
2.1.2 Input-output analysis 16
2.1.3 Water footprints..17
2.2 Materials and methodology..18
2.2.1 Leontief input-output (IO) model...............................18
2.2.2 Extension of the hybrid water IO model.....................19
2.2.3 Freshwater and wastewater footprints.......................22
2.2.4 Intersectoral linkages for water consumption and pollution...23
2.2.5 Data collection...25
2.3 Results and discussion 26
2.3.1 Characteristics of water consumption........................26
2.3.2 Characteristics of wastewater discharge 29
2.3.3 Results of freshwater and wastewater footprints 31
2.3.4 Economic pull and push effects on water consumption and pollution...37
2.3.5 Projection of alternative scenarios.............................38
2.4 Conclusion and remarks 40
Chapter 3. Assessing the Economic Impact of Mitigating North China's Water Scarcity Strategy: an Econometric-Driven Water Computable General Equilibrium Analysis 45
3.1 Introduction...47
3.2 Description of study area 48
3.3 Description of model structure 49
3.3.1 Regional disaggregation..49
3.3.2 Production technology...50
3.3.3 Local final demands 51
3.3.4 Interregional, domestic and international trade..........52

3.3.5 Macro closure...53
3.4 Social Accounting Matrix 53
3.4.1 Economic data 56
3.4.2 Inter-regional trade..56
3.4.3 Water equilibrium price...56
3.4.4 Water SAM..58
3.5 Calibration 62
3.6 Defining the scenario groups 64
3.6.1 Scenario group 1: Reducing groundwater use to a renewable level 64
3.6.2 Scenario group 2: Receiving water transferred by the SNWT project 65
3.6.3 Scenario group 3: Reallocating water from agriculture to industry and the service sector 66
3.7 Results and discussion 67
3.7.1 Simulation results of the scenario group for reducing groundwater use..67
3.7.2 Simulation results for SNWT project scenario group..71
3.7.3 Simulation results of sectoral water reallocation scenario group 72
3.8 Conclusion and final remarks..76
Chapter 4. The Economic Impact of Water Tax Charges in China: A Static Computable General Equilibrium Analysis 79
4.1 Introduction..81
4.2 Analytical framework...83
4.2.1 Model structure 83
4.2.2 Social Accounting Matrix (SAM) 86
4.2.3 Calibration of the model 88
4.3 Experimental Simulation Scenarios 89
4.4 Results and Discussions..89
4.5 Conclusion and remarks 95
Chapter 5. Economic impacts of water pollution control policy in China: A dynamic computable general equilibrium analysis..99
5.1 Introduction..101
5.2 Description of the model 104
5.2.1 Production module 105
5.2.2 Household and government sectors........................106
5.2.3 Foreign sectors 106
5.2.4 Dynamic mechanisms and inter-temporal linkages..106
5.2.5 Environmental service module 107
5.3 Data and calibration..108
5.3.1 Environmental Social Accounting Matrix (ESAM) 108
5.3.2 Calibration of the model 115

5.4 Emission reduction scenarios 116
5.5 Policy simulations and key findings 118
5.5.1 Macroeconomic results 118
5.5.2 Sectoral results 123
5.5.3 Abatement and environmental results 132
5.5.4 Sensitivity analysis 136
5.6 Conclusion and remarks 137
Chapter 6. Main findings, policy implications and research issues ... 139
6.1 General summary 140
6.2 Research findings and policy recommendations 142
6.3 Some limitations and future research prospects 147
Bibliography 151
Author's biography 163
Summary 165
Samenvatting 169
ITC Dissertation List 172

List of figures

Figure 1.1 Watersheds in China 3
Figure 2.1 Precipitation in the Haihe River Basin in the period 1956-2005 (Unit: mm) 14
Figure 2.2 Water amount flowing to the sea in the Haihe River Basin in the period 1956-2005 (Unit: billion m3) 14
Figure 2.3 Water consumptions in the Haihe River Basin in 2002 27
Figure 2.4 Wastewater discharge in the Haihe River Basin in 2002 29
Figure 3.1 The structure of production technology 51
Figure 3.2 The Allocation structure of exported commodities 52
Figure 3.3 The origin structure of imported commodities 53
Figure 4.1 Water use patterns in the year 2007 in China 81
Figure 4.2 The structure of water CGE model 84
Figure 5.1 Diagrammatic overview of the main structure of the model 105
Figure 5.2 Total emission reduction paths in China 118
Figure 5.3 Impact of total emission control policy on GDP (%-change compared to benchmark projection) 120
Figure 5.4 Impact of total emission control policy on NNI (%-change compared to benchmark projection) 120
Figure 5.5 Impact of total emission control policy on growth rate 121
Figure 5.6 Impact of total emission control policy on total consumption of private households (%-change compared to benchmark projection) 122
Figure 5.7 Impact of total emission control policy on investment (%-change compared to benchmark projection) 123
Figure 5.8 Impacts of the total emission control targets on sectoral production in 2020 (%-change compared to benchmark projection) 128
Figure 5.9 Impacts of the total emission control targets on consumption of private households in 2020 (%-change compared to benchmark projection) 129
Figure 5.10 Impacts of the total emission control targets on exports in 2020 (%-change compared to benchmark projection) 130
Figure 5.11 Impacts of the total emission control targets on imports in 2020 (%-change compared to benchmark projection) 131
Figure 5.12 Development of abatement services over time with a 30 percent reduction of total emission permits (Benchmark index = 1) 133

List of tables

Table 2.1 Extended hybrid water input-output table 20
Table 2.2 Classification of sectors 25
Table 2.3 Direct water consumption (w_1^d, unit: 10^6 m^3) , direct (d_1, unit: $m^3/10^3$CNY) and total (t_1, unit: $m^3/10^3$CNY) water consumption per unit of output, direct (m_1^d) and indirect (m_1^{ind}) water consumption multipliers 28
Table 2.4 Direct wastewater discharge (w_2^d, unit: 10^6 m^3), direct (d_2, unit: $m^3/10^3$CNY) and total (t_2, unit: $m^3/10^3$CNY) wastewater discharge per unit of output, direct (m_2^d) and indirect (m_2^{ind}) wastewater discharge multipliers 30
Table 2.5 Freshwater and wastewater footprints for the Haihe River Basin..32
Table 2.6 Net imported freshwater and wastewater footprints (unit: 10^6 m^3) for Beijing, Tianjin and Hebei...................................36
Table 2.7 The pull effect index (PLEI), and the push effect index (PSEI) for water consumption and wastewater discharge in the Haihe River Basin..38
Table 2.8 Increase of economic output, water consumption and wastewater discharge associated with a 20% increase in final demand in the food and tobacco processing sector 40
Table 3.1 Basic structure of WSAM 55
Table 3.2 Computed output elasticity and marginal value of water in 2007 58
Table 3.3 Beijing WSAM for the year 2007 (unit: 10^8 CNY)...................59
Table 3.4 Tianjin WSAM for the year 2007 (unit: 10^8 CNY)...................60
Table 3.5 Hebei WSAM for the year 2007 (unit: 10^8 CNY) 61
Table 3.6 Estimated elasticity parameters of substitution across production factors..64
Table 3.7 Water volume transferred by the SNWT project and changes in water supply level in the scenarios 66
Table 3.8 Changes in sectoral water supply levels in the water reallocation scenarios...67
Table 3.9 Changes in main economic variables under the scenario group for reducing groundwater use (unit: percent) 70
Table 3.10 Changes in main economic variables under scenario group for transferring water through the SNWT project (unit: percent).....72
Table 3.11 Changes in the main economic variables under the scenario group of reallocating water from agriculture to other sectors (unit: percent)...75
Table 4.1 Macro-SAM of China economy 2007, unit: Billion CNY 87
Table 4.2 Values for key elasticity in the CGE model............................89

Table 4.3 Results from simulations in changes of sectorial output (unit: percent) 90
Table 4.4 Results from simulations of changes in value-added (Unit: percent) 91
Table 4.5 Results from simulations of trade patterns in China (Unit: percent) 93
Table 4.6 Results from simulations of sectorial water use (Unit: percent) 94
Table 4.7 Results from simulations at the macro level (Unit: percent)...95
Table 5.1 Basic structure of ESAM 110
Table 5.2 Economic data of sectoral production, consumption and value-added for China, 2007 (in 10^8 CNY at 2007 prices)............111
Table 5.3 the simple version of Chinese ESAM for the year 2007 (unit: 10^8 CNY) 113
Table 5.4 Equivalences of pollutants included in the OHP emission accounts..114
Table 5.5 Sectoral and consumption emissions for COD, NH3-N and other pollutants to water for China, 2007 (unit: million kg)............115
Table 5.6 Prices of tradable emission permits (CNY/kilogram in constant 2007 prices) 132
Table 5.7 Changes in demand for abatement services and sectoral emissions in 2020 with a 30 percent of emission reduction in China (benchmark index = 1)...135
Table 5.8 GDP and EV losses in the 30% reduction scenario for alternative values of main parameters 137

Chapter 1. General Introduction

1.1 Overview of water issues in China

The economic success in China has come at the expense of over exploitation of natural resources and huge impacts on the environment and especially water resources. Natural resources, of which water is one, are the primary inputs either directly or indirectly of all goods and services. Because of a rising water demand in the agricultural, domestic and industrial sectors, as well as the emerging new demands from ecosystem preservation, the water availability with acceptable quality is predicted to the most urgent development constraint facing China.

The water challenge in China is primarily driven by both climate and human activities. China is a large continental country with a large endowment of water resources totalling 2800 billion m^3. However, the annual per capita renewable freshwater availability amounts to only 2196 m^3, or one quarter of the world’s average. Due to a marked continental monsoon climate, water resources are distributed unevenly both temporally and spatially. In China, 60–70 percent of precipitation, close to 80 percent in northern regions, occurs in the summer. The annual precipitation gradually declines from greater than 1600 mm/year in the southeast provinces to less than 50 mm/year in the northwest.

The distribution of the population and economy do not coincide with the spatial distribution of water resource distribution. Figure 1.1 depicts the spatial distribution of China's water. In 2007, the Haihe River Basin has the lowest water availability on a per capita basis, merely 189 m^3 per year, which is about 14 percent of the national average and about 4 percent of the world average. The per capita water availability of Yellow (Huanghe) and Huaihe basins are 592 and 668 m^3 per year respectively, which are also facing severe water scarcity. The North China Plain has 33 percent of national population and generates the same proportions of gross domestic product (GDP) and industrial output, but only shares 7.7 percent of national water resources (Ministry of Water Resources, 2004).

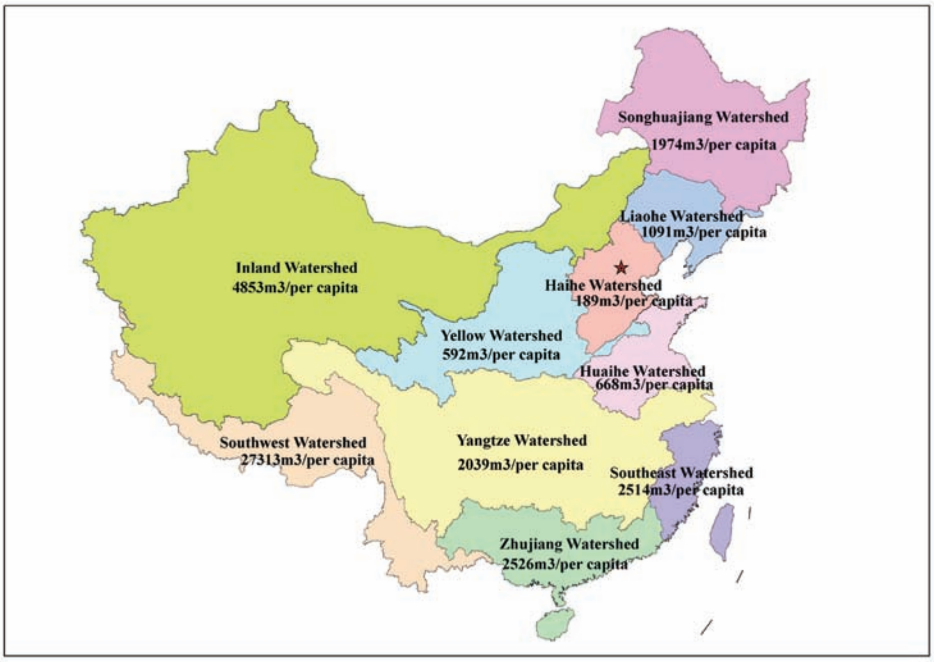

Figure 1.1 Watersheds in China

Demand for freshwater is rising in China due to an increasing population, rapidly developing economic and social needs, accelerated urbanization, and improvements in both the standard of living and surrounding ecosystems (Chen and Zhang *et al*., 2002). Total water use increased from 443.7 billion m^3 in 1980 (United Nations, 1997) to 581.8 billion m^3 in 2007 (Ministry of Water Resources, 2008). This increased water consumption has led to significant water scarcity in many regions, especially in the Haihe, Huanghe (Yellow), and Huaihe River Basins (World Bank, 2001). Increasing water shortages and increased water demand, have given rise to inter-sectoral competition for water among the major user groups, especially in the Haihe, Huanghe (Yellow), and Huaihe River Basins (World Bank, 2001), where agricultural production is negatively impacted due to unprecedented water competition (Yang and Zehnder, 2001). To compensate for surface water shortage, agriculture has been relying increasingly on groundwater, thus causing a rapid depletion of aquifers and a rapid decline in ground water tables.

Production and economic development not only consume water resources but also generate a large amount of wastewater that is released back into the environment. With rapid growth of economy and change of life styles, disposal of hazardous and municipal waste, discharge of industrial and municipal waste water, and agricultural runoff containing fertilizers, pesticides, and manure, have all contributed to polluting most of China's surface and ground water, thus reducing the country's available water resources. In 2007, only 59.5 percent of river sections, 48.9 percent of lakes, 78.5 percent of reservoirs, and 37.5 percent of groundwater wells met quality criteria for source water supply (MWR, 2008). Due to severe pollution, even southern parts of China with its relatively well-stocked resources face shortages of safe and clean drinking water.

Environmental and ecological losses are increasing as a consequence of water scarcity and pollution due to humans overindulging in their increasingly prosperous lifestyles afforded by industrialization. Considering the complex issues involving water, environment, food security, population growth and economic development, sustainable development in China has been facing unprecedented challenges. On the one hand, increasing water scarcity and pollution severely threaten economic development, food security and poverty reduction. On the other hand, the rising water demand and the waste water emissions due to rapid economic development and urbanization are likely to increase the water deficit, environmental deterioration and ecosystem degradation.

1.2 Ongoing mitigating strategies for water issues in China

According to the National Water Law 2002, the Chinese Government is custodian of all water resources of the country. They have the responsibility to construct water infrastructure, conduct water management, enact water pricing policy and allocate water resources among the user groups. To achieve sustainable development of economy, society and environment, the Chinese government has identified several options to mitigate the contradiction between the limited water resources and increasing water demand, including increasing efficiency of water use, reforming water price mechanism and expanding the capacity of water supply. On one hand, several large-scale projects have been launched or are under proposal to mitigate China's water scarcities. The South-to-North Water Transfer (SNWT) project and Three Gorges Dam are two of the most ambitious and controversial projects, although large-scale reservoirs and inter-basin transfer projects will play key roles in supplying freshwater and balancing unevenly-distributed water resources. On the other hand, a series of demand-side management policies, i.e. reallocating water from low to high-value sector, reforming water pricing mechanism, are also developed to improve the water use efficiency of the region.

To mitigate the impact of water pollution, a series of pollution control policies have been also adopted in China. When discharging wastewater, polluters are required to meet rigid discharge standards. However, with the enlargement of China's economy, total pollutant emission is still increasing and exceeds the assimilation capacity of many water bodies and thus worsens water quality, especially in the north of China. Therefore, the strictest environmental policy – controlling the total amount of emissions, was adopted by the Chinese government. In *the Eleventh Five-Year Plan for National Social and Economic Development* (SCCG, 2006), a strict total emission reduction target – 10 percent chemical oxygen demand (COD) reduction in 2010 based on 2005 benchmark data – was set by central government. Local governments were required to proportionately reduce their COD emission by 10 percent in 2010. In *the Twelfth Five-Year Planning for National Social and Economic Development* (SCCG, 2011), local governments are further required to reduce 8 to 10 percent of COD emission in 2015 based on 2010 benchmark data. The same reduction target is also set for total emission amount of ammonia nitrogen (NH3-N) in the Twelfth Five-Year Planning. The *Twelfth Five-Year Planning for Heavy Metal Pollution Comprehensive Prevention* (MEP, 2011) is also released to reduce the total emission of heavy metal in the key areas. When implementing the total emission reduction target, local governments not only invest in end-of-pipe and process-integrated measures but also attempt to adopt tradable emission permit systems to trade emission rights thereby reducing the abatement cost of reducing pollutant emission. Several environment permit exchange centers have been established by local governments in places such as Beijing, Shanghai and Tianjin.

1.3 Problem statement

Rapid economic growth in China has resulted in over exploitation of natural resources and increasing of pollution levels that affect the country's sustainable development. Sustainable development does not focus only on environmental issues. In 1987, the United Nations released the Brundtland Report, which defined the term "Sustainable development" as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The United Nations 2005 World Summit Outcome Document (WHO, 2005) refers to the "interdependent and mutually reinforcing pillars" of sustainable development as economic development, social development, and environmental protection.

As above described, the Chinese government has adopted a series of measures and policies to mitigate water scarcities and pollutions. Effective resource use and pollution control strategies could yield multiple benefits, including protecting both the natural environment and human health, improving water quality for various uses and alleviating water shortages. Moreover, many resource and environmental policies also impact economic growth, household welfare and income distribution. Questions addressed include: How can the decision-makers assess the policy impacts on each of these dimensions? How will the economic and social dimensions be impacted due to the implementation of water and environmental policies? Will production, consumption and trade be affected significantly and in which sector? Whether can welfare of the residents benefit from the policies or they will adversely be affected? Can they bear the burden of the policies? The complexity of the direct and indirect relationships between economic, environmental and social variables calls for tools to answer these questions and provide important insights into the systemic impacts of environmental policies as well identifying and quantifying the effectiveness of water management and pollution control strategies as well as the economic and welfare impacts of these policies.

Many scholars have used partial equilibrium models to analyze changes in GDP and industry output arising from water resource policies (Hou, 1991; Liu 1996; Brown and Halweil, 1998; Conrad *et al*., 1998; Yang and

Zehnder, 2001; Rosegrant *et al*., 2002; Fraiture and Cai *et al*., 2004). However, partial equilibrium analysis usually investigates the effects of policies in a specific market or sector without considering the backward and forward linkages between them when assessing the effectiveness and the associated cost of a policy measure, because partial equilibrium analysis assumes that other things do not change in the economy. Policy evaluations and decisions are undertaken separately in the partial equilibrium analysis.

Due to the complex interrelations between the diverse sectors and agents of the economy, a particular policy change or a shock will result in widespread effects on economic, social and environmental variables. As water usage and pollution control in a sector affects that of other sectors, an integrated assessment tool with an appropriate level of detail and disaggregation is needed to investigate environmental and economic effects of policies. Initially, input-output (IO) models are employed as a useful framework to capture the interrelations and interdependencies among production sectors and primary factors. The components of final demand and the value added of each specific sector are also involved in the input-output modelling framework. Input-output models can be linked with the use of resources and the emission of pollutants to analyze the inter-relationships between economy, resources and environment. It is useful to analyze how the level of resources consumption and pollution will adapt to the changes in production, final demand and trade patterns. However, input-output models have serious limitations, such as their lack of market mechanisms or optimization processes, their fixed coefficients that impose fixed relative prices, their poor substitution possibilities, and their lack of agents (O’Ryan, 2003).

To overcome the limitations of partial equilibrium approaches, computable general (CGE) models are developed for analyzing economic and policy aspects of water management and pollution control. A general equilibrium model will capture complex inter-linkages among production sectors, markets and agents. It also introduces substitution possibilities among them, better than input-output method. CGE models are applicable tools for analyzing how the entire economy adapts after a shock and measuring policy effects with considering integration and reflections among markets.

1.4 Objectives of the study

The main objective of the study is to develop the environmental input-output model and environmental computable general models, and apply them to investigate the inter-relationships between environment and economy, and assess the economy-wide effects of water management and pollution control strategies/mechanisms for mitigating China's water scarcities and pollutions. Specifically, this study is designed to:

i) Using the input-output techniques, analyze the interrelationship between economy and water consumption/pollution and investigate the key sectors with the highest impacts on water consumption and wastewater discharge in the Haihe River Basin;
ii) Using the econometric-driven, multi-regional, multi-sectoral, comparative-static computable general equilibrium model with a water equilibrium price mechanism using marginal value of water, investigate the economy-wide impacts of mitigating North China's water scarcity measures/policies;
iii) Using the single-country, multi-sectoral, comparative-static computable general equilibrium model with a water extension, investigate the economy-wide impacts of charging water resource fee in China;
iv) Using the multi-sectoral environmental extended computable general equilibrium model with a forward-looking dynamic mechanism, investigate the economy-wide impacts of implementing total emission control strategy and establishing emission permit trading mechanism; and
v) According to the simulation results, recommend measures and policies that would promote economic efficiency, environmental sustainability and social welfare in China.

1.5 Overview of the study

The thesis consists of six chapters, as follows:

In chapter two, the study uses input-output model to capture the interrelationship between economy and water consumption/pollution and investigate the key sectors with the highest impacts on water consumption and wastewater discharge in the Haihe River Basin.

Through the input-output techniques, a series of assessment indicators is calculated to assist in tracking both direct and indirect effects of freshwater consumption and wastewater discharge in the economic sector, as well as to distinguish the economic sectors that have greatest influence on water demand and pollution.

In chapter three, an econometric-driven, multi-regional, multi-sectoral water extended computable general equilibrium model is developed to analyze the effectiveness of measures and policies for mitigating North China's water scarcity issues, i.e., reducing over-exploitation of groundwater, constructing South to North Water Transfer project and reallocating water from low-value sectors to relatively high-value sectors. Water is introduced as an explicit factor of production into the model framework. The study adopts the marginal value of water to represent the equilibrium price of water. An econometric model is used to estimate the marginal value of water. The gravity model of trade is used to estimate the regional trade across Beijing, Tianjin and Hebei. The study also estimates the elasticities across production factors in the CES production function through an econometric analysis.

In chapter four, the study presents a comparative-static computable general equilibrium model of the Chinese economy with water as an explicit factor of production. This model is used to assess the broad economic impact of a policy based on water demand management mechanism, using water tax charges as a policy-setting tool. The author uses the model to evaluate the influences of water pricing under different scenarios.

In chapter five, the study applies an extended environmental dynamic computable general equilibrium model to assess the economic consequences of implementing total emission control strategy and establishing emission permit trading mechanism through simulating different emission reduction scenarios ranging from 20 to 50 percent emission reduction up to the year 2020 with respect to emission levels in 2007. A multi-abatement-sector structure is developed in the modelling framework, which can help us capture detailed information on changes of abatement costs for each specific pollutant. The study also presents an environmental social accounting matrix (ESAM) for China's economy 2007, which serves as a consistent dataset for calibrating the model.

Chapter six summarizes the empirical findings in the previous chapters and discusses some policy implications of these findings. This chapter gives a brief general conclusion and highlights the prospects for further and future studies.

Chapter 2. An Analysis of Water Consumption and Pollution with an Input-output Model in the Haihe River Basin, China

Based on

Qin, C., Su, Z., Jia, Y., Bressers, H.J.A., Wang, H., 2011. An Analysis of Water Consumption and Pollution with an Input-output Model in the Haihe River Basin, China. *Water and Environment Journal* (Under review).

Abstract:

This study is the first to apply a hybrid input-output (IO) model linking economic and ecological systems in order to analyze water consumption and wastewater discharge in the Haihe River Basin. Within the environmental IO framework, a series of assessment indicators is calculated to assist in tracking both direct and indirect effects of freshwater consumption and wastewater discharge in the economic sector, as well as to distinguish the economic sectors that have greatest influence on water demand and pollution. Assessment results indicate that water consumption and pollution can be reduced by readjusting the structure of production, consumption and trade in the Haihe River Basin. It is concluded that in order to achieve sustainable development in the Haihe River Basin with its very poor water endowment, not only the direct but also the indirect effects on water demand and pollution should be considered when production, consumption and trade policies are formulated.

Keywords: Input-output analysis; Hybrid accounting; Water consumption; Water pollution.

2.1 Introduction

2.1.1 Emerging water and development issues in the Haihe River Basin

Of all natural resources available to mankind, water holds a prominent position because it is indispensable to both human existence and economic activity. According to recent official statistics, the annual total of China's available water amounted to 2812 billion m^3. However, the annual per capita renewable freshwater availability amounts to only 2196 m^3, or one quarter of the world's average. Moreover, the spatial distribution of water resources in China is uneven. While water resources are relatively abundant in the south, the north of the country generally has poor water resources. The Haihe River Basin has the lowest water availability on a per capita basis, merely 189 m^3 in 2007, which is about 14 percent of the national average and less than 2.5 percent of the world average. Despite such poor water endowment, the region boasts a population of around 10 percent of the nation's total and contributes 15 percent of China's total amount of industrial production and 10 percent of the country's total agricultural output. The region produces about 30 and 20 percent, respectively, of the nation's wheat and corn. Furthermore, the key Jing-Jin (Beijing-Tianjin) economic zone is also located in this basin. Therefore, efficient use of water resources in the Haihe River Basin is important for national economic development and food security.

The water challenge in the Haihe River Basin is primarily driven by climate change as well as human activity. Average precipitation declined from 564 mm/year in the period 1956-1979 to 498 mm/year in the period 1980-2005 (see Figure 2.1). In the past two decades, water demand in the region has increased rapidly due to population growth, industrialization, and urbanization. Increased water demands, especially from sectors other than agriculture, have given rise to inter-sectoral competition for water among major user groups. Agricultural and ecological water uses have been supplanted by industrial and domestic use. Major rivers are already exploited to a maximum as fresh water source, leaving little or no water to flow out to sea. The average water amount flowing into the sea declined from 15.5 billion m^3 per year between 1956 and 1979 to 3.5 billion m^3 per year between 1980 and 2005 (see Figure 2.2). To compensate for surface water shortage, agriculture has been relying increasingly on groundwater, thus causing a rapid depletion of aquifers (Shi, 1997) and a rapid decline in ground water tables (Yang, 2001).

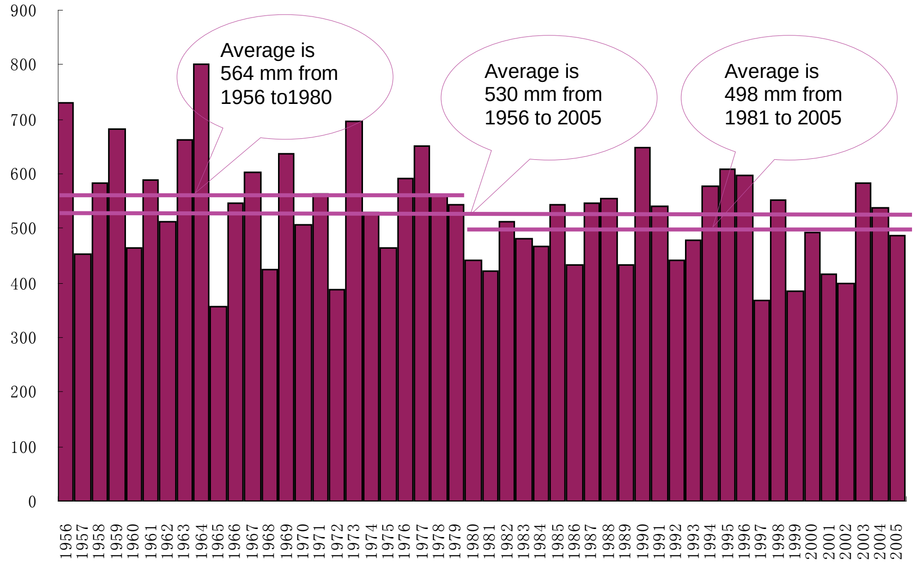

Figure 2.1 Precipitation in the Haihe River Basin in the period 1956-2005 (Unit: mm)

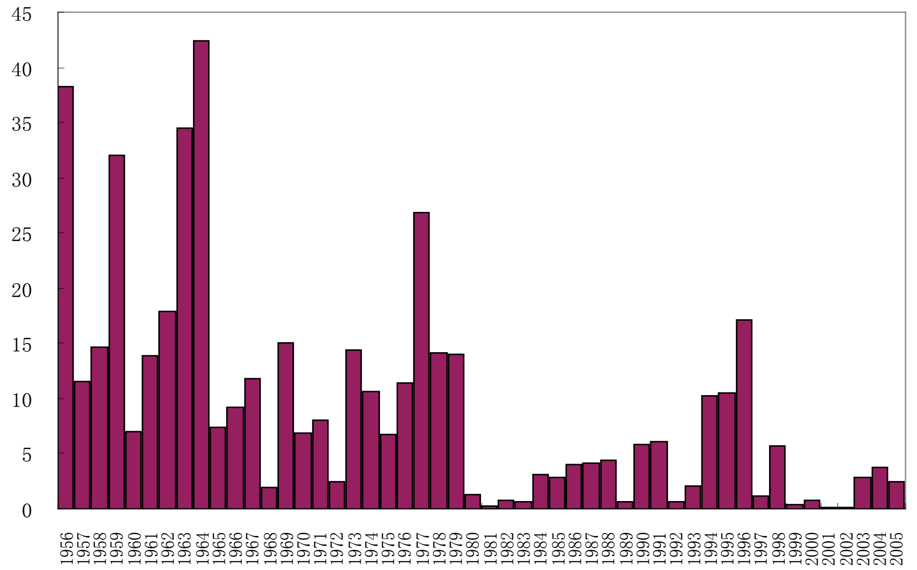

Figure 2.2 Water amount flowing to the sea in the Haihe River Basin in the period 1956-2005 (Unit: billion m3)

Production and economic development not only consume water resources, but also generate large amounts of wastewater, which are released back into the environment. In 2004, only about 36 percent of urban wastewater was being treated (Che, 2007), and in rural areas the percentage was even lower. The remainder was directly released without any treatment. Meanwhile, the intensive use of chemical fertilizers and pesticides in pursuit of higher yields led to a large amount of nonpoint pollution, also endangering the environment in the region (Huang, 2002). Official sources indicate that less than 30 percent of the whole river meets the minimum standard of Class III, below which water is too severely polluted to be used directly without treatment. Both pollution and environmental degradation contribute to the water scarcity by reducing the amount of usable fresh water.

Considering the complex issues involving water, environment, food security, population growth and economic development in the Haihe River Basin, sustainable development in the region has been facing unprecedented challenges. On the one hand, increasing water scarcity and pollution severely threaten economic development, food security and poverty reduction in the Haihe River Basin. On the other hand, the rising water demand and the water emissions due to rapid economic development and urbanization are likely to increase the water deficit, environmental deterioration and ecosystem degradation. To mitigate severe water crises in the Haihe River Basin, several large-scale projects have been launched or are proposed. The east and middle routes of the south to north water transfer will play key roles in supplying freshwater for the region. However, due to complex technical, economic, social, and environmental issues, solutions to meeting water demands *via* supply-side mechanisms are gradually becoming less viable. Alternative management options, such as demand-side management, should receive more attention when developing water policies (Ashton and Seetal, 2002).

In order to help decision makers develop a more balanced policy, it is necessary to carefully evaluate water consumption and wastewater discharge, caused by production, consumption, and associated trade activities. This paper addresses and analyzes the complex issues of water scarcity, pollution, development, food security and poverty reduction through a water extended hybrid input-output accounting and modelling framework. It is the first time such a method has been applied in the Haihe River Basin. Within this hybrid input-output framework, a series of assessment indicators have been calculated, which are expected to generate insights for environmental managers in the Haihe River Basin. These indicators focus on the following questions: What are the implications of increasing competition for water use across sectors? Which sector has the highest rate of water consumption and pollution? How are water consumption and pollution affected by changes in production, consumption and trade for each sector? Can local water consumption and pollution be reduced by adjusting trade policies? Which key sector's percentual growth leads to the highest rise in water consumption and pollution considering the pull and push effects amongst the sectors?

2.1.2 Input-output analysis

Since the 1960s, economists have studied and analyzed the relationships between the economy and the environment, and more specifically in the production sectors, the consumption of natural resources and the pollution generated (Cumberland, 1966; Daly, 1968; Ayres and Kneese, 1969; Leontief, 1970; Isard, 1972; Victor, 1972; Leontief and Ford, 1972). Some of their ideas have been adopted in the ambitious System of Integrated Environmental and Economic Accounts (SEEA) developed by the United Nations *et al*. (1993), clarifying concepts and classifications for physical and 'hybrid' (mixed monetary-physical) accounts and illustrating how physical flows and stocks can be made compatible with national account conventions. Water accounts are amongst the most widely implemented components of the SEEA framework, and the System of Environmental and Economic Accounting for Water (SEEAW), a specialized manual for water, has subsequently been developed (United Nations, 2006), greatly enhancing the capability to manage precious water resources and assets. The National Accounting Matrix including Environmental Accounts (NAMEA), developed in the Netherlands based on the SEEA indicators forms an extension of these efforts (Keuning *et al*., 1999). The environmental accounts in the NAMEA are denominated in physical units, focusing on consistent presentation of the input of natural resources and the output of residuals for the national economy.

These accounting frameworks offer environmental statistics consistent with the IO tables and are particularly suitable for environmental economic modellers. The input-output analysis is a top-down economic technique used globally. In this method, sectoral monetary transaction data are used to quantify the complex interdependencies of industries in modern economies. The method has been extended to analyze environmentally related issues such as environmental pollution, energy consumption, and water pollution associated with industrial production (Daly, 1968; Ayres and Kneese, 1969; Leontief, 1970; Isard, 1972; Victor, 1972; Miller, 1985; Duchin and Lange, 1994).

The input-output analysis has also frequently been applied to water consumption and wastewater discharge. Hartman (1965) examined the efficacy of the input-output model analyzing regional water consumption allocation. Chen (2000) studied the balance between supply and demand for water resources in the Shanxi Province of China by introducing water inputs as production factors (measured in physical units) in a traditional input-output model. Leistrtz *et al*. (2002) examined the regional economic impact of water management on Devils Lake in North Dakota in the US. Sánchez-Chóliz and Duarte (2005) discussed the relationships between production processes and water pollution, based on the Satellite Water Accounts and input-output tables for the Spanish economy. Velázquez (2006) explored intersectoral water relationships in Andalusia by combining the extended Leontief input-output model with the model for energy use developed by Proops (1988), and establishing a number of indicators for water consumption. This approach was later applied in Zhangye, an arid area in northwest China, to analyze the structural relationship between economic activities and their physical ties to the region’s water resources (Wang *et al*., 2009). Okadera *et al* (2006) evaluated water demand and the discharge of water pollutants in relation to socio-economic activities in the city of Chongqing in China, using a regional input-output table.

2.1.3 Water footprints

The concept ‘ecological footprint’, well known amongst ecological economists, clearly represents human impact on the earth. Since its first introduction in the 1990s (Rees, 1992; Rees and Wackernagel, 1994; Wackernagel and Rees, 1996), the ecological footprint concept has been developed and applied in studies on resource consumption and environmental pollution. In the environmental input-output model, coefficients for resource consumption and pollution emission intensity are introduced to connect the resources and pollution to the productive activity of each industry. These coefficients can be further applied to develop ecological footprint indicators to account for embodied resource consumption and pollution emission. Hoekstra and Hung (2002) developed the water footprint as an analogy to the ecological footprint to measure the volume of water involved in the production of goods and services. Guan and Hubacek (2007) calculated virtual water flows for northern and southern China using an extended regional input-output model. Yu and Hubacek (2010) developed a regional input-output model extended with water consumption coefficients to quantify the domestic water footprint for different levels of water consumption in the south-east and north-east of England as well as for the UK as a whole.

This study does not aim to further discuss physical accounts, but focuses on the application of hybrid input-output tables in the Haihe River Basin. Section 2.2 presents the materials and methodology. Section 2.3 discusses the results for a series of indicators defined in the water extended hybrid input-output framework. Section 2.4 presents the conclusion together with findings useful for environmental management of the Haihe River Basin.

2.2 Materials and methodology

2.2.1 Leontief input-output (IO) model

The traditional IO table is a $n \times n$ matrix describing the flows of goods between economic sectors in monetary units. The key part of the static Leontief's input-output model is the following algebraic equation:

$$AX + Y = X \tag{2.1}$$

or

$$Y = (I - A)X \tag{2.2}$$

where x (element of X) represents sectoral production output; y (element of Y) represents final demand; I is the $n \times n$ identity matrix;

and A is an $n \times n$ matrix of technical coefficients or direct input coefficients which can be defined as,

$$A = \lfloor a_{ij} \rfloor, \ \ a_{ij} = \frac{x_{ij}}{x_j} \tag{2.3}$$

where a_{ij} refers to the amount of input from sector i and required by sector j for each unit of output. It is able to determine the fixed relationship between a sector's output and input (Miller and Blair, 1985).

If $|I - A| \neq 0$, then we can get:

$$X = (I - A)^{-1} Y \tag{2.4}$$

where $(I\text{-}A)^{-1}$ is known as the Leontief inverse matrix, or the so-called Leontief multiplier matrix

$$(I - A)^{-1} = [\alpha_{ij}] \tag{2.5}$$

where α_{ij} indicates the total production of sector i required to satisfy the final demand in sector j in the economy. Thus the final demand is linked with the corresponding direct and indirect production by the Leontief inverse matrix.

2.2.2 Extension of the hybrid water IO model

For an account of resource or emission of the economy, the economic input-output table is incorporated in an ecological input-output table thus covering both economic and biophysical flows within and across the boundaries of the economic system. An $m \times n$ physical water accounting matrix measuring the amounts of freshwater consumed and wastewater discharged by economic production processes is linked to the traditional IO table. The extended hybrid water IO table is presented in Table 2.1.

Table 2.1 Extended hybrid water input-output table

		Intermediate Demands	Final Demands & Water	Total Outputs & Water
		1 … n		
Intermediate Inputs	1 … n	$[x_{ij}]$	$[y_i]$	$[x_i]$
Primary Inputs		$[v_j]$		
Total Inputs		$[x_j]$		
Water	1 … m	$[w_{kj}]$	$[l_k]$	$[q_k]$

Production and economic development not only consume water resources, but also generate large amounts of wastewater, which are released back into the environment. According to IO theory, the production of a good need utilize other goods supplied by other sectors for their own production inputs. To produce these goods, it would also consume water resources and discharge wastewater. IO technique provides a useful to calculate indirect water consumption and pollution.

In this study, the connection between monetary economic flows and physical water accounts are first captured by freshwater consumption intensity and wastewater discharge intensity, which are defined as follows:

$$d_{kj} = \frac{w_{kj}^d}{x_j} \tag{2.6}$$

where k represents ‘freshwater’ and ‘wastewater’, and d_{kj} (element of D) represents the direct water consumption intensity ($k=1$, unit: m³/10⁴Yuan) and direct wastewater discharge intensity ($k=2$, unit: m³/10⁴Yuan). They are calculated by dividing w_{kj}^d, the total amount of consumed water and discharged wastewater of sector j , with the total input x_j into that sector.

Then a matrix equation is obtained as follows:

$$DX + L = Q \quad (2.7)$$

where DX is the matrix of water consumed and wastewater discharged by intermediate industrial activity, and L is the vector of water consumed and wastewater discharged in the final demand sectors.

By substituting (2.4) into (2.7), Q can be calculated as a function of Y and L as follows:

$$Q = D(I - A)^{-1}Y + L \quad (2.8)$$

Therefore, the overall water input-output balance can be presented by grouping equations (2.4) and (2.8) together as follows:

$$\begin{bmatrix} X \\ Q \end{bmatrix} = \begin{bmatrix} I - A & 0 \\ -D & I \end{bmatrix}^{-1} \begin{bmatrix} Y \\ L \end{bmatrix} = \begin{bmatrix} (I - A)^{-1} & 0 \\ D(I - A)^{-1} & I \end{bmatrix} \begin{bmatrix} Y \\ L \end{bmatrix} \quad (2.9)$$

A matrix T is defined to represent the total water consumption intensity and the total wastewater discharge intensity. The matrix can be expressed as:

$$T = D + DA + DA^2 + \cdots DA^n + \cdots \quad (2.10)$$

$$\text{or } T = D(I - A)^{-1} \quad (2.11)$$

Therefore, the matrix of total water consumption and wastewater discharge intensity in this model is the direct intensity matrix multiplied by the Leontief Inverse, which present not only direct water consumption and wastewater discharge but also indirect water consumption and wastewater discharge in the production process.

The Leontief model also accounts for the ‘drag’ effect that indicates how the evolution of a given sector can exert a drag upon the total economic production. In order to describe the ‘drag’ effect on water consumption and wastewater discharge, two indicators, namely, the water consumption multiplier ($m_k^d, \quad k = 1$) and the wastewater discharge multiplier ($m_k^d, \quad k = 2$), are introduced. They can be calculated by dividing the total water consumption intensity or the total wastewater discharge intensity by the direct water consumption or wastewater intensity:

$$m_{kj}^{d} = \frac{t_{kj}}{d_{kj}} \tag{2.12}$$

Once the above multipliers have been defined, it is easy to obtain multipliers of indirect water consumption and wastewater discharge simply by subtracting one:

$$m_{kj}^{ind} = m_{kj}^{d} - 1 = \frac{t_{kj}}{d_{kj}} - 1 \tag{2.13}$$

2.2.3 Freshwater and wastewater footprints

When producing a good, both direct and indirect water consumption and wastewater discharge can be determined by the input-output analysis. Therefore, we can subsequently determine total water consumption and pollution when a unit of good is consumed or exported.

In this study, two categories of water footprints (WF) are defined: freshwater footprints (FWF) and wastewater footprints (WWF). The method calculating water footprints should incorporate total domestic water consumption and wastewater discharge, including both direct and indirect water consumption and discharge, plus the amount of water and pollution embodied in imported products minus the amount of water and pollution embodied in exported goods and services (Guan and Hubacek, 2007; Hoekstra and Chapagain, 2007; Yu *et al.*, 2010).

The domestic freshwater footprint (DFWF) is defined by Guan and Hubacek (2007) as the use of domestic water resources to produce goods and services consumed by inhabitants of the country, minus the water used for export. Similarly, the domestic wastewater footprint (DWWF) can be defined as the discharge of wastewater for the production of goods and services minus the wastewater discharged for producing exported products. They can be calculated using the following equation:

$$DFWF = d_k \cdot (I - A)^{-1} \cdot \hat{y}^{dom}, \quad k = 1 \tag{2.14a}$$

$$DWWF = d_k \cdot (I - A)^{-1} \cdot \hat{y}^{dom}, \quad k = 2 \tag{2.14b}$$

It is much more complex to calculate the imported water footprint, because imports into the study region come from a number of countries with different production technologies. Therefore, due to data limitations, it is assumed here that the water consumption and pollution intensity of an imported product is the same as that of a domestic one. This assumption means that the virtual water and wastewater embodied in the trade depends on how much water is saved or how much pollution is reduced by trade instead of by producing it at the production site (Renault, 2003). So the net imported freshwater footprint (NFWF) and wastewater footprint (NWWF) can be achieved by:

$$NFWF = d_k \cdot (I - A)^{-1} \cdot (\hat{m} - \hat{e}), \quad k = 1 \tag{2.15a}$$

$$NWWF = d_k \cdot (I - A)^{-1} \cdot (\hat{m} - \hat{e}), \quad k = 2 \tag{2.15b}$$

By adding up the domestic water footprints and net imported water footprints, the total freshwater footprint (TFWF) and total wastewater footprint (TWWF) can be obtained.

$$TFWF = DFWF + NFWF \tag{2.16a}$$

$$TWWF = DWWF + NWWF \tag{2.16b}$$

2.2.4 Intersectoral linkages for water consumption and pollution

In the context of input-output tables, the linkages can be categorized into two groups according to the direction of interdependencies: the backward linkage (the pull effect) and the forward linkage (the push effect), which have been extensively used for the analysis of interdependent relationships in economic sectors in order to determine appropriate development strategies. In terms of the backward linkage: if sector i increases its output, then demands put upon the sectors with products that are used as input into sector i are increased. In terms of the forward linkage: increased output from sector i also means that additional amounts of product i become available as input in the production in other sectors. Increased output in sector i can also lead to increases in water demand and pollution for the sectors where production needs to be increased to satisfy the input necessary for production in sector i. Similarly, increase in production in sector i of products used as input in other sectors, leads to additional water demand and pollution. According to the concepts of indirect water consumption and wastewater discharge, the two linkages can indicate a sector's economic pull and push forces on water demand and pollution, because the direction and level of such linkages present the potential of each sector to stimulate other sectors thus reflecting the role of this sector in the economy as a whole (Pietroforte and Gregori, 2003). In this section, two indices, the pull effect index (PLEI) and the push effect index (PSEI), are used to mathematically measure the backward and forward linkages for water consumption and wastewater discharge (Miller and Blair, 1985; Yu *et al.*, 2010).

The pull effect index can be expressed as follows:

$$PLEI_j^k = \frac{\hat{d}_k \sum_{i=1}^{n} \overline{\alpha_{ij}}}{\frac{1}{n} \sum_{i=1}^{n} \hat{d}_k \sum_{j=1}^{n} \overline{\alpha_{ij}}} \tag{2.17}$$

and the push effect index thus:

$$PSEI_i^k = \frac{\hat{d}_k \sum_{j=1}^{n} \overline{\alpha_{ij}}}{\frac{1}{n} \sum_{i=1}^{n} \hat{d}_k \sum_{j=1}^{n} \overline{\alpha_{ij}}} \tag{2.18}$$

In equations (2.17) and (2.18), $\hat{d}_k$ represents the element of the diagonal matrix of the water consumption intensity vector ($k = 1$) and that of the wastewater discharge intensity vector ($k = 2$), respectively. If PLEI is greater than 1, expansion of the final demand in sector j can lead to an above-average increase in water demand and pollution for all sectors. If PSEI is greater than 1, expansion of the final demand in the economy can result in an above-average increase in water demand and pollution for sector i. Sectors where this occurs are considered to be key sectors as they may influence the whole water consumption and pollution process in the economy to a great extent (Lesher and Nordas, 2006).

2.2.5 Data collection

In this study, the 2002 China national and provincial IO tables from the National Bureau of Statistics of China have been used. The Haihe River Basin primarily covers the Hebei province as well as the two large cities, Beijing and Tianjin. The basin also partially covers five other provinces. Since Inner Mongolia and Liaoning province only contain tiny parts of the Haihe River Basin, they have not been taken into account in the processing of the model. Shandong, Shanxi, and Henan province each partially fall within the Haihe River Basin, so the input-output tables for the areas within the basin of those three provinces are estimated using a simple location quotient (Richardson, 1972; Mayer and Pleeter, 1975; Round, 1983; Miller and Blair, 1985; Brand, 1997; Flegg *et al*., 1995; Flegg and Webber, 1997, 2000; Hubacek and Sun, 2005; McCann and Dewhurst, 1997; Yu *et al*., 2010) based on their respective provincial IO tables. As Beijing, Tianjin, and almost all of Hebei Province are located within the basin, their three IO tables are directly used in the input-output analysis. Corresponding to the available water consumption and wastewater discharge data, the 42-sector classification of the national and provincial IO tables has been aggregated into a total of 27 sectors and two final demand sectors (see Table 2.2).

Table 2.2 Classification of sectors

Code	Sectors	Code	Sectors
01	Agriculture	16	Industrial machinery
02	Coal mining and processing	17	Transport equipment
03	Extraction of petroleum & gas	18	Electric equipment
04	Metal ore mining	19	Electronic and telecom equipment
05	Non-ferrous mineral mining	20	Instruments, cultural, office equipment
06	Food and tobacco processing	21	Artwork and other manufacturing
07	Textile apparel	22	Scrap and waste
08	Clothing products	23	Electricity
09	Sawmills and furniture	24	Gas production and supply
10	Paper, publishing and printing	25	Water production and supply
11	Petroleum & nuclear fuel processing	26	Construction
12	Chemical industry	27	Service industry
13	Nonmetalic mineral products	R-HHD	Rural households
14	Metal smelting and pressing	U-HHD	Urban households
15	Metal products		

All available datasets have been taken into account in order to improve the estimation of sectoral water consumption and wastewater discharge. The datasets on water availability, consumption and wastewater discharge are extracted from *The Water Resources Statistics Bulletins* annually published by the Ministry of Water Resources (MWR), the Haihe River Water Resources Commission, and provincial bureaus of water resources. The datasets on wastewater discharge can also be found in the *China Environmental Yearbook* from the Ministry of Environmental Protection (MEP) and in *Environmental Condition Bulletins* from the MEP and provincial bureaus of environmental protection. Official reports on water resources and environmental planning from the MWR and the MEP as well as other publications have also been collected. Based on the information collected, the data on water consumption and wastewater discharge are disaggregated into different industrial sectors according to regional consumption and emission levels. The amounts of water consumption and wastewater discharge in the service sector have been separated from the municipal and domestic water consumption and wastewater discharge data of each province and each municipality. Unlike point source pollution from industrial, municipal and domestic wastewater discharge, agricultural non-point source pollutants are discharged during runoff and infiltration processes caused by both irrigation and rainfall. In this study, the amount of wastewater discharge was assumed to be equal to the amount of recharge from irrigation plus the amount of wastewater produced by other agricultural activities.

2.3 Results and discussion

2.3.1 Characteristics of water consumption

Figure 2.3 shows the pattern of water consumption in the Haihe River Basin in 2002. In that year, the total net water consumption of all production sectors was 25,606 million m^3 (excluding precipitation in rain-fed agricultural areas), and the total households' net water consumption was 2,132 million m^3. Agriculture was the largest water consumer, accounting for over 81 percent of total direct water consumption. Household consumption came second with 7.7 percent of the total. Amongst the secondary sectors, electricity as well as metal smelting and pressing were main water consumers, accounting for about 4.6 and 1.3 percent, respectively. About 3.9 percent of the total direct water consumption was consumed by other industrial sectors. The service sector contributed to the remaining 1 percent of the total.

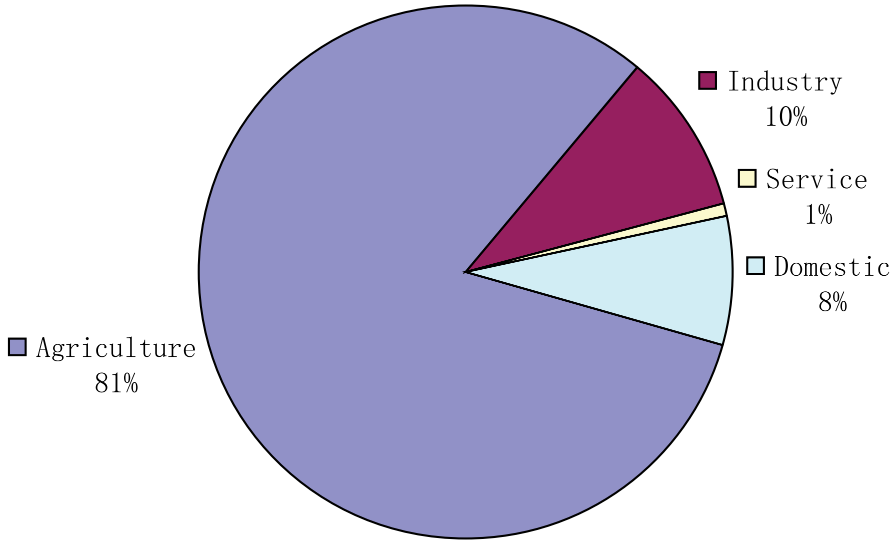

Figure 2.3 Water consumptions in the Haihe River Basin in 2002

Table 2.3 represents direct water consumption, direct and total water consumption intensities, as well as direct and indirect water consumption multipliers. According to the derived direct water consumption intensities in Table 2.3, agriculture requires the highest water input with 76 m^3 of direct water consumption per thousand CNY (monetary unit: Chinese Yuan) of sectoral output. Amongst the secondary sectors, water production and electricity are the two most water-intensive sectors with more than 15 m^3 of direct water consumption per thousand CNY of output, followed by gas production and supply, metal ore mining, coal mining & processing, metal smelting & pressing, and paper manufacturing. The direct water intensity in the service industry is relatively low. The data on total consumption indicate that agriculture consumes the greatest amount of water with 97 m^3 of total water consumption per thousand CNY of sectoral output. But the direct and indirect consumption multiplier both indicate that agricultural water demand is almost exclusively direct. When indirect water is considered, it becomes obvious that water consumption by the industrial and service sectors increases greatly, as is shown by the total consumption intensities. For example, food & tobacco processing, as well as the textiles sector have a high total consumption intensity of 39 and 30 m^3 per thousand CNY output, respectively. Although these sectors use only a small amount of water directly for production, high water consumption by the input from other sectors causes the total to increase markedly. This is confirmed when analyzing the water consumption multipliers (Table 2.3). For instance, the direct and indirect multipliers of clothing, sawmills & furniture, electronic & telecommunication equipment *etc*., are more than 100. This means these sectors have a very large drag effect on the water consumption of the whole economy.

Table 2.3 Direct water consumption (w_1^d, unit: 10^6 m^3) , direct (d_1, unit: $m^3/10^3$CNY) and total (t_1, unit: $m^3/10^3$CNY) water consumption per unit of output, direct (m_1^d) and indirect (m_1^{ind}) water consumption multipliers

Sectors	w_1^d	d_1	t_1	m_1^d	m_1^{ind}
01 Agriculture	22627	76.13	97.52	1.28	0.28
02 Coal mining and processing	114.3	2.36	8.31	3.53	2.53
03 Extraction of petroleum & gas	16.0	0.42	2.58	6.08	5.08
04 Metal ore mining	167.8	4.84	12.28	2.54	1.54
05 Non-ferrous mineral mining	8.9	0.68	5.48	8.00	7.00
06 Food and tobacco processing	165.3	0.78	39.09	49.85	48.85
07 Textile apparel	66.0	0.75	30.30	40.19	39.19
08 Clothing products	10.3	0.15	18.99	124.9	123.9
09 Sawmills and furniture	0.9	0.03	15.17	526.8	525.8
10 Paper, publishing and printing	109.2	1.38	14.30	10.35	9.35
11 Petroleum & nuclear fuel processing	29.0	0.34	4.37	13.01	12.01
12 Chemical industry	132.4	0.50	10.52	21.03	20.03
13 Nonmetallic mineral products	69.5	0.48	6.18	12.97	11.97
14 Metal smelting and pressing	352.0	1.76	7.88	4.47	3.47
15 Metal products	14.8	0.18	5.63	31.80	30.80
16 Industrial machinery	8.0	0.05	5.02	95.96	94.96
17 Transport equipment	8.5	0.09	6.17	65.63	64.63
18 Electric equipment	7.3	0.09	6.68	70.86	69.86
19 Electronic $ telecom equipment	2.4	0.01	4.55	391.6	390.6
20 Instruments, cultural, office equipment	3.6	0.13	14.47	111.9	110.9
21 Artwork and other manufacture	1.0	0.08	8.48	103.8	102.8
22 Scrap and waste	0.7	0.06	0.06	1.00	0.00
23 Electricity	1264	16.32	22.69	1.39	0.39
24 Gas production and supply	23.5	5.50	12.21	2.22	1.22
25 Water production and supply	101.5	18.29	25.54	1.40	0.40
26 Construction	29.5	0.08	5.67	67.31	66.31
27 Service industry	273.6	0.21	4.86	23.00	22.00
Rural households	1788				
Urban households	344				

2.3.2 Characteristics of wastewater discharge

Figure 2.4 shows wastewater discharge patterns in the Haihe River Basin in 2002. That year, agriculture discharged about 6,100 million m^3 of wastewater, and industrial sectors discharged 2,200 million m^3 of wastewater, with electricity, metal smelting & pressing, paper manufacturing, and food & tobacco processing accounting for 61 percent of the total. Municipal and domestic wastewater discharged by service and household sectors was about 2,600 million m^3 in 2002. Although agriculture formed the largest discharger, its pollution level was much lower than that of many industrial and domestic sectors due to its low concentration of pollutants (COD, Total Nitrogen, Total Phosphorus, *etc*.).

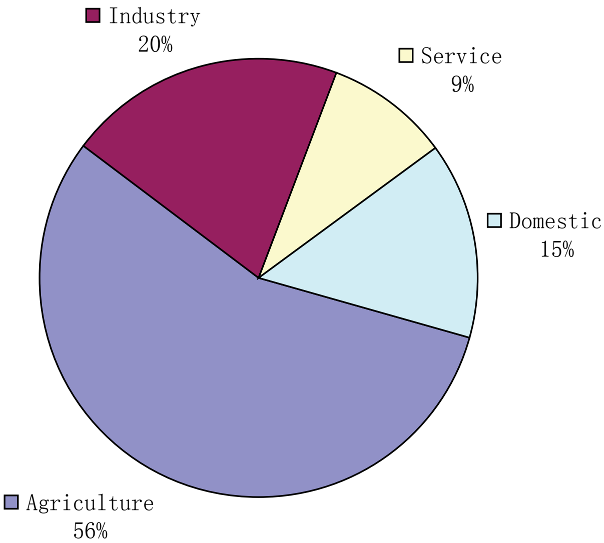

Figure 2.4 Wastewater discharge in the Haihe River Basin in 2002

Table 2.4 represents direct wastewater discharge, direct and total wastewater discharge intensities, as well as direct and indirect wastewater discharge multipliers. According to the direct and total wastewater discharge intensities shown in Table 2.4, agriculture discharges 20 m^3 of direct wastewater and 27 m^3 of the total wastewater per thousand CNY of sectoral output. In the industrial sectors, 6.8, 5.6, 3.1, and 2.0 m^3 of wastewater are directly discharged per thousand CNY of sectoral output by the electricity, water production & supply, paper manufacturing, and gas production & supply sectors, respectively. Food & tobacco processing, textile products, electricity, water production &

supply, and the paper manufacturing each have high total discharge intensities of 12.3, 10.5, 9.6, 8.6 and 8.5 m^3 of wastewater per thousand CNY of production, respectively. The column of 'direct and indirect wastewater discharge multipliers' in Table 2.4 also shows that many industrial sectors indirectly discharge a large amount of wastewater. For instance, for each cubic meter of wastewater discharged because of an increase in production in the clothing sector, an additional 38.0 m^3 of wastewater is discharged by other production sectors.

Table 2.4 Direct wastewater discharge (w_2^d, unit: 10^6 m^3), direct (d_2, unit: $m^3/10^3$CNY) and total (t_2, unit: $m^3/10^3$CNY) wastewater discharge per unit of output, direct (m_2^d) and indirect (m_2^{ind}) wastewater discharge multipliers

Sectors	w_2^d	d_2	t_2	m_2^d	m_2^{ind}
01 Agriculture	6053	20.37	26.82	1.32	0.32
02 Coal mining and processing	49.8	1.03	3.55	3.46	2.46
03 Extraction of petroleum & gas	10.2	0.27	1.34	4.95	3.95
04 Metal ore mining	87.0	2.51	5.92	2.36	1.36
05 Non-ferrous mineral mining	7.9	0.61	2.98	4.89	3.89
06 Food and tobacco processing	192.2	0.91	12.28	13.48	12.48
07 Textile apparel	97.3	1.11	10.52	9.47	8.47
08 Clothing products	11.8	0.17	6.60	37.96	36.96
09 Sawmills and furniture	2.9	0.10	5.51	57.41	56.41
10 Paper, publishing and printing	246.3	3.12	8.51	2.73	1.73
11 Petroleum & nuclear fuel processing	59.2	0.69	2.81	4.09	3.09
12 Chemical industry	374.1	1.41	5.88	4.15	3.15
13 Nonmetallic mineral products	139.3	0.95	3.94	4.13	3.13
14 Metal smelting and pressing	248.5	1.24	4.51	3.62	2.62
15 Metal products	16.7	0.20	3.23	16.17	15.17
16 Industrial machinery	24.5	0.16	2.84	17.85	16.85
17 Transport equipment	16.1	0.18	3.24	18.07	17.07
18 Electric equipment	9.5	0.12	3.46	28.40	27.40
19 Electronic and telecom equipment	14.6	0.07	2.59	36.04	35.04
20 Instruments, cultural, office equipment	2.9	0.11	5.28	50.14	49.14
21 Artwork and other manufacturing	1.9	0.15	3.83	26.04	25.04
22 Scrap and waste	0.7	0.06	0.06	1.00	0.00
23 Electricity	525.6	6.79	9.56	1.41	0.41
24 Gas production and supply	8.7	2.03	5.05	2.49	1.49
25 Water production and supply	31.0	5.59	8.58	1.53	0.53
26 Construction	31.6	0.09	3.04	33.62	32.62
27 Service industry	993.4	0.77	2.95	3.85	2.85
Rural households	326				
Urban households	1249				

2.3.3 Results of freshwater and wastewater footprints

Table 2.5 describes the freshwater and wastewater footprints for the Haihe River Basin. As can be seen from Table 2.5, the agriculture, food, textile, clothing, chemical industry, general & specialized industrial machinery, construction, and the service sector all have a relatively high domestic freshwater footprint. The agriculture, food & tobacco processing, clothing, metal smelting & pressing, general & specialized industrial machinery, electricity, construction, and the service sector are the sectors contributing most to the domestic wastewater footprint. The water footprints describe both direct and indirect water and pollution involved in the production of goods and services. Combining the results on water consumption and wastewater discharge intensity of Table 2.3 and 2.4, indicates that direct water input and pollution are the main contributors to the freshwater and wastewater footprints of the agriculture and the electricity sector. Food & tobacco processing, clothing, construction, services as well as some other industrial sectors add a huge amount of freshwater or wastewater to their footprint indirectly through purchasing goods and services from other water-intensive or pollution-intensive sectors.

Table 2.5 Freshwater and wastewater footprints for the Haihe River Basin

Sectors	Freshwater Footprints		Wastewater Footprints	
	DFWF[1]	TFWF[2]	DWWF[3]	TWWF[4]
01 Agriculture	11028.8	8038.9	3033.2	2210.9
02 Coal mining and processing	56.1	377.7	24.0	161.4
03 Extraction of petroleum & gas	-0.6	9.0	-0.3	4.6
04 Metal ore mining	0.5	-158.5	0.2	-76.4
05 Non-ferrous mineral mining	9.0	85.3	4.9	46.4
06 Food and tobacco processing	2592.3	1640.0	814.8	515.5
07 Textile apparel	358.1	-371.4	124.4	-129.0
08 Clothing products	522.8	150.6	181.6	52.3
09 Sawmills and furniture	247.5	500.2	89.9	181.6
10 Paper, publishing and printing	135.4	61.4	80.6	36.6
11 Petroleum & nuclear fuel processing	12.9	68.1	8.3	43.8
12 Chemical industry	310.8	132.9	173.5	74.2
13 Nonmetallic mineral products	61.3	-162.8	39.0	-103.7
14 Metal smelting and pressing	171.1	447.4	97.9	256.0
15 Metal products	64.3	166.3	36.9	95.4
16 Industrial machinery	614.6	819.2	348.2	464.1
17 Transport equipment	174.8	219.7	91.7	115.2
18 Electric equipment	171.4	98.8	88.8	51.2
19 Electronic and telecom equipment	178.9	41.3	101.9	23.5
20 Instruments, cultural, office equipment	98.4	92.2	35.9	33.6
21 Artwork and other manufacturing	69.1	134.6	31.2	60.8
22 Scrap and waste	0.0	-0.1	0.0	-0.1
23 Electricity	229.1	651.4	96.5	274.4
24 Gas production and supply	39.6	85.9	16.4	35.6
25 Water production and supply	54.5	99.7	18.3	33.5
26 Construction	1949.2	2032.2	1044.1	1088.6
27 Service industry	2505.8	2271.1	1523.7	1381.0
Final demand	2132.0	2132.0	1575.2	1575.2
Total	23787.7	19663.0	9689.9	8506.2

In terms of total freshwater footprint, the agriculture, food & tobacco processing, sawmills & furniture, clothing, chemical industry, general & specialized industrial machinery, electricity, construction, and the service sector all form key water consumers within the Haihe River Basin.

[1] DFWF = domestic freshwater footprint (unit: 10^6 m^3)
[2] TFWF = total freshwater footprint (unit: 10^6 m^3)
[3] DWWF = domestic wastewater footprint (unit: 10^6 m^3)
[4] TWWF = total wastewater footprint (unit: 10^6 m^3)

Similarly, the agriculture, food products, general & specialized industrial machinery, construction, as well as the service sector cause large amounts of emission according to the total wastewater footprints in the Haihe River Basin. The total freshwater and wastewater footprints show that the Haihe River is a net exporter of both freshwater and wastewater of 4125 million and 1184 million m^3 per annum, respectively. Figure 2.5 and 2.6 present the variations in net imported freshwater and wastewater footprints between sectors in the Haihe River Basin. The sectors appearing above the horizontal line are the net virtual water importers, while those below the line are net exporters. As can be seen, the agriculture, food & tobacco processing, textile products, clothing, chemical industry, and service sector all export a considerable amount of freshwater and wastewater footprints, while the coal mining & processing, metal smelting and pressing, general & specialized industrial machinery, as well as the electricity sector are key net freshwater and wastewater importers.

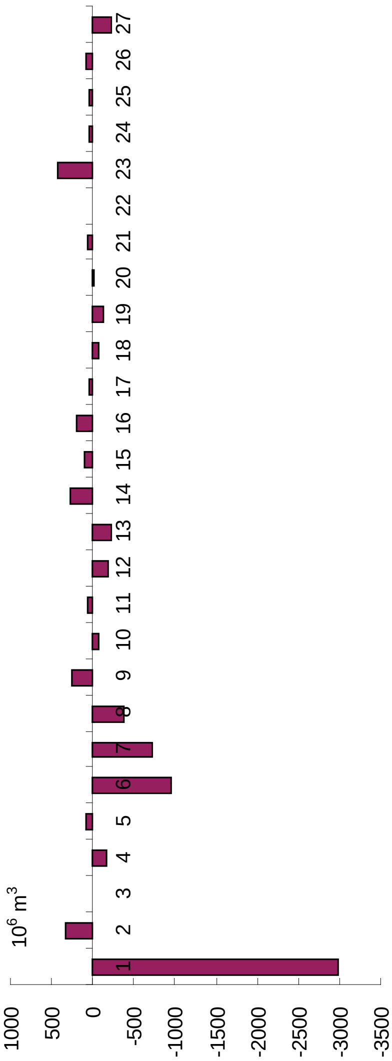

Figure 2.5 Net imported freshwater footprints for the Haihe River Basin

Figure 2.6 Net imported wastewater footprints for the Haihe River Basin

Table 2.6 shows the results of net imported freshwater and wastewater footprints amongst the sectors for Beijing, Tianjin, and Hebei. As the most developed region in China, Beijing has agricultural and industrial sectors with water footprints indicating the import of a great amount of fresh water and wastewater, mainly because of its highly developed service industry. Although Tianjin, the third largest city of China, achieves a balance between import and export of virtual freshwater and wastewater, its highly water-intensive agriculture is still exporting water, while some low water-intensive and low pollution-intensive industrial and service sectors are relying on the import of freshwater and wastewater. This shows there is potential to reduce the domestic water footprints in Tianjin by restructuring economic sectors. Hebei Province, a less developed region in the Haihe River Basin, is a large net exporter of both freshwater and wastewater, especially the agriculture sector which has a large amount of direct water consumption, and some industrial sectors which have high indirect water consumption and pollution, such as the food & tobacco processing sector. These results lead to the conclusion that differences in the level of development and economic structure have an important impact on the consumption of local water resources and the reduction of pollution.

Table 2.6 Net imported freshwater and wastewater footprints (unit: 10^6 m^3) for Beijing, Tianjin and Hebei

	Freshwater			Wastewater		
Sectors	Beijing	Tianjin	Hebei	Beijing	Tianjin	Hebei
01 Agriculture	548	-139	-2957	55	-79	-822
02 Coal mining and processing	10	9	394	11	7	151
03 Extraction of petroleum & natural gas	0	-12	9	0	-9	4
04 Metal ore mining	16	0	-197	17	0	-95
05 Non-ferrous mineral mining	4	5	44	5	4	21
06 Food and tobacco processing	60	38	-1143	15	28	-352
07 Textile apparel	10	4	-552	4	3	-192
08 Clothing products	5	-20	-285	2	-17	-98
09 Sawmills and furniture	21	-2	168	14	-2	55
10 Paper, publishing and printing	45	0	-329	105	0	-180
11 Petroleum & nuclear fuel processing	-6	-7	117	-9	-7	61
12 Chemical industry	13	-36	-47	12	-48	-24
13 Nonmetallic mineral products	16	7	-318	23	7	-175
14 Metal smelting and pressing	35	29	142	43	26	75
15 Metal products	20	11	0	26	11	0
16 Industrial machinery	39	30	-33	49	30	-17
17 Transport equipment	14	-8	10	17	-9	5
18 Electric equipment	8	-23	-17	10	-24	-9
19 Electronic and telecom equipment	-13	-40	16	-16	-43	8
20 Instruments, cultural, office equipment	1	2	-86	1	2	-28
21 Artwork and other manufacturing	7	1	25	6	1	12
22 Scrap and waste	0	0	0	0	0	0
23 Electricity	123	70	-104	125	32	-37
24 Gas production and supply	8	1	36	6	1	12
25 Water production and supply	0	33	0	0	13	0
26 Construction	2	24	22	3	22	10
27 Service industry	-155	29	164	-193	34	90
Total	832	6	-4923	332	-18	-1527

2.3.4 Economic pull and push effects on water consumption and pollution

The results on the pull and push effect indices are shown in Table 2.7. As can be seen in terms of both water consumption and wastewater discharge, the agriculture, electricity and water supply sectors have the largest pull and push effects. Since the indices of both effects are greater than 1 for these sectors, they are key sectors in the economy, with more influence on the whole water consumption and pollution process, through both purchases and sales. One unit of change in their final demand will cause an above average change in both water consumption and wastewater discharge throughout the entire economy, and one unit of change in the final demand of the whole economy may also lead to an above average change in both water consumption and wastewater discharge in these sectors. Food & tobacco processing, textile, clothing, as well as sawmills and furniture all have pull effect indices greater than 1 for water consumption, as do the metal ore mining, food & tobacco processing, textile, clothing and chemical sectors for wastewater discharge. This indicates that these sectors pull water consumption and/or pollution to a larger extent than other sectors do, when purchasing products from other sectors. In terms of wastewater discharge, the paper, chemical, metal smelting and service sector all have push effect indices greater than 1, which means that these sectors push water pollution up higher than other sectors do, when selling their products to other sectors.

Table 2.7 The pull effect index (PLEI), and the push effect index (PSEI) for water consumption and wastewater discharge in the Haihe River Basin

	Freshwater		**Wastewater**	
Sectors	PLEI	PSEI	PLEI	PSEI
01 Agriculture	6.67	18.51	4.68	12.63
02 Coal mining and processing	0.57	0.56	0.62	0.62
03 Extraction of petroleum & natural gas	0.18	0.07	0.23	0.12
04 Metal ore mining	0.84	0.56	1.03	0.74
05 Non-ferrous mineral mining	0.37	0.07	0.52	0.16
06 Food and tobacco processing	2.67	0.14	2.14	0.41
07 Textile apparel	2.07	0.12	1.83	0.46
08 Clothing products	1.30	0.02	1.15	0.04
09 Sawmills and furniture	1.04	0.00	0.96	0.03
10 Paper, publishing and printing	0.98	0.20	1.48	1.15
11 Petroleum & nuclear fuel processing	0.30	0.06	0.49	0.33
12 Chemical industry	0.72	0.18	1.02	1.30
13 Nonmetallic mineral products	0.42	0.07	0.69	0.34
14 Metal smelting and pressing	0.54	0.67	0.79	1.20
15 Metal products	0.38	0.03	0.56	0.09
16 Industrial machinery	0.34	0.01	0.50	0.07
17 Transport equipment	0.42	0.01	0.56	0.07
18 Electric equipment	0.46	0.01	0.60	0.04
19 Electronic and telecom equipment	0.31	0.00	0.45	0.04
20 Instruments, cultural, office equipment	0.99	0.01	0.92	0.03
21 Artwork and other manufacturing	0.58	0.01	0.67	0.04
22 Scrap and waste	0.00	0.00	0.01	0.01
23 Electricity	1.55	3.45	1.67	3.66
24 Gas production and supply	0.83	0.52	0.88	0.49
25 Water production and supply	1.75	1.52	1.50	1.19
26 Construction	0.39	0.01	0.53	0.02
27 Service industry	0.33	0.19	0.51	1.75

2.3.5 Projection of alternative scenarios

The effects on total output (Δx) of the economy are calculated by multiplying the Leontief inverse matrix $(I-A)^{-1}$ with the final demand vector (Δy), which represents changes in the final demand:

$$\Delta x = (I-A)^{-1}\Delta y \tag{2.19}$$

Scenario analysis is an indispensable tool for analyzing large-scale interactions between social, economic, and environmental systems. In order to compare different development strategies and demonstrate the potential application of the hybrid water IO model, a “what if” scenario is developed based on equation (2.19) to evaluate the influence of economic development on water consumption and pollution.

In order to test the impact of economic development on water consumption and wastewater discharge, the food & tobacco processing sector is taken as an example for a scenario simulation, because this sector shows an obvious pull effect on water consumption and pollution in the above analysis. It assumes a 20 percent increase in final demand in the food & tobacco processing sector. The scenario is based on an average total output growth rate of the food & tobacco sector during the period 2001-2005. Table 2.8 shows the increase in detailed sectoral output, water consumption and wastewater discharge associated with this increase in final demand of the sector. According to Table 2.7, increasing final demand by 20 percent can pull a 1.4 percent increase in total output of 56,494 million CNY for the whole economy. In the meantime, water consumption would increase by 7.7 percent with an amount of 2,132 million m^3, and wastewater discharge would increase by 6.2 percent with an amount of 669 million m^3 for the whole economy associated with the increase in final demand in the food & tobacco processing sector. This indicates that the sector has a great pull effect on water consumption and pollution throughout the whole economy by purchasing products from other sectors as input. Agriculture is the second largest contributor to the increase in water consumption and wastewater. This is because the food & tobacco processing sector needs a lot of agricultural products as input to be able to increase its production.

Table 2.8 Increase of economic output, water consumption and wastewater discharge associated with a 20% increase in final demand in the food and tobacco processing sector

Sectors	Total Output (10^6 CNY)	Water Consumption (10^6 m^3)	Wastewater Discharge (10^6 m^3)
01 Agriculture	9589	935.2	257.2
02 Coal mining and processing	1012	8.4	3.6
03 Extraction of petroleum & gas	440	1.1	0.6
04 Metal ore mining	131	1.6	0.8
05 Non-ferrous mineral mining	111	0.6	0.3
06 Food and tobacco processing	26290	1027.6	323.0
07 Textile apparel	363	11.0	3.8
08 Clothing products	106	2.0	0.7
09 Sawmills and furniture	283	4.3	1.6
10 Paper, publishing and printing	1058	15.1	9.0
11 Petroleum & nuclear fuel processing	919	4.0	2.6
12 Chemical industry	3123	32.9	18.3
13 Nonmetallic mineral products	426	2.6	1.7
14 Metal smelting and pressing	872	6.9	3.9
15 Metal products	673	3.8	2.2
16 Industrial machinery	431	2.2	1.2
17 Transport equipment	391	2.4	1.3
18 Electric equipment	188	1.3	0.6
19 Electronic and telecom equipment	387	1.8	1.0
20 Instruments, cultural, office equipment	144	2.1	0.8
21 Artwork and other manufacturing	189	1.6	0.7
22 Scrap and waste	114	0.0	0.0
23 Electricity	969	22.0	9.3
24 Gas production and supply	46	0.6	0.2
25 Water production and supply	61	1.5	0.5
26 Construction	142	0.8	0.4
27 Service industry	8037	39.0	23.7
Total	56494	2132.3	669.1

2.4 Conclusion and remarks

The economic success in China is achieved at the expense of natural resources and has resulted in severe pollution of the environment, especially water resources. In the Haihe River Basin, water scarcity and associated problems have increasingly imposed constraints on economic development. Rapid economic development and urbanization also result in the discharge of great amounts of pollutants, causing the environment to deteriorate. In this paper the direct and indirect impact of the regional production, consumption and trade structure on water consumption and wastewater discharge have been explored for the Haihe River Basin by employing a water extended hybrid input-output model.

One of the first conclusions to be drawn from the analysis of these indicators is that the structure of the sectoral production has an important impact on water consumption and pollution in the Haihe River Basin, both directly and indirectly. First of all, two coefficients were calculated: direct water consumption intensity and direct wastewater discharge intensity, based on the water extended input-output table, which establishes direct relationships between sectoral production and water consumption or wastewater discharge. Then, based on Leontief's input-output technology, another two coefficients (total water consumption intensity and total wastewater discharge intensity) are quantified, which help capture indirect effects of sectoral production on water consumption and pollution. Through the analysis of these indicators, clear distinctions are made between direct and indirect water consumption and pollution. It was found that agriculture is the highest water consumer and polluter with high rates of water consumption and pollution, though only showing low rates of indirect water consumption and pollution. Industrial and service sectors, on the other hand, show low rates of direct consumption and pollution and high rates of indirect water consumption and pollution. This is because these sectors purchase goods and services from other sectors with high water consumption and pollution. Paradigmatic examples of these sectors are food & tobacco processing and the textile industry, because these two sectors have close relationships with agriculture, the highest water-intensive sector in the Haihe River Basin. Therefore, investing in water saving and pollution reduction technology and equipment for sectors with high direct water consumption/pollution would improve water use efficiency and reduce discharge of wastewater for the entire economy of the Haihe River Basin. However, a rise in production in sectors with high indirect water consumption and pollution would again drive an increase in water consumption and wastewater discharge for the entire economy. In order to achieve sustainable development of the economy and the environment, special attention should be paid to these sectors when planning production policies for the Haihe River Basin. Water should be made available for other economic purposes, which can contribute more to the region, but consume less water and produce less pollution (Allan, 1998 and 2002).

The second conclusion to be drawn from the analysis of virtual water footprints is that the trade structure of the Haihe River Basin leads to negative effects on water availability and quality in the region. The derived direct and total water consumption and wastewater discharge intensity coefficients provide a quantitative method for assessing water consumption and pollution embodied in the products and services. Based on these indicators, virtual water footprints are calculated through the input-output modelling framework, which help to understand how water consumption and pollution in the Haihe River Basin interact with the trade of goods and services. The results show that the Haihe River Basin is still a net freshwater exporter, which means that the region is exporting relatively more water-intensive products and services than it imports. In the Haihe River Basin, agriculture and its related sectors (food & tobacco processing, clothing and textile industry) contribute most to the export of virtual freshwater, because these sectors have high direct and/or indirect water consumption intensities. A similar situation is found when considering wastewater: the water-scarce Haihe River Basin discharges more wastewater, based on exported local products and services, than is virtually created through its imports. The two evaluation results mentioned above are promising concerning the saving of water and the reduction of pollution from a global point of view. Decision-makers should consider achieving water security by importing water/pollution-intensive products and services from outside the Haihe River Basin instead of producing all the goods locally.

Last but not least, a conclusion to be drawn from the analysis of pull and push effect indices is that the expansion of the final demand in some sectors can lead to a great increase in water demand and pollution for the entire economy, and that the expansion of the final demand in the entire economy can result in a great increase in water demand and pollution in some sectors. A simple scenario analysis (assuming a 20% increase in the final demand of the food & tobacco processing sector) demonstrates how a change in final demand can lead to changes in sectoral water demand and pollution. Results show that agriculture, electricity, and water production and supply are key sectors for water consumption, while agriculture, paper & printing, petroleum & nuclear fuel processing, electricity, as well as water production and supply are key sectors for wastewater discharge. Not only can expansion of final demand in these sectors pull the above-average rising of water demand and pollution in the other sectors, but expansion of final demand in the entire economy can also push the above average rising of water demand and pollution in these sectors. The implications are that unlimited expansion of final demand in these sectors would further endanger the water resources in the Haihe River Basin and even constrain the economy. From the sustainability point of view it is important to emphasize that the inter-sectoral impact on water demand and pollution, due to the expansion of final demand, need to be incorporated in decision-making processes and public policies, especially in the Haihe River Basin.

All in all, within this environmental IO framework, a series of assessment indicators has been calculated, which assist in tracking both direct and indirect interrelationships of water consumption and pollution with sectoral production, trade structure and final demand. Assessment results indicate that water consumption and pollution can be reduced by readjusting the structure of production, consumption and trade in the Haihe River Basin. In order to achieve sustainable development in the Haihe River Basin with its very poor water endowment, not only direct effects but also indirect effects on water demand and pollution should be considered in production, consumption and trade policies.

Chapter 3. Assessing the Economic Impact of Mitigating North China's Water Scarcity Strategy: an Econometric-Driven Water Computable General Equilibrium Analysis

Based on
Qin, C., Su, Z., Jia, Y., Bressers, H.J.A., Wang, H., 2011. Assessing the Economic Impact of Mitigating North China's Water Scarcity Strategy: an Econometric-Driven Water Computable General Equilibrium Analysis. *Journal of Environmental Planning and Management* (Under review)

Abstract:

In this chapter, we present an econometric-driven, multi-regional, multi-sectoral water extended computable general equilibrium model to analyze the effectiveness of measures and policies for mitigating North China's water scarcity issues with respect to three different scenario groups. Water is introduced as an explicit factor of production into the model framework. The marginal value of water, estimated by an econometric model, is used to represent the equilibrium price of water. The gravity model of trade is used to estimate the regional trade across Beijing, Tianjin, and Hebei. We also estimate the elasticities across production factors in the CES production function through an econometric analysis. Experimental results of the scenario for reducing groundwater indicate that a reduction in the water supply level has a severe negative impact on the economy and household welfare. Experimental results of the scenario for the South-to-North Water Transfer project indicate that construction of the project has a positive impact on economic development, household welfare, and environmental sustainability. Experimental results of the scenario for reallocating water from agriculture to the industrial and service sectors show that transferring water from a low-value sector to high-value sectors has a positive impact on the macro-economy and household welfare, and promotes economic restructuring from a low water efficiency sector to relatively high water efficiency sectors.

Keywords: Computable general equilibrium; Water scarcity; Marginal value of water; Water reallocation; Economic impact.

3.1 Introduction

Water, as natural capital, is increasingly becoming a limiting factor for development (Aronson et al., 2006) in developing countries. Because of a rising water demand in the agricultural, domestic and industrial sectors, as well as emergent new demands from ecosystem preservation, the availability of water with acceptable quality is predicted to be the most urgent development constraint facing China.

According to the National Water Law 2002, the Chinese government is the custodian of all water resources in the country, and thus, has the responsibility to construct water infrastructure, conduct water management, enact water pricing policies, and allocate water resources to user groups. To achieve sustainable development of the economy, society and environment, the Chinese government has identified several options for mitigating the trade-off between limited water resources and increasing water demand, including increasing the efficiency of water use, reforming the water price mechanism, and expanding the capacity of the water supply (World Bank, 2009).

Effective water management strategies could yield multiple benefits for the economy, society, and environment. Partial equilibrium analysis usually ignores backward and forward linkages among sectors when assessing the effectiveness and the associated cost of a policy measure, because it assumes that other aspects do not change in the economy. As water usage in one sector affects the usage in other sectors, an integrated assessment tool is needed to investigate the environmental and economic effects of policies.

The aim of this study is to investigate the role of water in the Chinese economy. Focusing specifically on the Jing(Beijing)-Jin(Tianjin)-Ji(Hebei) economic zone of North China, we analyze the role of water in the regional economy with respect to different scenario groups by using a multi-region, multi-sector computable general equilibrium (CGE) model.

The structure of this paper is as follows. Section 3.2 provides an overview of the study area, while Section 3.3 briefly describes the main structure of the model. Section 3.4 introduces the creation of the Social

Accounting Matrix (SAM). Section 3.5 presents the calibration of the model parameters. Section 6 gives the settings for the different scenario groups, while Section 3.7 presents and discusses the results of the model simulations. Finally, Section 3.8 discusses the conclusions drawn from the study.

3.2 Description of study area

According to recent official statistics, the total amount of water available annually in China is 2812 billion m^3. However, the annual per capita renewable freshwater availability amounts to only 2196 m^3, or one quarter of the world's average. Due to a marked continental monsoon climate, water resources are distributed unevenly both temporally and spatially. Water resources are relatively abundant in the south, whereas the north of the country generally has poor water resources. However, the distribution of the population and economy do not coincide with the spatial distribution of water resources. Our study area – Beijing, Tianjin and almost the whole Hebei province – is located in the Haihe River Basin of North China (see Figure 1.1), which is facing a most severe water crisis.

In China, the Haihe River Basin has the lowest water availability on a per capita basis, only 189 m^3 in 2007, which is about 14% of the national average and less than 2.5% of the world average (MWR, 2008). Despite such poor water endowment, the region boasts 10% of the national population and contributes 15% of China's industrial production and 10% of the national agricultural output. The region produces about 30% and 20%, respectively, of the nation's wheat and corn. Efficient use of water resources in the Haihe River Basin is important for national economic development and food security.

The water challenge in the Haihe River Basin is becoming more and more urgent due to climate change and increasing human activities. Average precipitation declined from 564 mm/year in the period 1956-1979 to 498 mm/year in the period 1980-2005 (see Figure 2.1). Decreasing precipitation in the basin further reduced the limited available water resources. On the other hand, water demand in the region has increased rapidly due to population growth, industrialization, and urbanization. In addition, the Jing-Jin-Ji economic zone, an important part of the national development strategy, will also exert greater pressure on the supply of water. Major rivers are already being exploited to the maximum as fresh water sources, leaving little or no water to flow out to sea. To compensate for the surface water shortage, agriculture has been relying increasingly on groundwater, thus causing a rapid depletion of aquifers (Shi, 1997) and a rapid decline in ground water tables (Yang, 2001). The average over-exploitation of groundwater is estimated to be close to 8 billion m^3 per year (GEF, 2008).

Considering the complex issues involving water, environment, food security, population growth and economic development in the Haihe River Basin, sustainable development in the region is facing unprecedented challenges. To mitigate a severe water crisis in the Haihe River Basin, several large-scale projects have been proposed, with some having already been launched. The east and middle routes of the south to north water transfer project will play key roles in supplying freshwater for the region. On the other hand, a series of demand-side management policies, i.e., transferring water and reallocating water from low- to high-value sectors, have also been developed to improve the water use efficiency of the region. These measures and policies will inevitably generate a variety of impacts on the economy, society, and environment. Therefore, effective policy assessment tools are needed to evaluate the effectiveness of these options.

3.3 Description of model structure

A model has been developed using the mathematical program system for general equilibrium (MPSGE), which is a general algebraic modelling system (GAMS) extension developed by Rutherford (1998), with the MCP GAMS solver. The model has a multi-regional, multi-sectoral structure to help quantify similarities, differences, and linkages between regions. Each region is modeled separately as an individual economy. The theoretical structure is typical of most static CGE models, with the main equations as given in Robinson (1999).

3.3.1 Regional disaggregation

Because Inner Mongolia and Liaoning provinces only contain tiny parts of the Haihe River Basin, and Shandong, Shanxi, and Henan provinces fall partially within the Haihe River Basin, they do not currently have such regional input-output data available for their parts of the basin. Therefore, this study focuses on three other regions – Beijing, Tianjin, and Hebei, which constitute the core area of the Haihe River Basin (see Figure 1.1). The model adopts a bottom-up method for regional disaggregation, which could gain key advantages compared with simply adding a top-down regional disaggregation module of economy-wide simulation results. Within a bottom-up regional structure, each region is modeled separately as an individual economy, with many variables, including a region subscript in the equations. Regional differences can be captured through region-specific prices, region-specific industries, region-specific consumers, etc. Economic linkages across regions can be reflected by interregional trade, factor flows, and so on.

3.3.2 Production technology

The model assumes that each region includes three sectors – agriculture (AGR), industry (IND), and service (SER). Producers are constrained in their choice of inputs by multi-level nested production technology. A diagrammatic overview of the production structure is shown in Figure 3.1. At the top level, the technology is specified by a constant elasticity of substitution (CES) function of two broad categories of inputs in each sector: primary factors and aggregated intermediate inputs. The aggregate intermediate input is determined by a Leontief function of disaggregated intermediate inputs, whereas value-add is itself a nested CES function of primary factors. Water, as an explicit factor of production, is introduced into the CGE framework in this study. Water and labour are combined by a CES function at the bottom level, and this water-labour composite is subsequently linked with capital by a CES function. Because water is currently allocated to the major user groups in China, it is assumed not to be mobile across sectors and regions. Therefore, water pricing may differ in each sector of each region.

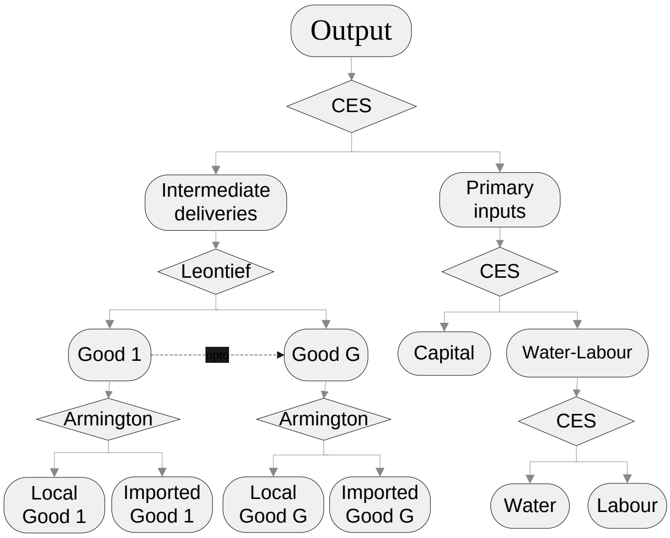

Figure 3.1 The structure of production technology

3.3.3 Local final demands

There are two representative household consumers in each region – rural and urban households. In each region, households receive direct and indirect income from factor endowments (labour and water), and transfer payments from other institutions (i.e., enterprises). Furthermore in each region, the household maximizes its utility by adjusting its consumption choices on different goods subject to a budget constraint. The expenditure is determined by the linear expenditure system.

In each region, enterprises do not consume any commodities and the major source of income is the return on regional capital. After paying direct taxes to government, one part of net profit after tax is transferred to the households, while the remaining part is kept as enterprise savings.

The model assumes that there is only one government sector in each region. The government receives its main income from tax revenues. Government's expenditure is determined by a Cobb-Douglas (C-D) consumption function.

3.3.4 Interregional, domestic and international trade

In each region, aggregated domestic output is allocated between local sales and exports to other regions of the study area, the rest of China (ROC), and the rest of the world (ROW). A multi-level nested constant elasticity of transformation (CET) function is used to formalize this concept of imperfect substitution between goods with different destinations. Figure 3.2 shows the regional output allocation structure.

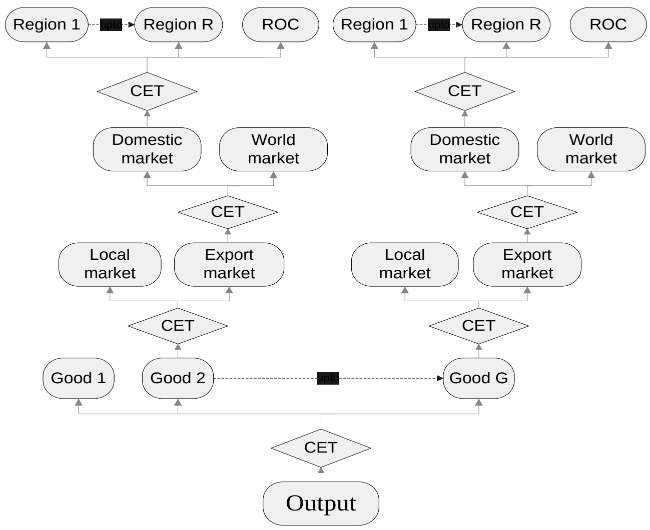

Figure 3.2 The Allocation structure of exported commodities

In each region, local market demand consists of the sum of demands that stem from the intermediate demands of producers, rural and urban household consumption, government consumption, investment, and intermediate inputs. All local market demands are for a composite commodity made up of local supply and imports from other regions of the study area, the ROC, and the ROW. In this study, a multi-level nested Armington (1969) CES-function form is used to determine demand composition between local outputs and imported goods differing in origin. Figure 3.3 shows the regional commodity supply structure.

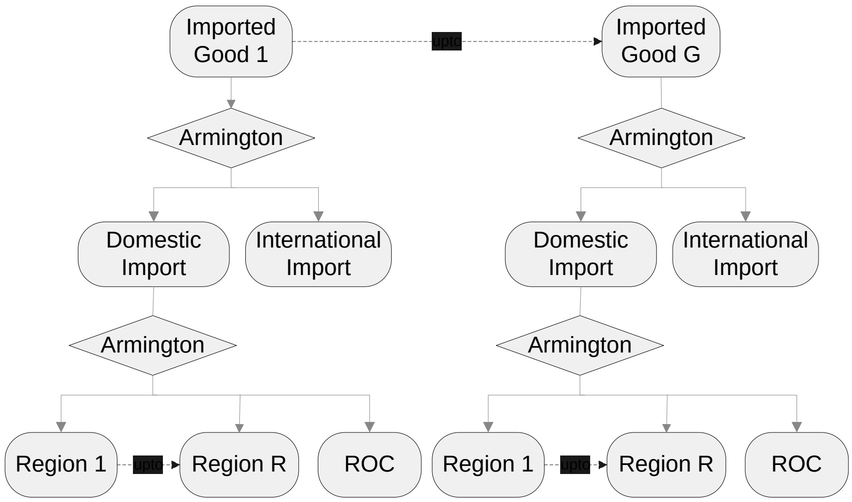

Figure 3.3 The origin structure of imported commodities

3.3.5 Macro closure

The model adopts the neoclassic closure rule. For each region, the closure rules for macro system constraints in this model are composed of three parts: government expenditure-receipts balance, savings-investment balance, and trade balance. The government savings rate is exogenous, while government expenditure is endogenous. Regional capital formation is flexible, and marginal propensity to save for all households is fixed. The real exchange rate is exogenous, while foreign savings (equal to imports minus exports) are endogenous.

3.4 Social Accounting Matrix

The social accounting matrix (SAM) used in the CGE model is a consistent, multi-sectoral, economy-wide data framework that integrates national accounts, input-output, flow-of-funds, and foreign trade statistics into a comprehensive and consistent dataset and typically set-up to represent the economy of a nation (Jennifer, 2002). Its basic structure is shown in Table 3.1.

Due to the lack of an official Social Accounting Matrix (SAM) published by the government in China, we need to build a multi-regional SAM for Beijing (BJ), Tianjin (TJ), and Hebei (HB) by incorporating data from various sources into a consistent SAM framework. Social accounting matrix is usually developed based on the input-output table, which can be regard as an extension of input-output table. Especially, compared with IO table income distribution is an important extension. SAM is balanced, because its row must equal to column. Therefore, CGE models usually use SAM to calibrate many important parameters by making the models replicate the benchmark data of the SAM.

Table 3.1 Basic structure of WSAM

Receipts		Activity	Commodity	Factors: Labour	Factors: Capital	Factors: Water	Households	Government	Saving-investment	Rest of the world	Total
		Expenditures									
Activity	**Production**		Marked outputs								Gross output
Commodity	**Goods**	Intermediate input					Private consumption	Government consumption	Investment	Exports	Total demand
Factors	**Labour**	Value-added									Factor income
	Capital										
	Water										
Household				Factor incomes				Subsidies to household		Transfer to household	Household income
Government		Indirect taxes	Tariff	Factor taxes		Water tax	Transfer to government			Transfer to government	Government income
Savings-Investment (S-I)							Household savings	Government savings		Foreign savings	Total savings
Rest of the World (ROW)			Imports								ROW income
Total		Total cost	Total absorption	Total factor expenditures			Household expenditures	Government expenditures	Total investment	ROW expenditures	

3.4.1 Economic data

The data for activities, commodities, and import and export accounts are based on the 2007 national input-output table for Beijing, Tianjin, and Hebei. The data for import tariffs are taken from the *Customs Statistics Yearbook 2008* (GAC, 2008), while the revenue for the government expenditure accounts comes from the *Finance Yearbook of China 2008* (MOF, 2008) and tax data from the *Tax Yearbook of China 2008* (SAT, 2008). The revenue and expenditure of households and the government are adjusted based on the flow-of-funds accounts of the *China Statistical Yearbook 2008* (NBS, 2008).

3.4.2 Inter-regional trade

Because the domestic trade accounts in the provincial level input-output table of China only provide the total commodity imported from the rest of China and total commodity exported to the rest of China, interregional trade data within the study area cannot be obtained directly. Therefore, we adopted the gravity model of trade (Tinbergen, 1962) to estimate the interregional trade flows across Beijing, Tianjin, and Hebei. In this study, the following equation (Li, 2010) is used:

$$x_i^{gh} = e^{\alpha}(x_i^{gO})^{\beta_1}(x_i^{Oh})^{\beta_2}\frac{(G^g)^{\beta_3}(G^h)^{\beta_4}}{(d^{gh})^{\beta_5}} \tag{3.1}$$

where x^{gh} represents the volume of product i traded from region g to region h, x_i^{gO} represents the volume of product i exported from region g to the rest of China, x_i^{Oh} represents the volume of product i imported from the rest of China to region h, G^g and G^h typically represent the GDP for regions g and h, respectively, d^{gh} denotes the distance between region g and h, and e is a constant.

3.4.3 Water equilibrium price

In this study, the marginal value of water (shadow price of water) in the base year is adopted to represent the water equilibrium price. The marginal value of water represents the GDP generated by giving an additional unit of water to the economy. In a completely competitive market, the marginal value of an input is equal to its marginal cost (Browning and Zupan, 2006; Agudelo, 2001). Therefore the water shadow price is equal to the market equilibrium price. In this study, a marginal productivity model is developed for valuing sectoral use of water in each region. In the model, water, like capital and labour, is treated as an input to a Cobb-Douglas (1928) production function, which is widely used in the empirical analysis of factor inputs (i.e., Intriligator, 1965; Lau and Yotopoulos, 1971; Wang and Lall, 2002). The equation is expressed as

$$Z = AK^{\alpha} L^{\beta} W^{\gamma} \tag{3.2}$$

where Z represents the value-added, measured in hundred million CNY (Chinese Yuan), L and K represent labour and capital, respectively, measured in hundred million CNY, and W represents the quantity of water input measured in hundred million m^3. A is a constant term, which represents the technical efficiency of the industry, while α, β, and γ represent the output elasticity of labour, capital, and water, respectively.

In this study, constant returns to scale are assumed in the production function:

$$\alpha + \beta + \gamma = 1 \tag{3.3}$$

and therefore

$$Z = AK^{\alpha} L^{\beta} W^{1-\alpha-\beta} \tag{3.4}$$

The above equation can be linearly transformed by taking the natural logarithm:

$$Ln(\frac{Z}{W}) = LnA + \alpha \cdot Ln(\frac{K}{W}) + \beta \cdot Ln(\frac{L}{W}) \tag{3.5}$$

Using data from the years 1978 to 2009, we estimated the values of α and β through regression analysis using the SPSS software package. Then, by substituting these values into Eq. (3.3), the output elasticity of water (σ) is obtained for each sector in each region as

$$\sigma = \frac{\partial \ln Z}{\partial \ln W} = \gamma = 1 - \alpha - \beta \tag{3.6}$$

The marginal value (ρ) of water can similarly be computed as

$$\rho = \sigma * \frac{Z}{W} \tag{3.7}$$

The computed output elasticity and marginal values of water are presented in Table 3.2. Agriculture sector has the highest output elasticity for water input, but its water use has a low marginal value. This means that water supply plays an important role in agricultural production, although the marginal value of water use in this sector is lower than that in other sectors. Water use in the service sector has the highest marginal value. For the macro economy, water use in Beijing has the highest marginal value in the entire economy, because the service sector in Beijing contributes to value-add in a greater proportion than that in Tianjin and Hebei. Because the agriculture sector consumes a large amount of water in Hebei, the marginal value for water use in the Hebei economy is very low.

Table 3.2 Computed output elasticity and marginal value of water in 2007

	Output elasticity of water			Marginal Value of water (CNY/m^3)		
Sectors	Beijing	Tianjin	Hebei	Beijing	Tianjin	Hebei
Agriculture	0.420	0.447	0.434	3.42	3.50	5.03
Industry	0.079	0.069	0.088	32.24	45.78	24.32
Service	0.109	0.091	0.087	125.27	163.14	184.57
Total	0.105	0.086	0.133	41.41	23.05	9.86

3.4.4 Water SAM

To carry out a water policy analysis, it is necessary to establish the water embedded Social Accounting Matrix (WSAM) to provide a consistent macroeconomic database for the calibration of the model parameters.

In this study, we use the computed marginal value of water to estimate the total return of water in the economy (total economic value of water, TEV):

$$TEV = \rho \times W \tag{3.8}$$

where W represents water quantity measured in hundred million m^3. Information on water supply and usage is taken from *The Water Resources Statistics Bulletins 2007* (MWR, 2008).

Because water is treated as a primary input to be added into the production function in this study, the water accounts are extracted from the corresponding capital and labour accounts. The households of each region receive the income of water endowments of that region. The final WSAMs for the base year 2007 for Beijing, Tianjin, and Hebei are shown in Tables 3.3, 3.4 and 3.5.

Table 3.3 Beijing WSAM for the year 2007 (unit: 10^8 CNY)

		Activity			Commodity			Factor		Water			Household		Institution		S-I	Trade				TOT
		AGR	IND	SER	AGR	IND	SER	CAP	LAB	AGR	IND	SER	RHH	UHH	ENT	GOV	INV	TJ	HB	ROC	ROW	Total
ACT	AGR				273																	273
	IND					11391																11391
	SER						15650															15650
COM	AGR	94	173	101									16	123		8	14	0	0	0	33	562
	IND	45	7213	3732									76	1102		0	3134	372	498	2089	2304	20565
	SER	32	1443	4618									130	1425		2206	1411	460	445	3792	2022	17984
FAC	CAP	18	1082	2766																		3866
	LAB	39	847	3109																		3995
WAT	AGR	42																				42
	IND		166																			166
	SER			721																		721
HHD	RHH								296	42	5	22			55							420
	UHH								3700		161	699			690							5250
INS	ENT							3866														3866
	GOV	2	467	603	2	47	21						34	305	2026							3507
S-I	SAV												164	2295	1095	1294		-2	314	164	-765	4558
TRA	TJ				5	742	83															830
	HB				66	1007	183															1257
	ROC				106	4972	967															6045
	ROW				109	2405	1079															3594
TOT	Total	273	11391	15650	562	20565	17984	3866	3995	42	166	721	420	5250	3866	3507	4558	830	1257	6045	3594	

Table 3.4 Tianjin WSAM for the year 2007 (unit: 10^8 CNY)

		Activity			Commodity			Factor		Water			Household		Institution		S-I	Trade				TOT
		AGR	IND	SER	AGR	IND	SER	CAP	LAB	AGR	IND	SER	RHH	UHH	ENT	GOV	INV	BJ	HB	ROC	ROW	Total
ACT	AGR				241																	241
	IND					11664																11664
	SER						3891															3891
COM	AGR	30	100	15									8	75		58	-5	5	13	58	18	375
	IND	74	6484	843									57	525		0	2370	742	488	3834	1771	17187
	SER	26	2188	986									80	564		697	557	83	111	943	451	6687
FAC	CAP	2	1425	940																		2367
	LAB	59	707	656																		1422
WAT	AGR	49																				49
	IND		159																			159
	SER			159																		159
HHD	RHH								279	49	11	11			265							617
	UHH								1143		148	148			1085							2524
INS	ENT							2367														2367
	GOV	0	601	293	0	24	7						11	62	336							1335
S-I	SAV												461	1297	680	580		2	-62	589	-625	2922
TRA	BJ				0	372	460															832
	HB				21	402	127															551
	ROC				93	3498	1833															5424
	ROW				20	1227	368															1615
TOT	Total	241	11664	3891	375	17187	6687	2367	1422	49	159	159	617	2524	2367	1335	2922	832	551	5424	1615	

Table 3.5 Hebei WSAM for the year 2007 (unit: 10^8 CNY)

		Activity			Commodity			Factor		Water			Household		Institution		S-I	Trade				TOT
		AGR	IND	SER	AGR	IND	SER	CAP	LAB	AGR	IND	SER	RHH	UHH	ENT	GOV	INV	BJ	TJ	ROC	ROW	Total
ACT	AGR				3076																	3076
	IND					28067																28067
	SER						8955															8955
COM	AGR	475	1190	156									112	283		6	-275	66	21	1772	21	3827
	IND	668	17040	2119									575	1132		0	6659	1007	402	11141	1243	41987
	SER	128	2526	2017									653	1196		1958	377	183	127	2706	124	11997
FAC	CAP	32	3947	1953																		5933
	LAB	1017	1507	1652																		4176
WAT	AGR	804																				804
	IND		524																			524
	SER			342																		342
HHD	RHH								1432	804	24	16			376							2652
	UHH								2744		500	326			1511							5081
INS	ENT							5933														5933
	GOV	-49	1333	715	1	11	2						29	116	393							2551
S-I	SAV												1283	2354	3653	587		-314	62	-196	-668	6761
TRA	BJ				0	498	445															942
	TJ				13	488	111															613
	ROC				664	12355	2405															15423
	ROW				74	567	79															720
TOT	Total	3076	28067	8955	3827	41987	11997	5933	4176	804	524	342	2652	5081	5933	2551	6761	942	613	15423	720	

3.5 Calibration

In the CGE model, the shared parameters, including consumer and government consumption, average savings rate, average tax rate, can be calibrated by the constructed WSAM. The calibration procedure ensures that the initial dataset can be reproduced in the benchmark tests.

The other type of parameter comprises the elasticity parameters, including elasticity parameters of substitution between production factors, Armington elasticity, and CET elasticity, which are fixed exogenously. Ideally, all the parameters should be econometrically estimated in the CGE model. However, due to the required sophistication of techniques, and limitations of the data, it is usually difficult to determine them using this method. Based on the studies of other researchers (Dervis, *et al*., 1982; Zhuang, 1996; Zheng and Fan, 1999; Zhai, 2005; Willenbockel, 2006; He *et al*. 2010), we determined the values of CES elasticity between primary factors and aggregated intermediate inputs, Armington elasticity, and CET elasticity.

In this study, water, as an explicit factor of production, is introduced into the production function. As such, the elasticity parameters of substitution across production factors are much more critical in determining the results of the alternative water policy simulations. Therefore, we estimated their values for each sector of each region through econometric analysis. In the model framework, water and labour are combined by a CES function at the bottom level, and this water-labour composite is subsequently linked to capital by a CES function. Actually, they formulate a two-level CES production function:

$$Y_{WL} = (aW^{-\rho_1} + (1-a)L^{-\rho_1})^{-\frac{1}{\rho_1}} \tag{3.9}$$

$$Y = A(bY_{WL}^{-\rho} + b(1-b)K^{-\rho})^{-\frac{m}{\rho}} \tag{3.10}$$

where Y_{WL} represents the combination of water (W) and labour (L), Y is the value-add, A represents technical efficiency, m presents the return level to scale, a and b are shared parameters ($0 < a,b < 1$), and ρ_1 and ρ are shift parameters ($\infty > \rho_1, \rho > -1$).

The above equations can be linearly and approximately transformed by taking the natural logarithm:

$$\ln Y = \ln A + bm\ln Y_{WL} + (1-b)m\ln K - \tfrac{1}{2}\rho mb(1-b)(\ln(\frac{Y_{WL}}{K}))^2 \quad (3.11)$$

$$\ln Y_{WL} = a\ln W + (1-a)\ln L - \tfrac{1}{2}\rho_1 a(1-a)(\ln(\frac{W}{L}))^2 \quad (3.12)$$

Substituting Eq. (3.12) into Eq. (3.11), we get

$$\begin{aligned}\ln Y = {} & \ln A + bma\ln W + bm(1-a)\ln L + (1-b)m\ln K \\ & - \tfrac{1}{2}mb\rho_1 a(1-a)(\ln(\frac{W}{L}))^2 - \tfrac{1}{2}\rho mb(1-b)(\ln(\frac{W}{K}))^2\end{aligned} \quad (3.13)$$

Through regression analysis, we can compute the values of a, b, m, ρ_1, and ρ. Then, we obtain the value of the substitution elasticity (σ_1) between water and labour, and that (σ) between capital and the water-labour composite:

$$\sigma_1 = -\frac{1}{\rho_1} \quad (3.14)$$

$$\sigma = -\frac{1}{\rho} \quad (3.15)$$

The computed results are shown in Table 3.6. The preceding values of elasticities of substitution for each sector in each region are all greater than 0 and less than 1, which not only explain well the existence of the bottom-level CES relation between water and labor, but also confirm the top-level CGE relation between capital and water-labor composite. Differences in elasticity values reflect that production factors have different substitution possibilities for each sector in each region due to their different combinations of factor endowments and their different level of production technology.

Table 3.6 Estimated elasticity parameters of substitution across production factors

Regions	Sectors	CES elasticity between water and labour	CES elasticity between capital and water-labour composite
Beijing	Agriculture	0.72	0.13
	Industry	0.29	0.43
	Service	0.73	0.84
Tianjin	Agriculture	0.74	0.26
	Industry	0.34	0.50
	Service	0.52	0.82
Hebei	Agriculture	0.79	0.60
	Industry	0.40	0.67
	Service	0.40	0.87

3.6 Defining the scenario groups

To achieve sustainable development of the economy, society, and environment, a series of measures and policies for the region have been proposed or adopted to solve the water crisis, including reducing the over-exploitation of groundwater, constructing the South-to-North Water Transfer project (SNWT), and implementing demand-side management policies. After completing the calibration procedure, we defined three alternative groups of scenarios and applied the CGE model to assess the impact of such water strategies on the region.

3.6.1 Scenario group 1: Reducing groundwater use to a renewable level

Due to increased water demand, ecological water uses have been supplanted by productive and domestic use. Major rivers are already being exploited to the maximum as fresh water sources, leaving little or no water to flow out to sea. To maintain and increase production, the groundwater is severely over-exploited in the Haihe River Basin. To protect the precious water resources, the Chinese government is considering adopting rigorous measures to control the total volume of water use. For the Haihe River Basin, this would inevitably lead to a reduction in the level of groundwater exploitation to achieve sustainable development of available water resources. Based on the research report in GEF (2008), the average amount of groundwater over-exploited is estimated to be close to 8 billion m^3 annually, which is equivalent to about

20% of the total volume of water use in the Haihe River Basin. In this study, we assumed that the water users in Beijing, Tianjin, Hebei, and other regions are proportionately afforded the task of reducing groundwater use. In this scenario group, we set the following three scenarios.

S1a: A reduction in water supply of 5% with respect to water use level in 2007 for the production sector in Beijing, Tianjin, and Hebei.

S1b: A reduction in water supply of 10% with respect to water use level in 2007 for the production sector in Beijing, Tianjin, and Hebei.

S1c: A reduction in water supply of 20% with respect to water use level in 2007 for the production sector in Beijing, Tianjin, and Hebei. This would enable the groundwater to reach a renewable level.

3.6.2 Scenario group 2: Receiving water transferred by the SNWT project

To alleviate the environmental and ecological issues due to over-exploitation of water resources and provide enough water for future development of the North China economy, the South-to-North Water Transfer (SNWT) project has been launched. The east and middle routes of the South to North Water transfer project will supply freshwater for the study area. The project will be gradually constructed in the following two decades. Based on the construction stage of the project, we developed two scenarios within this scenario group. According to the planning, the transferred water is supplied mainly for industrial, service, and domestic use. However, agriculture would receive a greater proportion of local water resources after the construction of the SNWT project. Therefore, in this scenario group we made two assumptions: local water supply is reduced to 80% of the base year level, and transferred water is proportionately allocated across water users in each region. The setting of the scenarios is given below.

S2a: Local water supply is reduced to 80% of the base year level, and transferred water is supplied to each region according to the water transferring capacity of the project in 2020 (1st stage project).

S2b: Local water supply is reduced to 80% of the base year level, and transferred water is supplied to each region according to the water transferring capacity of the project in 2030 (2nd stage project).

The water volume transferred by the project and changes in the water supply level for Beijing, Tianjin, and Hebei are given in Table 3.7.

Table 3.7 Water volume transferred by the SNWT project and changes in water supply level in the scenarios

	Water transferring capacity (Unit: 10^8 m^3)		Change of water supply level (base year =1)	
Regions	1st stage	2nd stage	S2a	S2b
Beijing	10.5	14.3	1.10	1.21
Tianjin	11.2	18.6	1.28	1.60
Hebei	32.4	52.3	0.96	1.06
Total	54.1	85.2	1.01	1.13

3.6.3 Scenario group 3: Reallocating water from agriculture to industry and the service sector

In the past two decades, the proportion of water supply for agriculture in the region has gradually been reduced owing to the competition for water from industrial and domestic use and the limited available water resources. As the economy grows, especially the construction of the Jing-Jin-Ji economic zone, water demand from the non-agricultural sector will increase further. Water would then be reallocated from agriculture to other sectors because agriculture has the smallest marginal value of water. The main purpose of this scenario group is to investigate whether water reallocation from agriculture to non-agricultural sectors will promote water use efficiency. Three scenarios are set in this water reallocation scenario group.

S3a: 5% of water used in the agriculture sector of each region is transferred and allocated proportionately between industry and the service sector of the same region on the basis of the estimated sectoral marginal value of water.

S3b: 10% of water used in the agriculture sector of each region is transferred and allocated proportionately between industry and the service sector of the same region on the basis of the estimated sectoral marginal value of water.

S3c: 20% of water used in the agriculture sector of each region is transferred and allocated proportionately between industry and the service sector of the same region on the basis of the estimated sectoral marginal value of water.

The volume of sectoral water use and changes in sectoral water supply levels for Beijing, Tianjin, and Hebei are shown in Table 3.8.

Table 3.8 Changes in sectoral water supply levels in the water reallocation scenarios

Regions	Sectors	Water use of base year (Unit: 10^8 m^3)	Changes in water supply level		
			S3a	S3b	S3c
Beijing	Agriculture	12.44	0.95	0.90	0.80
	Industry	6.17	1.05	1.10	1.20
	Service	6.32	1.05	1.10	1.20
	Total	24.93	1.00	1.00	1.00
Tianjin	Agriculture	14.06	0.95	0.90	0.80
	Industry	4.39	1.12	1.25	1.50
	Service	1.25	1.12	1.25	1.50
	Total	19.70	1.00	1.00	1.00
Hebei	Agriculture	155.73	0.95	0.90	0.80
	Industry	25.96	1.28	1.55	2.11
	Service	2.16	1.28	1.55	2.11
	Total	183.85	1.00	1.00	1.00

3.7 Results and discussion

3.7.1 Simulation results of the scenario group for reducing groundwater use

The results of changes in the main economic variables under the scenario group for reducing groundwater use are shown in Table 3.9.

Reduction in groundwater use affects the output of the production sector, resulting in changes in product prices, which are closely related to consumer consumption levels, the import and export levels of the trade sector, and gross domestic product (GDP).

As the CGE model shows, water inputs decline due to a reduction in groundwater exploitation. In Table 3.9, the output level and GDP of all regions decline in a similar way. By decreasing the water supply level, the macroeconomic losses become increasingly severe. When groundwater exploitation is reduced to a renewable level, the output level and GDP of the whole study area declines by 2.76% and 2.66%, respectively.

As shown in Table 3.9, the level of household and government income also declines due to a decline in the level of output and GDP. This is especially severe for rural households. If the groundwater exploitation is reduced to a renewable level, the income level of rural households declines by 13.76%. A decline in the level of households reduces the purchasing power of households and their welfare. In this study, we used the Hicksian equivalent variation (EV) to analyze the impact of readjusting water strategies on household welfare. From Table 8, we can see that with a reduction in the level of water supply, welfare losses become more and more severe for both rural and urban households in all study regions. This is especially true for rural households. If the groundwater exploitation is reduced to a renewable level, the welfare level of rural households decreases by more than 14%.

At the sectoral level, Table 3.9 shows that the output level of the sectors in each region declines due to a decline in water inputs. Agricultural production suffers the most in each region. When the groundwater exploitation is reduced to a renewable level, the production level of agriculture for the whole study area would decrease by approximately 9%. This is because agriculture has the highest output elasticity for water input and water plays a very important role in the production of agricultural goods, although agricultural water use has a low marginal value. Declines in the levels of output and consumption lead to declines in the export and import levels. Only the export level of service goods increases slightly; this may be because the level of local demand declines due to a reduction in purchasing power, and more service goods need to be sold in the world market and domestic market outside the study regions. A decrease in the level of local demand and consumption can also impact the level of imports.

Currently, economic benefits are achieved to some extent through over-depleting groundwater aquifers in North China. Although experimental results of the scenario group for reducing groundwater exploitation show that reduction in the water supply level has a severe negative impact on the economy and household welfare, over-depletion of water resources would lead to severe threats on environment and ultimately make the economic development run out of control. If this situation is not reversed and the security of water supply guaranteed, it would severely threat sustainable development of economy, social and environment. Once groundwater is exhausted, the water supply crisis will result in huge GDP, welfare, and environmental losses. Thus, the Chinese government should adopt effective measures to mitigate North China's water scarcities and guarantee the security of water supply.

Table 3.9 Changes in main economic variables under the scenario group for reducing groundwater use (unit: percent)

Economic Variables	S1a: Reducing 5% of water supply				S1b: Reducing 10% of water supply				S1c: Reducing 20% of water supply			
	Beijing	Tianjin	Hebei	Total	Beijing	Tianjin	Hebei	Total	Beijing	Tianjin	Hebei	Total
GDP	-0.56	-0.43	-0.65	-0.58	-1.17	-0.91	-1.35	-1.21	-2.56	-2.04	-2.97	-2.66
Total Output	-0.7	-0.44	-0.54	-0.58	-1.48	-0.94	-1.15	-1.23	-3.3	-2.17	-2.58	-2.76
Agricultural Output	-3.77	-2.02	-1.8	-2.12	-7.66	-4.15	-3.65	-4.31	-15.8	-8.73	-7.58	-8.94
Industrial Output	-0.83	-0.4	-0.42	-0.52	-1.8	-0.87	-0.89	-1.11	-4.19	-2.06	-2	-2.54
Service Output	-0.53	-0.42	-0.59	-0.53	-1.09	-0.89	-1.27	-1.12	-2.35	-1.97	-2.97	-2.51
All Household EV	-0.85	-1.07	-1.93	-1.41	-1.76	-2.24	-4.01	-2.93	-3.84	-5	-8.7	-6.39
Rural Household EV	-0.75	-3.88	-3.56	-3.22	-1.63	-8.15	-7.34	-6.67	-3.84	-18.14	-15.66	-14.33
Urban Household EV	-0.86	-0.72	-1.1	-0.93	-1.77	-1.51	-2.31	-1.94	-3.84	-3.37	-5.13	-4.28
All Household Income	-0.76	-1.01	-1.87	-1.32	-1.58	-2.12	-3.87	-2.75	-3.44	-4.73	-8.39	-5.98
Rural Household Income	-0.64	-3.61	-3.5	-3.1	-1.39	-7.59	-7.2	-6.4	-3.29	-16.89	-15.36	-13.76
Urban Household Income	-0.77	-0.68	-1.05	-0.86	-1.59	-1.43	-2.2	-1.8	-3.45	-3.19	-4.89	-3.97
Government Income	-1.27	-1.28	-0.95	-1.14	-2.65	-2.73	-2.04	-2.42	-5.81	-6.32	-4.75	-5.46
Total Export to ROC & ROW	-0.54	-0.43	-0.56	-0.53	-1.15	-0.92	-1.18	-1.12	-2.59	-2.13	-2.58	-2.49
Agricultural Export	-9.46	-4.64	-3.36	-3.52	-18.5	-9.24	-6.71	-7.02	-35.4	-18.29	-13.38	-13.96
Industrial Export	-1.24	-0.49	-0.37	-0.57	-2.7	-1.07	-0.79	-1.24	-6.39	-2.6	-1.86	-2.94
Service Export	0.03	0.04	0.36	0.12	0.11	0.15	0.66	0.27	0.48	0.62	1.09	0.67
Total Import from ROC & ROW	-0.56	-0.46	-0.59	-0.55	-1.19	-0.99	-1.23	-1.17	-2.66	-2.29	-2.71	-2.61
Agricultural Import	0.6	0	-0.6	-0.3	1.19	-0.1	-1.29	-0.66	2.22	-0.71	-2.98	-1.69
Industrial Import	-0.49	-0.34	-0.46	-0.45	-1.03	-0.73	-0.96	-0.94	-2.3	-1.67	-2.11	-2.08
Service Import	-0.95	-0.74	-1.26	-1	-2.01	-1.59	-2.63	-2.1	-4.48	-3.7	-5.76	-4.7

3.7.2 Simulation results for SNWT project scenario group

The results of changes in the main economic variables under the scenario group for constructing the SNWT project are given in Table 3.10.

As shown in Table 3.10, the output level of the study area increases once the SNWT project has been constructed. The GDP also increases in accordance with the increase in the output level. Only the levels of the output and GDP in Hebei province decline before the construction of the second-stage of the project. However, all scenarios in this scenario group are set on the basis of reducing groundwater use to a renewable level. Water volume allocated to Hebei by the first-stage of the project is less than the volume of reduced groundwater in the region. Comparing the results in Table 3.10 with the results of S1c (that is, a 20% reduction in water supply level) in Table 3.9, we find that the construction of the SNWT project has a positive impact on the economy of all study regions. From Table 3.10, we also find that the level of household and government income also declines due to the construction of the SNWT project. Increasing the level of household income raises the purchasing power of households, and improves their welfare. Therefore, based on the experimental results of this scenario group we conclude that the construction of the SNWT project leads to positive economic, social, and environmental effects for the study regions.

At the sectoral level, Table 3.10 shows that the output level of agricultural production increases greatly after the construction of the SNWT project; this increase is much higher than the increase in the output levels of the industrial and service sectors. Because agriculture only comprises a small proportion of the whole economy, economic gains achieved through the construction of the SNWT project are lower than expected, as shown in Table 3.10. Once the project is fully constructed, the levels of total output and GDP increase by less than 2% each. This is because transferred water is allocated proportionately across sectors in this scenario group, and agriculture receives a greater amount of water. However, the marginal value of water is low. Limited water availability in the study area should be transferred from low-value use to high-value use. In the next scenario group, we study the economic impact of the water reallocation strategy by reallocating water from agriculture to other sectors.

Table 3.10 Changes in main economic variables under scenario group for transferring water through the SNWT project (unit: percent)

Economic Variables	S2a: Stage-1 project				S2b: Stage-2 project			
	Beijing	Tianjin	Hebei	Total	Beijing	Tianjin	Hebei	Total
GDP	0.96	1.66	-0.44	0.41	1.96	2.99	1.52	1.93
Total Output	1.2	1.77	-0.44	0.5	2.29	2.86	1.17	1.84
Agricultural Output	7.36	10.38	-1.5	0.94	14.63	19.87	4.34	7.34
Industrial Output	1.34	1.47	-0.38	0.39	2.4	2.12	0.89	1.49
Service Output	0.95	1.85	-0.39	0.61	1.89	3.33	1.21	1.85
All Household EV	1.43	3.96	-1.3	0.51	3.02	7.31	4.62	4.49
Rural Household EV	1.22	15.63	-2.72	-0.65	2.19	28.01	8.48	9.32
Urban Household EV	1.45	2.51	-0.57	0.82	3.09	4.74	2.64	3.21
All Household Income	1.28	3.75	-1.25	0.48	2.7	6.92	4.46	4.2
Rural Household Income	1.04	14.55	-2.67	-0.63	1.84	26.08	8.32	8.95
Urban Household Income	1.3	2.38	-0.55	0.77	2.78	4.49	2.52	2.98
Government Income	2.18	4.36	-0.33	1.51	4.35	7.18	2.14	3.9
Total Export to ROC & ROW	0.98	1.74	-0.51	0.4	1.74	2.67	1.25	1.69
Agricultural Export	19.03	26.54	-2.72	-1.17	42.88	57.54	8.76	11.3
Industrial Export	1.89	1.62	-0.35	0.58	3.3	2.04	0.7	1.55
Service Export	0.18	0.88	0.2	0.28	0.33	2.24	-1.1	0.18
Total Import from ROC & ROW	0.95	1.62	-0.43	0.41	1.84	2.61	1.35	1.77
Agricultural Import	-0.76	-1	-0.45	-0.57	-2.41	-2.99	1.26	0.07
Industrial Import	0.83	1.3	-0.36	0.3	1.61	2.13	1.04	1.41
Service Import	1.55	2.44	-0.75	0.99	3.12	3.94	3	3.34

3.7.3 Simulation results of sectoral water reallocation scenario group

The results of the changes in the main economic variables under the scenario group for reallocating water from agriculture to other production sectors are given in Table 3.11.

As shown in Table 3.11, reallocating between 5% and 20% of water from agriculture to the industrial and service sectors could result in similar growth in the levels of output and GDP of all regions. If 20% of the water is transferred from agriculture to the industrial and service sectors, the output level and GDP of the whole study area increases by 3.26% and 2.05%, respectively. The experimental results indicate that reallocating water from a low-value sector to high-value sector can achieve substantial macroeconomic effects.

From Table 3.11, the levels of household and government income also increase by reallocating water from agriculture to other sectors. If 20% of the water is transferred from agriculture to industrial and service sectors, the income levels of households and the government in the whole study area increases by 3.1% and 8.1%, respectively. Growth in the income level of households improves the purchasing power of the households and their welfare. From Table 3.11, we see that welfare gains increase by 4.16% and 3.08% for rural and urban households, respectively, if 20% of the water is transferred from agriculture to the industrial and service sectors. The results indicate that reallocating water from agricultural sector to other sectors has a positive impact on the level of welfare of both rural and urban households, this is because rural households can currently receive income from other sector by supplying labour to these sectors. However, we must keep in mind that water reallocation policy would inevitably have led to welfare losses on some rural household who mainly receive their income from the sale of agricultural products.

At the sectoral level, Table 3.11 shows that agricultural production suffers substantial losses because part of the agricultural water is transferred to other production sectors. If 20% of the water is reallocated from agriculture to the industrial and service sectors, the output level of agriculture for the whole study area declines by more than 10%. On the one hand, reallocating water from a low-value sector to a high-value sector could promote economic restructuring from a low water efficiency sector to relatively high water efficiency sectors. On the other hand, the region produces a substantial amount of good quality agricultural products, especially wheat and corn. Agricultural water plays an important role in the food security of the country. To maintain the stability of agricultural production and keep the life level of fragile agricultural households, the government should provide subsidies for farmers to invest in water saving technologies. The expenditure can be justified because the level of government income grows substantially when water is transferred from agriculture to other sectors.

Due to increases in the levels of output and consumption, the level of trade also increases. When 20% of the water is reallocated from agriculture to the industrial and service sectors, the levels of total exports and total imports grow by 2.73% and 2.85%, respectively. However, a decline in the level of agricultural production leads to a substantial reduction in the level of agricultural output. If 20% of the water is reallocated from agriculture to other sectors, the level of agricultural exports declines substantially by more than 32%. To satisfy the local supply of agricultural products, the level of agricultural import in this approach increases to 13%. Based on the Heckscher-Ohlin (HO) theorem (Heckscher, 1919; Ohlin, 1933) for trade, the comparative advantage of different regions is dependent on the endowment of their relative factors. Experimental results in Table 3.11 indicate that reallocating water from a low-value sector to a high-value sector changes the relative comparative advantage of different sectors. Sectors with low water use efficiency increase their imports to satisfy local demand, whereas sectors with relatively high water use efficiency increase their competitive advantage and export more products to other regions. Based on the “virtual” water theory (Allan, 1998), this is equivalent to reducing local water demand and improving the water use efficiency.

Table 3.11 Changes in the main economic variables under the scenario group of reallocating water from agriculture to other sectors (unit: percent)

Economic Variables	S3a: Reallocating 5% Agri. water				S3b: Reallocating 10% Agri. water				S3c: Reallocating 10% Agri. water			
	Beijing	Tianjin	Hebei	Total	Beijing	Tianjin	Hebei	Total	Beijing	Tianjin	Hebei	Total
GDP	0.48	0.71	1.22	0.87	0.89	1.25	1.89	1.43	1.54	1.99	2.44	2.05
Total Output	0.49	0.77	2.08	1.31	0.93	1.34	3.37	2.18	1.66	2.07	4.81	3.26
Agricultural Output	-3.33	-1.97	-2.49	-2.57	-6.91	-4.12	-4.92	-5.14	-14.7	-8.87	-9.73	-10.4
Industrial Output	0.59	0.77	2.01	1.43	1.09	1.3	3.29	2.38	1.87	1.92	4.8	3.53
Service Output	0.53	0.95	3.18	1.49	1.03	1.75	5.26	2.57	1.96	3.07	7.84	4.12
All Household EV	0.84	1.75	2.11	1.6	1.53	3.07	3.05	2.52	2.63	4.92	3.27	3.31
Rural Household EV	1.87	6.29	2.09	2.42	3.57	11.12	2.88	3.67	6.64	17.94	2.26	4.16
Urban Household EV	0.75	1.18	2.12	1.39	1.36	2.07	3.15	2.21	2.3	3.3	3.78	3.08
All Household Income	0.75	1.66	2.03	1.5	1.37	2.91	2.95	2.36	2.36	4.66	3.15	3.1
Rural Household Income	1.66	5.84	2.02	2.3	3.18	10.32	2.77	3.49	5.94	16.65	2.13	3.95
Urban Household Income	0.67	1.12	2.04	1.29	1.21	1.97	3.03	2.07	2.05	3.14	3.66	2.88
Government Income	1.31	2.48	5.14	3.01	2.47	4.35	8.51	5.16	4.45	6.91	12.66	8.1
Total Export to ROC & ROW	0.43	0.83	1.6	1.09	0.85	1.43	2.58	1.82	1.61	2.21	3.62	2.73
Agricultural Export	-12.4	-9.87	-10.9	-10.8	-23.7	-18.5	-19.2	-19.3	-43.4	-33.3	-32.5	-32.7
Industrial Export	0.93	1.04	2.93	2.06	1.68	1.74	4.86	3.45	2.72	2.5	7.27	5.18
Service Export	0.13	0.53	3.69	1.19	0.36	1.25	6.39	2.18	1.03	2.97	10.49	3.97
Total Import from ROC & RC	0.54	0.84	1.63	1.14	1.02	1.44	2.64	1.91	1.85	2.22	3.73	2.85
Agricultural Import	3.31	4.27	4.38	4.15	6.56	8.07	7.63	7.46	13.26	14.99	12.59	12.98
Industrial Import	0.34	0.58	1.28	0.87	0.66	0.99	2.05	1.44	1.21	1.52	2.85	2.12
Service Import	0.95	1.23	2.67	1.68	1.73	2.08	4.23	2.76	2.94	3.06	5.65	3.98

3.8 Conclusion and final remarks

In this paper, through a general equilibrium analysis we have evaluated the effectiveness of the options for mitigating North China's water crisis. Water was introduced as an explicit factor of production into the model framework and we adopted the marginal value of water to represent the equilibrium price of water. An econometric model was used to estimate the marginal value of water, while the gravity model of trade was used to estimate the regional trade across Beijing, Tianjin, and Hebei. We also estimate the elasticities across production factors in the CES production function through an econometric analysis. According to this econometric analysis, an econometric-driven, multi-regional, multi-sectoral water extended computable general equilibrium model was developed, and applied to analyze the effectiveness of measures and policies for mitigating North China's water scarcity issues under three different scenario groups.

Experimental results of the scenario group for reducing groundwater show that reduction in the water supply level has a severe negative impact on the economy and household welfare. On the one hand, over-exploitation of water resources in the region can lead to severe ecological degradation. On the other hand, once groundwater is exhausted, the water supply crisis will result in huge GDP, welfare, and environmental losses. Thus, the Chinese government should adopt effective measures to reduce the over-exploitation of groundwater and maintain the water supply at a sustainable level.

Experimental results of the scenario group for the South-to-North Water Transfer project indicate that construction of the project has a positive impact on economic development, household welfare, and environmental sustainability. Once construction of the project has been completed, not only can exploitation of groundwater be reduced to a renewable level, but the water supply capacity for productive and domestic use can also be improved. This project will improve the sustainable development of the economy, society, and environment of North China, although the project inevitably has some negative impact, especially on the region from which water is transferred. Considering the extremely uneven distribution of population, economy, land and water resources, it is however in the author's vision necessary to construct the project. But it is also recommended to adopt corresponding measures to alleviate the negative impacts of the project. Actually, the Chinese government has already taken some measures to solve the problems, i.e., providing compensation for donor provinces through transfer payments.

Experimental results of the scenario group for reallocating water from agriculture to the industrial and service sectors indicate that transferring water from low-value sectors to high-value sectors can result in a positive impact on the macro-economy and household welfare, and promote economic restructuring from low water efficiency sectors to relatively high water efficiency sectors. This can improve water use efficiency and ensure the further development of the economy. It is therefore suggested that reallocation of water should be based on the marginal value of water. However, this would inevitably impact agricultural production and utilities of rural residents who mainly receive their income from the sale of agricultural products.

However, irrespective of whether groundwater exploitation is reduced or water from agriculture is reallocated to other sectors, there will inevitably be huge losses in agricultural production, because agriculture has the highest output elasticity for water input and water plays a very important role in the production of agricultural goods, although agricultural water use has a low marginal value. The region produces a substantial amount of good quality agricultural products, especially wheat and corn. In addition, the agriculture sector employs many farmers and provides a primary income source for agricultural households. Reductions in agricultural water use would substantially affect China's food security and lead to welfare losses for agricultural households. To avoid these negative impacts, the government is recommended to provide subsidies to them to invest in water saving technologies.

From above analysis, it is concluded that over-depletion of groundwater aquifers would lead to ecological and environmental degradation, but reducing in groundwater use would affect the economic growth and household income. To guarantee the sustainable development of the region, it is necessary for government to adopt both supply management measures and demand management policies. Water transfer project can improve the level of water supply and reduce the over-exploitation of local water resources. Demand management policies can improve water use efficiency through reallocating water to the sectors with higher marginal product value.

This analysis needs to be extended in several ways to remove a number of limitations. The CGE model used here is comparative-static in nature, which cannot allow it to account for accumulation effects over time. Moreover, many measures and policies cannot be realized overnight. It is therefore necessary to develop a dynamic CGE model to investigate long run effects and capture accumulation impacts of these measures and policies. In addition, the modeling framework in this study does not include water source regions, and it is recommended that the model need further cover the source provinces to analyze the impacts of the SNWT project on water source regions in the future.

Chapter 4. The Economic Impact of Water Tax Charges in China: A Static Computable General Equilibrium Analysis

Based on

Qin, C., Jia, Y., Su, Z., Bressers, H.J.A., Wang, H., 2011. The Economic Impact of Water Tax Charges in China: A Static Computable General Equilibrium Analysis. *Water International* (Under editorial and will be resubmitted for publication).

Abstract:

In this chapter, we present a static computable general equilibrium model of the Chinese economy with water as an explicit factor of production. This model is used to assess the broad economic impact of a policy based on water demand management, using water tax charges as a policy-setting tool. We use the model to evaluate the influences of water pricing under different scenarios. We find that imposing water taxes can redistribute sectoral water use, and lead to shifts in production, consumption, value-added gains, and trade patterns. Sectors not imposing water levies are nonetheless affected by the introduction of taxes from other sectors. Specifically for China, water taxes imposed on the agricultural sector drives most of the effects on sectoral water reallocation, shifts in production, consumption and trade patterns as well as welfare changes.

Keywords: Computable general equilibrium; Water allocation; Water pricing; Water tax; Water scarcity.

4.1 Introduction

The economic success in China has come at the expense of over exploitation of natural resources and huge impacts on the environment and especially water resources. Natural resources, of which water is one, are the primary inputs either directly or indirectly of all goods and services. Environmental and ecological losses are increasing as a consequence of water scarcity and pollution due to humans overindulging in their increasingly prosperous lifestyles afforded by industrialization.

In the year 2007, agriculture received about 63.5 percent of the total, industry received 24.1 percent, construction and services received 0.6 percent and 1.8 percent respectively, rural and urban residential received 3.5 percent and 4.8 percent respectively, and the remaining 1.8 percent was designated for environmental use (see Figure 4.1). Increasing water shortages and increased water demand, have given rise to inter-sectoral competition for water among the major user groups. This is especially true in northern regions, where agricultural production is negatively impacted due to unprecedented water competition (Yang and Zehnder, 2001). Agriculture still remains an important source of income and employment for a majority of rural households in China. Moreover, climate change has also placed pressure on inter-sectoral competition for water resources. Therefore, it is necessary for water managers to rethink current water allocation policies.

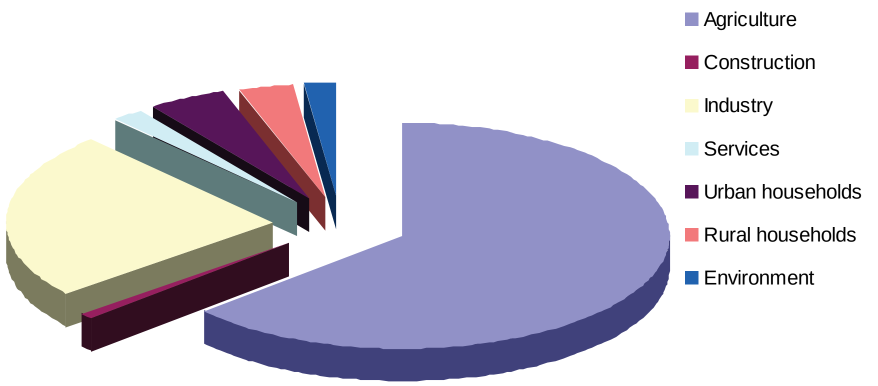

Figure 4.1 Water use patterns in the year 2007 in China

To mitigate severe water crises in China, several large-scale projects have been launched and other have been proposed. The South-to-North Water Transfer Project and Three Gorges Dam are two of the most ambitious and controversial projects, although large-scale reservoirs and inter-basin transfer projects will play key roles in supplying freshwater and balancing unevenly-distributed water resources. However, due to complex technical, economic, social, and environmental issues, such solutions to rising water demands *via* supply-side mechanisms are gradually becoming less viable due to resource constraints and increasing marginal costs of such engineering solutions. Alternative options, such as demand-side management, must receive more attention in developing water policies (Ashton and Seetal, 2002). Now according to China's Water Law, local governments are increasing water prices and water resource fees. Water resource fees can be regarded as a kind of water tax. As such, it is crucial to analyze the impact of such a water policy on China's economic output.

Many scholars have used partial equilibrium models to analyze changes in GDP and industry output arising from water resource policies (Hou, 1991; Liu 1996; Brown and Halweil, 1998; Conrad *et al*., 1998; Yang and Zehnder, 2001; Rosegrant *et al*., 2002; Fraiture and Cai *et al*., 2004). However, this approach fails to take into account interactions between water markets and the rest of the economy, which in some cases yield unreasonable results (Horridge, 1993). In contrast, general equilibrium analysis allows for consideration of a wider set of economic feedbacks and for a complete assessment of welfare implications. For this reason, this study analyzes the likely effects of water tax charges on the Chinese economy *via* an economy-wide static Walrasian computable general equilibrium (CGE) model with water as a production factor.

In the general equilibrium methodology, it is easy to determine how the entire economy adapts after a policy change and the interactions between the different activities. Therefore, CGE models are well-suited to compare alternative policy scenarios concerning water management. Susangkarn and Kumar (1997) used a CGE model to incorporate water use costs into the production sector. Decaluwé *et al*. (1999) developed another model to compare different water pricing policies. Seung *et al*. (2000) combined a country-level dynamic CGE model with a recreation demand model to analyze temporal effects of reallocating water from agricultural to recreational use. Diao and Roe (2003) and Diao *et al*. (2005) used an inter-temporal CGE model, allowing for analysis of both top-down and bottom-up linkages, to analyze water and trade policies for Morocco. Diao *et al.* (2008) extended their Morocco model, differentiating ground water and surface water as inputs for agricultural production and urban water demand, to evaluate direct and indirect effects of ground water regulation on agricultural and non-agricultural sectors. Xia *et al*. (2010) used a general equilibrium model to analyze changes in GDP and industry output under water price increases in Beijing using the GEMPACK software tool. Fang *et al*. (2006) investigated the economic impacts of efficient intra-regional and/or inter-regional water reallocation, and examined their corresponding economic gains in China with a Ramsey-type growth model of a small, open, competitive economy. Juana *et al*. (2009) used the CGE model to investigate socio-economic consequences impacted by climate change on water resources in South Africa. Based on the global general equilibrium model GTAP-W, Calzadilla *et al*. (2010) offered a method for investigating the role of green (rain) and blue (irrigation) water resources in agriculture within the context of international trade.

This paper is organized as follows: Section 4.2 discusses the CGE model, data, and parameters. Section 4.3 gives scenarios behind the simulations of water taxation policies. Section 4.4 analyzes the impact of water taxes on China's economy, and Section 4.5 presents the conclusion.

4.2 Analytical framework

This section describes the structure of our CGE model, building of the Social Accounting Matrix (SAM), and calibration of model parameters.

4.2.1 Model structure

The model is developed by using the mathematical program system for general equilibrium (MPSGE), which is a general algebraic modelling system (GAMS) extension developed by Rutherford (1998), with the MCP GAMS solver. We have presented a diagrammatic overview of the structure of the model in Figure 4.2. Its theoretical structure is typical of most static CGE models, and consists of equations describing producers' demands for produced inputs and primary factors; producers' supplies of commodities; demands for capital investment; household demands; export demands; government demands; relationships of basic values to production costs and to purchasers' prices; market-clearing conditions for commodities and primary factors; and numerous other macro-economic variables and price indices (Robinson, 1999).

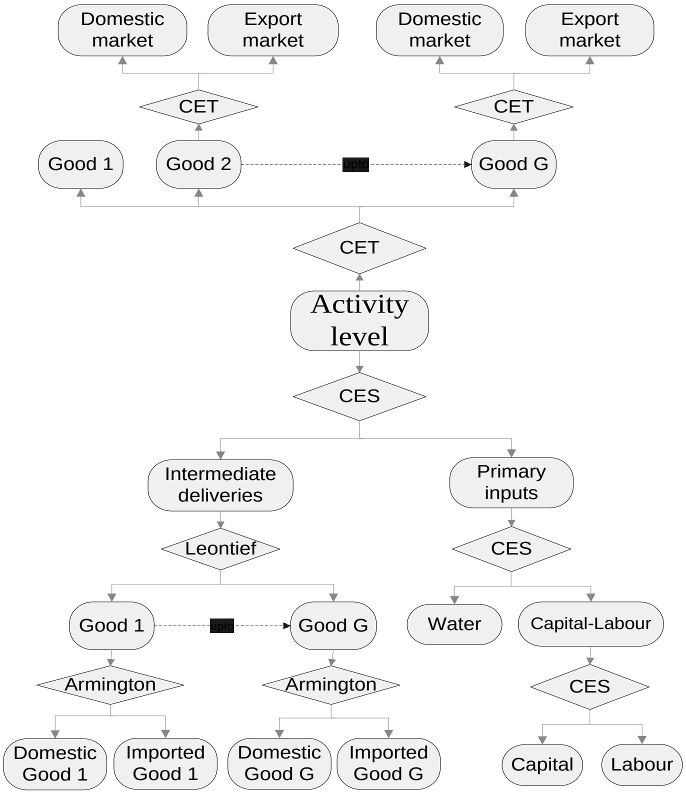

Figure 4.2 The structure of water CGE model

In this study's standard neo-classical CGE model, each activity is assumed to maximize profits, defined as the difference between revenue earned and the cost of factors and intermediate inputs. As full competition and constant returns to scale are assumed, no excess profits can be reaped and the maximum-profit condition diminishes to a least-cost condition. Profits maximized are subjected to a production technology. The model uses multi-level nested production functions to determine the level of production. At the top level, the technology is specified by a constant elasticity of substitution (CES) function of two quantities: value-added and aggregated intermediate inputs. The aggregate intermediate input is determined by a Leontief function of disaggregated intermediate inputs, whereas value-added is itself a nested CES function of primary factors. Capital and labour are combined by a CES function at the bottom level, and this capital-labour composite is subsequently linked with water by a CES function. This combination of composite primary inputs is the same across production sectors. However, this does not imply the same composite factor endowment combination for every product because the input combination and the behavioral parameters are not the same across the production sectors.

Each activity is assumed to produce a single commodity, which is used to satisfy domestic and foreign demands. The revenue of the activity is determined by the level of the activity, yields, and commodity prices at the producer level (Phuwanich and Tokrisna, 2007). Factors are assumed to be freely mobile across sectors. The capital and labour markets are closed by assuming that the demand for each of these factors is equal to their supply. In contrast, the total water usage cannot be greater than the total water supply; moreover, water pricing may differ across sectors. Therefore, these assumptions imply that labour and capital are fully employed whereas water demand may not fully exhaust supply.

The model also assumes imperfect substitution among goods differing in origin or destination. Aggregated domestic output is allocated between domestic sales and exports by maximizing revenue for any given output level. The constant elasticity of transformation (CET) function is used to formalize this concept of imperfect substitution between domestic consumption of sectoral output and foreign demands. Domestic market demand is made up of the sum of demands stemming from household consumption, government expenditure, investment, and intermediate inputs. All domestic market demands are for a composite commodity made up of imports and domestic outputs. In this study, the Armington (1969) CES-function form is used to determine demand composition between domestic outputs and imported goods. The trade distortions against export and import flows are specified as foreign savings and *ad valorem* tariffs.

Households receive direct and indirect income from factor endowments of labour and capital, enterprises, and transfer payments from other institutions (*i.e*. government and rest of the world). Each household's consumption decision is subject to a budget constraint. After a fixed share of the income is transferred in remittances and another fixed proportion goes to private savings, the household maximizes its utility through adjusting its consumption choices on different goods which are characterized by the linear expenditure system (LES).

Enterprises do not consume any commodities and the major source of income is the return on capital. Enterprise obtains net profits after paying direct taxes and receiving transfer payments from government. One part of net profits after tax is transferred to households, and the remaining is kept as enterprise savings. The government receives its income from tax revenues, water revenues and lump-sum transfer payments from the rest of the world (ROW). Government expenditure consists of consumption for different goods, transfer payments to households, enterprises, and to the rest of world. The residual of revenue over expenditure constitutes government's saving.

4.2.2 Social Accounting Matrix (SAM)

The social accounting matrix (SAM) used in the CGE model is a consistent, multi-sectoral, economy-wide data framework that integrates national accounts, input-output, flow-of-funds, and foreign trade statistics into a comprehensive and consistent dataset and typically set-up to represent the economy of a nation (Jennifer, 2002).

Due to lack of official SAM published by government in China, we need to build a SAM by involving data from various sources into a consistent SAM framework. Following the method adopted by He et al., (2010) for building China's SAM 2005, we first build a macro-SAM for China's economy 2007, and then the micro-SAM is compiled by splitting further the accounts in the macro-SAM. The data of activities, commodities, and import and export accounts are based on the national input-output table of China's economy for that year. The quantity of import and export commodities and the data of tariffs come from the *Customs Statistics Yearbook 2008* (GAC, 2008). Because the trade tariffs are included in the accounts of intermediate inputs of the input-output table, they need to be extracted from the accounts of activities and commodities when compiling the SAM. The revenue and expenditures accounts of the government comes from *Finance Yearbook of China 2008* (MOF, 2008) and tax data come from *Tax Yearbook of China 2008* (SAT, 2008). The revenue and expenditure of households, enterprises, and government are adjusted based on the flow-of-funds accounts of the *China Statistical Yearbook 2008* (NBS, 2008). The macro-SAM of China's economy for 2007 developed by the authors is shown in Table 4.1.

Table 4.1 Macro-SAM of China economy 2007, unit: Billion CNY

	1	2	3	4	5	6	7	8	9
1. Activities		80868.8							80868.8
2. Commodities	55281.5			9655.3		3519.1	9554.1	10513.1	88523.1
3. Factors	21168.3						40		21208.3
4. Households			12524		3122.7	544.7	294		16485.4
5. Enterprises			8463.8			206.1	160.6		8830.5
6. Government	4419	143.3	220.6	1399.7	877.9		-1.2		7059.2
7. Rest of the world		7511							7511
8. Saving-Investment				5430.4	4829.8	2789.4	-2536.4		10513.1
9. Total	80868.8	88523.1	21208.3	16485.4	8830.5	7059.2	7511	10513.1	

In this study, activities/commodities accounts in the micro-SAM are disaggregated into 14 sectors: agriculture (AGR), mining (MIN), food and tobacco (FOO), textiles and wearing apparel (TEX), wood, paper and printing (PPP), petroleum refining and coking (PET), chemicals (CHM), non-metallic products (NME), metal products (MET), machinery and equipment (MAC), other manufacturing (OHM), electricity (ELE), construction (CON), and services (SER). Due to limitations in the data, the households account is only divided into agricultural and non-agricultural constituents. The government activities are split into a main government account and several taxation accounts. As a key factor in this study a detailed water account is added into micro-SAM to properly account for sectoral water allocation and use in the economy. Information on water supply and usage comes from *The Water Resources Statistics Bulletins 2007* (MWR, 2008). National average water prices are estimated based on the statistics of water prices in different cities.

The design and construction methods of SAMs are not standardized. A SAM needs only to fulfill two conditions: the matrix must be square and the row total (total revenue) and column total (total expenditure) for each account must tally (Qin, 2007). Owing to the use of different sources of data and various statistical discrepancies, the compiled SAM for China's 2007 is not initially balanced. To fulfill the row-column constraint, we adopt the cross-entropy method (Robinson and El-Said, 2000) to balance the micro-SAM for China under the GAMS software environment.

4.2.3 Calibration of the model

The parameter values are crucial in determining the results of the alternative policy simulations. Ideally, all the parameters should be econometrically estimated in the CGE model. However, due to the required sophistication of techniques, and limitations of data, it is usually considered infeasible to determine them through this method (Gunning and Keyzer, 1995). Therefore, parameter values are determined by a calibration procedure (Mansur and Whalley, 1984).

In the CGE model, the share parameters, such as consumer and government consumption share, average savings rate, and average tax rate, etc., that can be calibrated by benchmark dataset provided in the balanced SAM (He *et al.*, 2010). The calibration procedure ensures that the parameters of the model are specified in such a way that the model will reproduce the initial dataset as an equilibrium solution.

The other type of parameter comprises of the elasticity parameters, such as elasticity parameters of substitution between production factors, Armington elasticity, and CET elasticity, which are fixed exogenously. Based on the studies of other scholars (Dervis *et al*., 1982; Zhuang, 1996; Zheng and Fan, 1999; He *et al*. 2002; Zhai, 2005; Willenbockel, 2006), the elasticity parameters used in the model are summarized in Table 4.2. In this study, CET elasticity between export and domestic demand equals 4, Armington elasticity between imported goods and domestic supply are between 1 and 3. CES elasticity between labour and capital are between 0.1 and 0.8 for different industries. CES elasticity between water and labour-capital composite are also between 0.1 and 0.8 for different industries.

Table 4.2 Values for key elasticity in the CGE model

Elasticity	Values
Export demand elasticity (σ_T)	4
CES between imported and domestic goods (σ_A)	1 to 3
CES between capital and labour (σ_{KL})	0.1 to 0.8
CES between capital-labour composite and water (σ_{KLW})	0.1 to 0.8
CES between factors and intermediate inputs (σ_{TOP})	0.6

4.3 Experimental Simulation Scenarios

With the view to protect limited water resources, the Chinese government is increasing water fee charges on all sectors of water users that ostensibly constitute a kind of water tax. Applying the previous model, we construct three plausible simulations, each dealing with the economic impacts of water tax policies. The scenarios are as follows:

Scenario 1 (S1): impose a selective pricing scheme of an extra water tax of 0.2 CNY per m^3 on just the agriculture sector;

Scenario 2 (S2): impose a uniform pricing scheme of an extra water tax of 0.2 CNY per m^3 for all sectors; and

Scenario 3 (S3): impose a differential pricing scheme of an extra water tax of 0.2 CNY per m^3 on the agriculture sector and 0.5 CNY per m^3 on non-agriculture sectors.

4.4 Results and Discussions

Table 4.3 presents the changes in sectoral output and their production prices for each of the three water tax charge scenarios. The results indicate that each total sectoral output declined slightly by 0.10 percent, 0.22 percent and 0.38 percent respectively. As the major consumer of water, the agricultural sector exhibited decreased output of more than 2 percent in all three scenarios, because its production costs increased due to the additional water tax charge. A similar pattern of decline is also noted for two non-agricultural sectors — food and tobacco, textiles and wearing apparel. This is because both sectors purchase a great amount of goods from the agricultural sector as inputs to their own production (Qin *et al*., 2011b). Thus, the added water charge on the agricultural sector will indirectly impact the production costs of these two sectors. Comparing the results of S2 and S3 with those of S1, we find that the outputs of the non-agricultural sector decrease in deferent ways; in particular, the output from the electricity sector declined more markedly than those of other non-agricultural sectors because it is a water-intensive user. Notably, water charges on these water-intensive users will impact production patterns, while on the agricultural sector it will drive most of the effects on that sectoral output.

Table 4.3 Results from simulations in changes of sectorial output (unit: percent)

	Price			Quantity		
	S1	S2	S3	S1	S2	S3
Agriculture	1.272	1.190	1.070	-2.098	-2.210	-2.374
Mining	-0.433	-0.342	-0.206	0.246	-0.021	-0.413
Food and tobacco	0.528	0.510	0.483	-1.367	-1.535	-1.782
Textiles and wearing apparel	0.169	0.194	0.231	-1.712	-1.887	-2.146
Wood, paper and printing	-0.185	-0.105	0.013	-0.121	-0.262	-0.470
Petroleum refining and coking	-0.403	-0.317	-0.190	0.140	-0.034	-0.288
Chemical products	-0.298	-0.170	0.017	-0.301	-0.541	-0.893
Nonmetallic products	-0.408	-0.330	-0.215	0.060	-0.021	-0.141
Metal products	-0.397	-0.304	-0.167	0.360	0.216	0.003
Machinery and equipment	-0.443	-0.400	-0.337	0.387	0.300	0.172
Other manufacturing	-0.083	-0.115	-0.163	-0.115	-0.212	-0.355
Electricity, heat-power and gas	-0.430	0.215	1.166	0.022	-0.681	-1.704
Construction	-0.422	-0.385	-0.331	0.003	-0.002	-0.009
Services	-0.359	-0.399	-0.459	0.373	0.416	0.480
Total	-0.209	-0.155	-0.075	-0.100	-0.215	-0.383

Changes in sectoral outputs due to increases in water prices under the different scenarios also have a direct impact on value-added. Table 4.4 reports the changes of sectoral demand of labour and capital. With the charge on water resources, some sectors can substitute water with other factors (labour and capital), but not other sectors. These will have varying impact on factor remuneration. Therefore, in Table 4.6 we present the possible impact of water taxes on labour wages and capital returns. Under S1, the average returns on capital increases slightly by 0.04 percent, while under S2 and S3 the average returns on capital decrease by 0.08 percent and 0.25 percent respectively. The possible economic reason is that water taxes may increase or decrease the demand for capital by some sectors. Since capital is fixed in the short-run, capital prices increase under S1 to reduce excess capital demand, while under S2 and S3 prices decrease to reduce excess capital supply. Results from simulations show that under the three scenarios average labour wages decrease by 0.97 percent, 1.10 percent and 1.29 percent respectively. Such declines indicate that water charges have negative impacts on the demand for labour in some sectors. Therefore, to reduce the excess in supply of labour, average wages must decline until market equilibrium is again achieved. This generally leads to decline in household incomes because incomes for most households come from wages.

Table 4.4 Results from simulations of changes in value-added (Unit: percent)

	Labour			Capital		
	S1	S2	S3	S1	S2	S3
Agriculture	-1.825	-1.895	-1.998	-2.321	-2.397	-2.507
Mining	0.546	0.371	0.111	0.038	-0.143	-0.409
Food and tobacco	-0.838	-0.943	-1.097	-1.009	-1.116	-1.272
Textiles and wearing apparel	-1.761	-1.833	-1.940	-2.109	-2.185	-2.297
Wood, paper and printing	0.196	0.120	0.006	-0.210	-0.290	-0.409
Petroleum refining and coking	0.434	0.365	0.262	-0.024	-0.098	-0.207
Chemical products	0.086	-0.067	-0.290	-0.420	-0.578	-0.808
Nonmetallic products	0.376	0.398	0.429	-0.081	-0.065	-0.041
Metal products	0.726	0.678	0.608	0.216	0.163	0.085
Machinery and equipment	0.824	0.837	0.855	0.467	0.476	0.488
Other manufacturing	0.224	0.229	0.236	-0.283	-0.284	-0.285
Electricity, heat-power and gas	0.251	-0.282	-1.073	-0.256	-0.792	-1.587
Construction	0.309	0.398	0.529	-0.198	-0.115	0.007
Services	0.722	0.840	1.015	0.213	0.324	0.490

Shifts in sectoral output and value-added has consequential impacts on supply, export and import of commodities. Table 4.5 reports the changes in trade patterns with each scenario. Exports of agricultural commodities declined by 7.93 percent, 7.58, and 7.05 percent respectively, while the domestic supply of agricultural commodities decreased by 1.97 percent, 2.10 percent and 2.28 percent respectively. Because the production of agricultural commodities requires a great deal of water, their production costs increase with water tax rises. Similar to the sectoral output, the same trend in export changes is recorded in two non-agricultural sectors — food and tobacco, textiles and wearing apparel — that utilize a great number of goods supplied from the agricultural sector for their own production inputs (Qin *et al*., 2011b). Thus, water charges indirectly raise their production cost. Comparing the results of S2 and S3 with those of S1, water charges on non-agricultural water use also results in reductions in exports of high water-intensive commodities and increases in exports of low water-intensive commodities. Taking electricity as an example, compared with S1, exports decrease by 3.09 percent and 7.43 percent in S2 and S3. Changes in trade patterns have an important role in appealing for a more reasonable level of water use. This is quantified by the water embedded in commodities called “virtual” water (Hoekstra and Chapagain, 2007). In terms of virtual water trade, as expected, a reduction of exports of high water-intensive commodities leads to a decrease in virtual water exports. Water-starved countries can meet their demand for water-intensive products by importing them rather that producing these themselves (Bouwer, 2000; Allan and Olmsted, 2003). Based on the results in Table 4.5, imports of most commodities decline slightly on imposing water charges. The possible reason for the decline is that domestic household consumption weakens due to reductions in household incomes and increases in the consumer price index (see Table 4.7) induced by the water taxes.

Table 4.5 Results from simulations of trade patterns in China (Unit: percent)

	Export			Import		
	S1	S2	S3	S1	S2	S3
Agriculture	-7.9309	-7.5788	-7.0535	0.3374	0.0236	-0.4372
Mining	0.8988	0.4357	-0.2439	-0.0761	-0.2464	-0.4974
Food and tobacco	-4.4656	-4.3945	-4.2878	-0.1791	-0.4411	-0.8252
Textiles and wearing apparel	-3.4286	-3.5291	-3.6783	-0.4914	-0.7216	-1.0597
Wood, paper and printing	-0.4664	-0.7526	-1.1732	0.1297	0.0945	0.0428
Petroleum refining and coking	0.6718	0.3251	-0.1838	-0.059	-0.1677	-0.3273
Chemical products	-0.1961	-0.7703	-1.609	-0.3401	-0.4548	-0.6238
Nonmetallic products	0.6117	0.3897	0.0633	-0.1079	-0.1462	-0.2027
Metal products	0.8665	0.5212	0.0142	0.191	0.1139	-0.0003
Machinery and equipment	1.0809	0.9963	0.8698	-0.0441	-0.132	-0.2613
Other manufacturing	-0.8657	-0.6609	-0.36	0.115	-0.0746	-0.3535
Electricity, heat-power and gas	0.6593	-2.4255	-6.771	-0.1713	-0.1425	-0.1049
Construction	0.6087	0.631	0.6628	-0.1807	-0.1942	-0.2137
Services	0.7243	1.1081	1.6745	0.2559	0.1864	0.0853
Total	-0.0317	-0.1224	-0.2559	-0.0403	-0.1557	-0.3256

Water charges can lead to shifts in production, consumption, value-added gains, and trade patterns. In turn, such changes in production, consumption and trade patterns also impact sectorial water demand and reallocate sectorial water use. Table 4.6 shows the changes in sectoral water use from simulations under each scenario. Results indicate that decreases in agricultural output and exports reduce agricultural water demand allowing water to be reallocated to sectors with higher water-use efficiency. Because taxing agricultural water use indirectly reduces output and exports of the food and tobacco sector, textiles and wearing apparel sector, their water demands also decline. Comparing the results of S2 and S3 with those of S1, water charges on non-agricultural water use also results in water demand reduction of high water-intensive sectors. Taking electricity again as an example, compared with S1 its water use decreased by 0.26 percent and 0.70 percent under S2 and S3 respectively. With water charge on sectoral water use, low-intensive sectors will increase their water demands. Therefore, these results indicate that water charges on water-intensive sectors lead to a reallocation of sectoral water use.

Table 4.6 Results from simulations of sectorial water use (Unit: percent)

	S1	S2	S3
Agriculture	-1.661	-1.650	-1.620
Mining	0.744	0.693	0.636
Food and tobacco	-0.456	-0.426	-0.359
Textiles and wearing apparel	-1.531	-1.491	-1.415
Wood, paper and printing	0.710	0.840	1.064
Petroleum refining and coking	0.801	0.899	1.070
Chemical products	0.009	-0.094	-0.236
Nonmetallic products	0.516	0.637	0.832
Metal products	0.801	0.846	0.928
Machinery and equipment	1.118	1.264	1.499
Other manufacturing	0.407	0.543	0.764
Electricity, heat-power and gas	1.031	0.775	0.431
Construction	0.548	0.770	1.118
Services	0.703	0.885	1.166

As a whole, the total water demand in China's economy decreased by 5.0, 5.2 and 5.3 billion cubic meters respectively under the three water tax scenarios that accounted for about 1 percent of total water use for production. The amount of water saved can be reallocated to other sectors with high water-use efficiency or returned to nature for environmental use, thus achieving economic and environmental gains. Real GDP decreases slightly by 0.21–0.23 percent. In this study, we use the Hicksian equivalent variation (EV) to analyze the impact of water charges on household welfare. Based on the results given in Table 4.7, the equivalent variation (EV) of agricultural households decreased 0.99 percent, 1.25 percent and 1.63 percent respectively for each pricing scenario, and the equivalent variation (EV) of non-agricultural households decreased 0.76 percent, 1.05 percent and 1.47 percent respectively. Therefore, these results indicate that water charges lead to general welfare decline within both agricultural and non-agricultural households.

Table 4.7 Results from simulations at the macro level (Unit: percent)

	S1	S2	S3
Wage	-0.970	-1.098	-1.286
Capital rent	0.040	-0.079	-0.252
Real GDP	-0.216	-0.222	-0.231
Government income	3.322	4.311	5.839
Consumer price index (CPI)	1.718	2.204	2.978
Agricultural household (EV)	-0.985	-1.245	-1.625
Non-agricultural household (EV)	-0.760	-1.047	-1.467
Total Water demand	-0.967	-0.989	-1.005

Policy makers wanting to use water taxation to achieve environmental dividends would find it hard to trade off a drop in GDP or losses in welfare. Here the environmental dividends are reductions and reallocations in water use. Results in Tables 4.6 and 4.7 shows that water charges do yield environmental dividends. Although a water tax changes production, consumption and trade patterns, it induces negative effects in achieving economic dividends, because it reduces GDP and household welfare. According to the double dividend theory, revenues from environmental taxes can lower the economic cost from the environmental tax. In this study, government incomes in each pricing scenario increased by 3.3 percent, 4.3 percent, and 5.8 percent, respectively. A subsidy, as a government transfer payment, can be provided to affected households to offset welfare losses in households. Due to the importance of food security for China’s large population, added government income can also be used as a production subsidy to invest in water-saving irrigation technology and equipment, and it would help avoid food shortages and reduce welfare losses for agricultural households. In addition to subsidies, negative economic effects can also be reduced by lowering other taxes, e.g., income taxes. Quantitative analysis on subsidies and other taxation cuts falls outside of this study. However, some empirical studies indicate that it is possible to achieve a double dividend if the environmental tax reform is given a smart implementation (Letsoalo, 2007).

4.5 Conclusion and remarks

In this chapter, we presented a static computable general equilibrium model of the Chinese economy introducing water as an explicit factor of production. The CGE model was used to assess the economy-wide impact of a water pricing policy in the form of a water tax. Through three arbitrary scenarios, we demonstrated these impacts on various sectors. Gathering data from different sources and adjusting, modelling and analyzing these data, results of simulations indicated that water-use charges can reallocate sectoral water use, and lead to shifts in production, consumption, value-added gains, and trade patterns. Water price increases lead to declines in total output, total export, GDP, and household welfare. Sectoral outputs and exports with high water-use intensity would be reduced by higher water charges. Specifically, output and exports of agriculture and related sectors decline markedly and most notably. Through water charges, total water use declined and water scarcity would be alleviated. In addition, water can be transferred into sectors with high water-use efficiencies. Furthermore, any water pricing policy should take into account who and what is being taxed. Sectors not levied directly by water taxes are nonetheless affected by other taxed sectors. Water tax charges on high water-intensive sectors lead to water reallocations to other sectors maintaining high water-use efficiencies. In China, water taxes in the agricultural sector drives most of this water reallocation, shifts in production, consumption and trade patterns as well as welfare changes.

In this study, simulation results indicated that decline in GDP was less than linear in the reduction of water usage, whereas losses in welfare were more than linear in the reduction of water usage. Usually, policy makers want to use a water tax to reduce water consumption but find it hard to trade off a drop in GDP or losses in welfare. To mitigate the negative effects of water taxes, we should pay more attention to revenues collected from water taxes that can lower the economic cost of the environmental tax (Letsoalo, 2007). Subsidies on water-saving irrigation technology and for impacted households and lowering of other taxes are measures that have been empirically concluded could help alleviate the negative impact of water taxes on the economy and household welfare.

This analysis needs to be extended in several ways to remove a number of limitations. First, welfare losses elicit a non-linear response under changes in water tax charges. We further need to include excess burdens and equity considerations into the model. Second, the amount of water saved can be released back into nature for environmental use, and water tax revenues can also be used to restore damaged environments arising from excess water use. Therefore, the functions of these environmental welfare effects can also be added into the model. Third, we used a single data set for water use and water resources, ignoring the uncertainties in the data. Fourth, the regional differences cannot be captured adequately by a single country model, because the distribution of water resources is extremely uneven in China and the economic development is also unbalanced among the different regions. Fifth, introduction of a dynamic mechanism is another extension for more accurate long-term water policy analysis. All this is deferred to future research.

Chapter 5. Economic impacts of water pollution control policy in China: A dynamic computable general equilibrium analysis

Based on

Qin, C., Bressers, H.J.A., Su, Z., Jia, Y., Wang, H., 2011. Economic impacts of water pollution control policy in China: A dynamic computable general equilibrium analysis. *Environmental Research Letters* (Under revision and will be resubmitted for acceptance).

Abstract:

In this chapter, we apply an extended environmental dynamic computable general equilibrium model to assess the economic consequences of implementing total emission control policy by simulating different emission reduction scenarios, with reductions ranging from 20 to 50% of the emission levels in 2007 by the year 2020. We develop a multi-abatement-sector structure in the model, which helps us capture detailed information on changes in abatement costs for each specific pollutant. The study also presents an environmentally extended social accounting matrix (ESAM) for China's economy in 2007, which serves as a consistent dataset for calibrating the model. The results indicate that a modest total emission reduction target can be achieved at a low macroeconomic cost. With the stringency of policy targets, macroeconomic cost (for example, GDP loss, NNI loss and welfare loss) will increase at an increasing rate. We also find that stringent environmental policy can lead to an important shift in production, consumption, and trade patterns, from dirty sectors to relatively clean sectors. Some sectors can benefit from their relatively low marginal abatement cost and the reallocation of resource endowments caused by the policy. Simulation results show that macroeconomic cost can be reduced via the trading of emission permits, and thus emission permit trading experiments by local governments should be further encouraged. It is highly recommended that efforts are made to establish emission permit trading mechanism at the national level.

Keywords: Environmental computable general equilibrium; Water pollution; Tradable emission permits; Emission control; Environmental policy.

5.1 Introduction

Water pollution in China is a pervasive problem that threatens the health of ecosystems, increases the cost of treating water for drinking, industrial, and commercial uses, and exacerbates water scarcity problems. If not immediately and effectively controlled, incidents of pollution caused by accidental release or accumulation can worsen water shortages and scarcity problems. This can result in environmental and economic damage, and cause widespread concern and social unrest.

Disposal of hazardous and municipal waste, discharge of industrial and municipal waste water, and agricultural runoff containing fertilizers, pesticides, and manure, have all contributed to polluting most of China's surface and ground water, thus reducing the country's available water resources. In 2007, of 407 monitored river sections, 50 percent met Grade I-III surface water quality standard (safe for human consumption after treatment), 26 percent met Grade IV-V standard (safe for industrial and irrigation use), and the remaining 24 percent were worse than Grade V standard (unsafe for any use). Of 28 major monitored lakes and reservoirs, only 29 percent met the Grade I-III standard, 32 percent met Grade IV-V standard, and 39 percent were worse than Grade V standard (MEP, 2008). Groundwater is also polluted by wastewater discharge from industrial, municipal, and agricultural sources. In about 50 percent of all regions, shallow groundwater is polluted. Also, in about 50 percent of cities, groundwater is quite seriously polluted. Because of severe pollution, even southern parts of China with their relatively well-stocked resources face shortages of clean, safe drinking water. According to results from monitoring in 2006, of 382 major drinking water sources in 107 key cities, only 72.3 percent met drinking standards. Water pollution accidents occurred frequently and caused water shortages with severe impacts on social and economic development. The environmental cost of water pollution was estimated at 286 billion CNY in 2004, equivalent to 1.7 percent of GDP for 2004 (SEPA and NBS, 2006).

These problems have severely threatened sustainable development in China and have caused great concern at all levels, from the general public to central and local government. To mitigate the impact of water pollution, a series of pollution control policies have been adopted in

China. When discharging wastewater, polluters are required to meet rigid discharge standards through taking effective measures, including end-of-pipe measures and process-integrated measures. However, with the enlargement of China's economy, total pollutant emission is still increasing and exceeds the assimilation capacity of many water bodies and thus worsens water quality. In addition, reduction in environmental flow due to increasing water demand for economic and domestic use also reduces the assimilation capacity of water bodies. This is especially severe in the north of China. Given the serious impacts of water pollution, the Chinese government has gradually become more aware of the importance of taking stronger action to control the total amount of emissions. Since the mid-1990s, COD (chemical oxygen demand) emission has been one of two major total emission control targets at the national level (the other one is SO_2). In the *Eleventh Five-Year Plan for National Social and Economic Development* (SCCG, 2006), a strict total emission reduction target – 10 percent COD reduction by 2010 based on 2005 benchmark data – was set by the central government. Local governments were required to reduce their COD emission by 10 percent by 2010, which more or less equates to going back to the 2005 emission levels. Total emission control of ammonia nitrogen (NH3-N) and other main pollutants is also receiving more and more attention from both central government and some local governments. When implementing the total emission reduction target, local governments not only invest in end-of-pipe and process-integrated measures but also attempt to adopt tradable emission permit systems to trade emission rights thereby reducing the abatement cost of reducing pollutant emission. Several environment permit exchange centers have been established by local governments in places such as Beijing, Shanghai and Tianjin.

Effective water pollution control policies could yield multiple benefits, including protecting both the natural environment and human health, improving water quality for various uses, and alleviating water shortages. Unfortunately, many environmental policies also impact economic growth, poverty, employment or income distribution. The complexity of the direct and indirect relationships between economic, environmental and social variables calls for tools for quantitative environmental and economic analysis that allow evaluation of the effectiveness of pollution controls and the economic and welfare impacts of these policies. Due to the complexity of modelling an economy with all its interrelations, agents and sectors, common practice has led to the study of the economic, social and environmental policies in the context of partial equilibrium. However, partial equilibrium analysis can generate unreasonable results (Horridge, 1993). This is because partial equilibrium analysis assumes that other aspects of the economy do not change. In contrast, computable general equilibrium (CGE) models are a powerful tool for multi-dimensional or multi-sectoral analysis, and allow full assessment of the effects of either macroeconomic policies on the environment or the impact of environmental or welfare policies on the macroeconomic variables.

The first CGE model was presented in Johansen (1960), and since the 1980s, it has become a leading multi-sector, economy-wide modelling tool for policy analysis. Since the late 1980s, CGE modelling has gradually been applied to analysis of environmental policy and natural resource management issues (Forsund and Strom, 1988; Dufournaud et al., 1988; Bergman, 1988, 1990a, 1990b and 1991; Hazilla and Kopp, 1990; Robinson, 1990; Jorgenson and Wilcoxen, 1990; Espinosa and Smith, 1994). Even though many of these applications are still in experimental stages, they show that the CGE approach has advantages for environmental policy modelling. More recently, we have seen the rapid growth of CGE applications in the arena of environmental policy analysis (Kremers et al., 2002; O'Ryan, 2003; Kumbarôglu, 2003; Nijkamp et al., 2005; Heggedal, 2008; Loisel, 2009; Qin et al., 2011a). To analyze the costs of environmental policy in the Netherlands, Dellink (2000, 2005) developed a dynamic applied general equilibrium (DEAN) model which allowed a choice between paying for pollution permits and increasing expenditure on pollution abatement. A third possibility to achieve corresponding environmental targets for producers and consumers is to reduce production and consumption of the pollution-intensive commodities (Dellink, 2005). In the original model, only one abatement sector is modeled as providing 'abatement services' for all environmental tasks.

The aim of this paper is to examine the effectiveness of total emission control policies in China and assess the impacts of emission reduction targets on macroeconomic, sectoral, social variables using an extended environmental dynamic computable general equilibrium (CGE) model.

This is the first time a dynamic CGE framework has been applied to analyze the direct and indirect economic impacts of China's water pollution control targets, an understanding of which is expected to generate useful insights for water pollution control strategies.

In this study, the theoretical framework and basic structure of the DEAN model is adapted and calibrated to benchmark data assumptions for China. A major extension in this study is that a multi-abatement-sector structure is specified to capture more detailed information on the abatement costs of different pollutants in each production activity. 'Abatement services' for various pollutants are provided by corresponding abatement sectors. A market for tradable emission permits is created in the DEAN model to redistribute the restricted emission permits (Dellink et al., 2003). To compare the economic impacts of different emission permit methods, two versions of the model are developed to analyze the economic cost of China's total emission reduction targets. One adopts a tradable emission permit system, whereas the other does not allowing trading of emission permits. The study also presents an environmentally extended social accounting matrix (ESAM) for China's economy in 2007, which serves as a consistent dataset for calibrating the model.

The structure of this paper is as follows. Section 5.2 provides an overview of the model; and Section 5.3 deals with the data and calibrations. Section 5.4 gives different scenarios for total emission reduction targets in China, and discusses the results of the model simulations. Section 5.5 concludes the paper.

5.2 Description of the model

The model used in this paper is a dynamic computable general equilibrium (CGE) model with perfect foresight in the Ramsey tradition. The model is developed by using the mathematical program system for general equilibrium (MPSGE), which is a general algebraic modelling system (GAMS) extension developed by Rutherford (1998), with the MCP GAMS solver. A diagrammatic overview of the main structure of the model is presented in Figure 5.1. For the main equations for the model, refer to Dellink (2000, 2005) and Dellink et al. (2003). We only give a general description of the model.

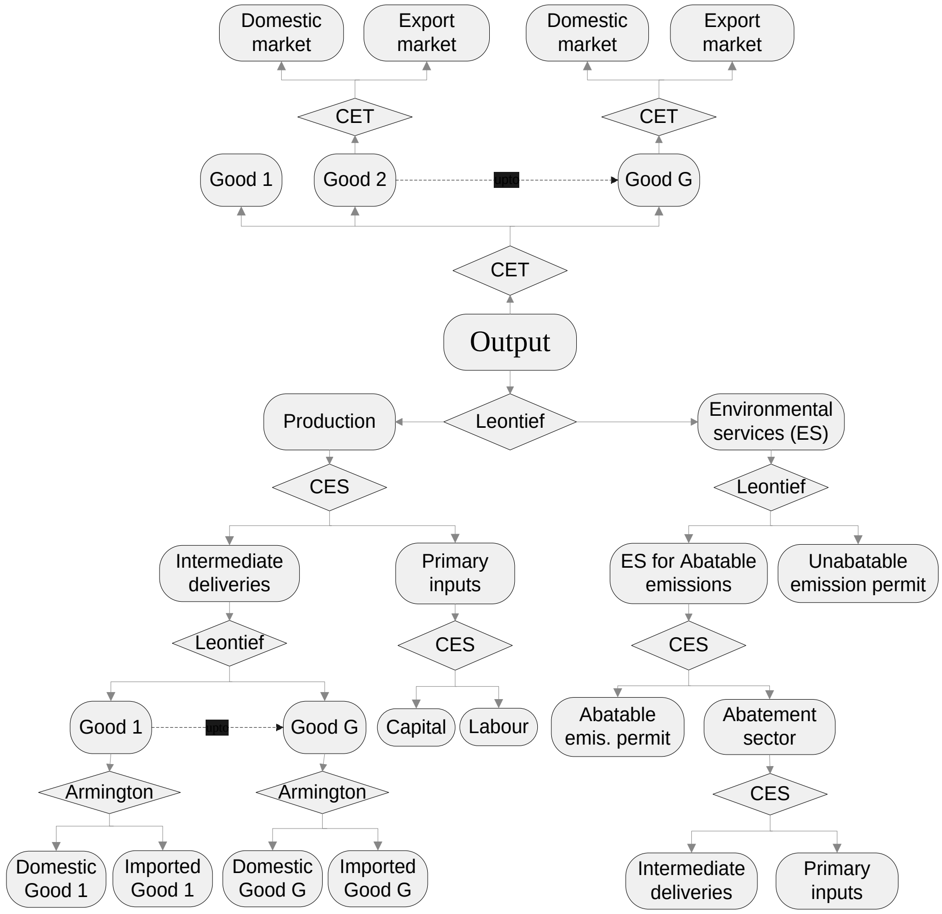

Figure 5.1 Diagrammatic overview of the main structure of the model

5.2.1 Production module

The levels of consumption of different goods and environmental services are combined in a nested constant elasticity of substitution (CES) utility function. Each level of consumption requires some combination of pollution permits and abatement, as will be explained in more detail below.

The production module of the model consists of 27 production sectors. It is assumed that each sector produces one kind of good and all sectors make production decisions in accordance with the principle of constant returns to scale to minimize production costs. Revenue is determined by the level of activity, yields, and commodity prices at the producer level

(Phuwanich and Tokrisna, 2007). The production module uses multi-level nested production functions to determine the level of production (see Figure 5.1). The technology is first specified by a CES function of two quantities: value-added and aggregated intermediate inputs. The aggregate intermediate input is determined by a Leontief function of disaggregated intermediate inputs, while value-added is itself a nested CES function of primary factors (labour and capital). Factors are assumed to be freely mobile across sectors. The capital and labour markets are closed by assuming that the demand for each of these factors is equal to their supply. Therefore, these assumptions imply that labour and capital are fully employed.

5.2.2 Household and government sectors

On the demand side, private households are included as a single representative consumer, receiving income from the sale of their endowments of capital goods and labour, reduced by lump-sum transfer payments to the government. The household maximizes its utility under budget constraint conditions through adjusting its consumption choices on different goods which are characterized by the linear expenditure system (LES). The government receives its income from taxation, sales of pollution permits and lump-sum transfer payments from the household sector. The lump-sum transfers are endogenously adjusted to ensure balanced budgetary consequences for the government (Dellink et al., 2003).

5.2.3 Foreign sectors

The model assumes imperfect substitution between goods differing in origin or destination. The constant elasticity of transformation (CET) function is used to formalize this concept of imperfect substitution between domestic consumption of sectoral output and foreign demands. The Armington (1969) CES-function form is used to determine imperfect substitutability between domestic outputs and imported goods.

5.2.4 Dynamic mechanisms and inter-temporal linkages

There are two possibilities for including dynamics in the model: (i) a new dynamic forward looking model; or (ii) a recursive-dynamic model based on the static CGE model. The model used in this paper is a forward-looking neo-classical growth model, which includes the inter-temporal elasticity lacking in recursive-dynamic models. Private households have the foresight to maximize the present value of current and future utility under a budget constraint. A simple growth path is specified in the model by the exogenous growth of labour supply in efficiency units, together with exogenous technical progress. The growth of capital is endogenously determined by the saving/investment ratio. For a detailed description of the dynamic path of the model, we refer the reader to Dellink (2005).

5.2.5 Environmental service module

Pollutants are often by-products of the process of production and consumption. These emissions are controlled by the government, who set the total emission reduction targets exogenously by issuing a restricted number of emission permits. Producers and households have the endogenous choice between paying for their emissions and investing in pollution abatement, and will always choose an optimal combination with the least cost (Dellink, 2005). Therefore, a substitution exists between them. To compare the economic impacts of tradable emission permits when implementing the total emission reduction policy in China, a second version of the model with a non-tradable emission permits system is also developed. In this version, all producers and consumers are required by the government to reduce their emission levels proportionately.

In Dellink and Van Ierland (2004), there is only a simple abatement sector which provides ‘abatement services’ for all environmental tasks. We disaggregate this sector into three distinct abatement sectors providing cleanup services for the emission of specific pollutants. A key feature of this extension is that the abatement expenditure captures as much information as possible about the technical measures underlying the options for each pollutant, and gives a more detailed specification for the abatement costs of different pollutants for each production activity.

The existing technical potential to reduce emissions through abatement measures provides an absolute upper bound on technical abatement activities in the model (Hueting, 1996). Therefore, emission permits come in two types – “abatable emission permits” and “un-abatable emission permits" (Dellink and Van Ierland, 2004). Substitution between abatable emission permits and the corresponding abatement options for specific pollutants is determined by the Pollution–Abatement Substitution (PAS) function which is a CES-type curve. A detailed description of the PAS method can be found in Dellink (2005). The estimated CES-elasticity (or PAS-elasticity) describes the pollutant-specific possibilities for substitution between emission and cleanup services, and reflects marginal abatement costs. Each abatement sector has the same production structure as the production sectors, which is specified by a constant elasticity of substitution (CES) function of aggregated value-added (labour and capital) and aggregated intermediate inputs from the production sectors (see Figure 5.1). We assume that the abatement sectors don't need abatement services provided to them, and also that the abatement processes do not lead to pollution.

If both the marginal abatement cost and the price of the permits are greater than the value-added foregone in reducing production for producers or the utility foregone in reducing consumption for consumers, a third possibility for reducing emission levels is to reduce production and consumption levels. This is especially true for more ambitious emission reduction targets (Dellink, 2005), and in fact readjusting economic structure to achieve the required environmental targets is actually a least-cost strategy.

5.3 Data and calibration

5.3.1 Environmental Social Accounting Matrix (ESAM)

The social accounting matrix (SAM) used in the CGE model is a consistent, multi-sectoral, economy-wide data framework that integrates national accounts, input-output, flow-of-funds, and foreign trade statistics into a comprehensive and consistent dataset, and that is typically set-up to represent the economy of a nation (Jennifer, 2002). However, a traditional SAM fails to represent elements like resource use, emission accounts, pollution abatement activities and their interactions with economic activities. Keuning (1993) proposed both that pollution impacts should be integrated into a SAM framework and that physical environmental accounts should be integrated into a national accounting matrix (NAMEA), but unfortunately ignored pollution abatement activities.

Xie (1996) developed an environmentally extended SAM framework (EESAM) which provides an integrated dataset for analyzing pollution abatement sectors, sectoral payments for pollution cleanup, pollution emission taxes, pollution control subsidies, and environmental investments. Based on the environmental accounting in NAMEA and abatement activity accounting in Xie's EESAM framework, we present an environmental SAM (ESAM) which includes both pollution abatement activity accounts and the corresponding pollution emission accounts. The ESAM captures the interactions between pollution and economic activities and provide a consistent and integrated data framework for calibrating the above model. Its basic structure is shown in Table 5.1.

Table 5.1 Basic structure of ESAM

		Expenditures												
		Activity		Commodity		Factors								
Receipts		**Production**	**Abatement**	**Goods**	**Cleanup**	**Labour**	**Capital**	**Households**	**Government**	**Saving-investment**	**Rest of the world**	**Total**	**Emission of Pollutants**
Activity	**Production**			Marked outputs								Activity income (Gross output)	Production pollution
	Abatement				Cleanup supply								
Commodity	**Goods**	Intermediate input (use)						Private consumption	Government consumption	Investment	Exports	Total demand	
	Cleanup	Payment for cleaning						Payment for cleaning					
Factors	**Labour**	Value-added (factor payments)										Factor income	
	Capital												
Household						Factor incomes			Subsidies to household		Transfer to household	Household income	Consumption pollution
Government		Indirect taxes		Tariff		Factor taxes		Transfer to government			Transfer to government	Government income	
Savings-Investment (S-I)								Household savings	Government savings		Foreign savings	Total savings	
Rest of the World (ROW)				Imports								ROW income	
Total		Total cost		Total absorption		Total factor expenditures		Household expenditures	Government expenditures	Total investment	ROW expenditures		
Pollutants emitted (in physical units)		Pollutants abated or reused											

The initial task when building a SAM involves compiling data from various sources into a SAM framework. The economic part of our ESAM for the Chinese economy includes 27 production sectors – one agricultural sector, 25 industrial sectors and one aggregated service sector. Some characteristics like production, private consumption and the amount of value-added in China in 2007 are given in Table 5.2. The data on activities, commodities, and import and export accounts are based on the national input-output table of China's economy for the year 2007. The revenue of expenditure accounts for the government come from the *Finance Yearbook of China 2008* (MOF, 2008) and tax data come from the *Tax Yearbook of China 2008* (SAT, 2008). Household and government revenue and expenditure are adjusted based on the flow-of-funds accounts of the *China Statistical Yearbook 2008* (NBS, 2008).

Table 5.2 Economic data of sectoral production, consumption and value-added for China, 2007 (in 10^8 CNY at 2007 prices)

No.	Sectors	Production	Consumption	Value-added
Y01	Agriculture	48893	11156	28659
Y02	Coal mining and processing	9645	148	4429
Y03	Petroleum & gas extraction	9535	0	5697
Y04	Metal ore mining	6149	0	2164
Y05	Non-ferrous mineral mining	3852	0	1511
Y06	Food and tobacco processing	41790	16688	10178
Y07	Textile apparel	25197	443	4915
Y08	Clothing products	18073	5671	4031
Y09	Sawmills and furniture	10994	517	2613
Y10	Paper and printing industry	14933	421	3557
Y11	Petroleum refineries	21075	746	3752
Y12	Chemical industry	61998	2351	12593
Y13	Nonmetallic mineral products	22804	280	6265
Y14	Metal smelting and pressing	61096	0	11929
Y15	Metal products	17705	411	3687
Y16	Industrial machinery	39487	65	9117
Y17	Transport equipment	32978	2456	6423
Y18	Electric equipment	27155	1923	4628
Y19	Electronic & telecom equipment	41190	1938	6808
Y20	Instruments & office equipment	4880	180	1033
Y21	Artwork & other manufacturing	6183	1383	1543
Y22	Scrap and waste	4366	0	3531
Y23	Electricity	31486	2353	8810

Y24	Gas production and supply	1108	322	222
Y25	Water production and supply	1179	322	548
Y26	Construction	62722	932	14513
Y27	Service industry	192385	45847	102889

Apart from the twenty-seven production sectors, the environmental portion of ESAM includes three pollution abatement sectors – one for chemical oxygen demand (COD), one for ammonia nitrogen (NH3-N) and one aggregate abatement sector for other pollutants (OHP). Cost data for removing pollution in both the production sector and households come from the *Annual Statistical Report on Environment in China 2007* (MEP, 2008). The intermediate demands of abatement sectors on commodities of production sectors are estimated from the intermediate consumption coefficients of the "environment management service sector", which can be calculated by the data in the input-output table which has 135 sectors. All payments from production sectors for pollution abatement or from abatement sectors for intermediate consumption of commodities from production sectors must be deducted from the accounts of activities and commodities when compiling the ESAM. Payments from households for pollution abatement must also be deducted from the accounts of household consumption to the service sector.

A SAM needs only to fulfill two conditions: the matrix must be square and the row total (total revenue) and column total (total expenditure) for each account must tally (Qin, 2007). Owing to the use of different sources of data and various statistical discrepancies, the ESAM for China in 2007 is not initially balanced. To fulfill the row-column constraint, we adopt the cross-entropy method (Robinson and El-Said, 2000) to balance the micro-SAM for China using the GAMS software environment. The simple ESAM developed by the authors for 2007 is shown in Table 5.3.

Table 5.3 the simple version of Chinese ESAM for the year 2007 (unit: 10^8 CNY)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Activity	**1.Agriculture**					48840										48840
	2.Industry						577337									577337
	3.Service							192189								192189
	4.Abatement								611							611
Commodity	**5.Agricultu**	7199	26372	2796	7							11478	351	2101	685	50990
	6.Industry	10045	361153	47931	216							39894	0	101823	82139	643202
	7.Service	2951	54902	38645	103							45882	34965	7257	13311	198017
	8.Abateme	29	428	37								117	0	0	0	611
Factors	**9.Labour**	27140	45956	36815	169											110080
	10.Capital	1429	61493	54507	108											117537
Institutions	**11.Household**									110080	117537					227617
	12.Goverm	48	27032	11459	7							24665				63210
	13.S-I											105580	27894		-22293	111181
	14.ROW					2150	65864	5828	0							73843
	Total	48840	577337	192189	611	50990	643202	198017	611	110080	117537	227617	63210	111181	73843	

Information on emissions comes from the *Annual Statistical Report on Environment in China 2007* (MEP, 2008) and *the First National Pollution Census* (MEP, NBS and MOA, 2010). To be consistent with the classifications of abatement sectors, the emission accounts are comprised of an individual account each for COD and for NH3-N, and an aggregate account for the other pollutants (OHP) which include oils, volatile phenol, cyanogens, mercury, cadmium, hexavalent chromium, lead, and arsenic. These pollutants are merged into an aggregate emission account by calculating their pollution equivalents (PEs) based on the different damage levels caused to the environment. PE values for each pollutant are shown in Table 5.4, calculated based on the *Effluent Fee Charge Standards and Accounting Method* which was released in 2003. Sectoral and consumption emissions for COD, NH3-N and other pollutants to water for the year 2007 are shown in Table 5.5. The initial price of emission permits comes from the *Effluent Fee Charge Standards and Accounting Method* released by the Chinese government. The initial pollution permit expenditures are 0.7 CNY/kg for COD, 0.875 CNY/kg for NH3-N and 0.7 CNY/kg pollution-equivalents for other pollutants, respectively.

Table 5.4 Equivalences of pollutants included in the OHP emission accounts

1kg Pollutants =	Pollution Equivalents (kg)
Oils	10
Volatile Phenol	12.5
Cyanogens	20
Mercury	2000
Cadmium	20
Hexavalent Chromium	50
Lead	40
Arsenic	50

Table 5.5 Sectoral and consumption emissions for COD, NH3-N and other pollutants to water for China, 2007 (unit: million kg)

No.	Sectors	COD	NH3-N	OHP (PEs)
Y01	Agriculture	13240.90	1134.00	0.00
Y02	Coal mining and processing	92.14	3.71	6.57
Y03	Petroleum & gas extraction	24.10	1.65	11.12
Y04	Metal ore mining	65.49	1.52	16.27
Y05	Non-ferrous mineral mining	11.76	0.30	0.19
Y06	Food and tobacco processing	1048.85	43.58	20.20
Y07	Textile apparel	389.05	18.38	2.99
Y08	Clothing products	100.24	10.09	0.70
Y09	Sawmills and furniture	22.94	0.94	0.37
Y10	Paper and printing industry	1778.96	33.35	4.84
Y11	Petroleum refineries	92.66	11.59	54.95
Y12	Chemical industry	800.51	157.70	43.88
Y13	Nonmetallic mineral products	50.79	3.00	2.30
Y14	Metal smelting and pressing	186.60	19.57	43.97
Y15	Metal products	31.63	1.21	3.47
Y16	Industrial machinery	28.00	2.56	7.37
Y17	Transport equipment	30.42	1.86	7.07
Y18	Electric equipment	11.97	0.58	1.89
Y19	Electronic & telecom equipment	30.00	2.33	1.36
Y20	Instruments & office equipment	7.56	0.42	0.51
Y21	Artwork & other manufacturing	6.11	0.30	0.10
Y22	Scrap and waste	2.31	0.04	0.01
Y23	Electricity	68.43	2.00	5.80
Y24	Gas production and supply	17.34	3.65	4.27
Y25	Water production and supply	17.31	0.87	0.20
Y26	Construction	195.47	19.64	1.59
Y27	Service industry	2344.29	264.63	0.00
	Private households	6363.71	718.37	0.00

5.3.2 Calibration of the model

The parameter values are crucial in determining the results of the various policy simulations. Ideally, all the parameters in the CGE model should be econometrically estimated. However, due to the sophistication of the model and data limitations, it is usually difficult to determine all parameters through the econometric method (Gunning and Keyzer, 1995). Therefore, parameter values are usually determined by a calibration procedure (Mansur and Whalley, 1984).

There are two different types of parameters in the CGE model. One consists of the share parameters, such as consumer and government consumption share, average savings rate, and average tax rate, that can be determined from information provided in the SAM (He et al., 2010). The other type of parameter is the elasticity parameters, such as elasticity of substitution between production factors, Armington elasticity, and CET elasticity, which are all fixed exogenously based on previous studies (Dervis et al., 1982; Zhuang, 1996; Xue, 1998; Zheng and Fan, 1999; He et al., 2002; Wu and Xuan, 2002; Zhai, 2005; Willenbockel, 2006). In this study, the CET elasticity between export and domestic demand equals 4, the Armington elasticity between imported goods and domestic supply equals 2 and CES elasticity between labour and capital lies between 0.1 and 1 for the different production sectors. According to benchmark projections, the Chinese economy is assumed to be on a balanced growth path. Economic activity grows by 8 percent per year, whereas the emissions are determined from a combination between the economic growth rate and the assumed autonomous pollution efficiency improvements, which is estimated based on prediction results reported by CAEP and SIC (2008). The interest rate and depreciation rate are calibrated to 8.7 percent and 4.5 percent respectively. The pollution-abatement substitution (PAS) elasticities are 0.55 for COD, 0.57 for NH3-N, and 0.48 for other pollutants and are assumed to be constant over time, while the existing technical potential to reduce emissions is 0.67 for COD, 0.75 for NH3-N and 0.6 for other pollutants.

5.4 Emission reduction scenarios

In 2007, emission of some pollutants began to decline for the first time and the *First National Pollution Census* (MEP, NBS and MOA, 2010) was also conducted. Thus we take 2007 rather than 2005 as the benchmark year for our simulations. The four scenarios with tradable emission permits system are as follows:

S-20%: 20 percent reduction in emissions needed by the year 2020 with respect to 2007 emission levels, and emission permits can be traded amongst polluters;

S-30%: 30 percent reduction in emissions needed by the year 2020 with respect to 2007 emission levels, and emission permits can be traded amongst polluters;

S-40%: 40 percent reduction in emissions needed by the year 2020 with respect to 2007 emission levels, and emission permits can be traded amongst polluters;

S-50%: 50 percent reduction in emissions needed by the year 2020 with respect to 2007 emission levels, and emission permits can be traded amongst polluters.

To examine the impacts of tradable emission permits, we also construct two other plausible scenarios in which emission permits are not allowed to be traded. The scenarios are as follows:

S-20%N: 20 percent reduction in emissions needed by the year 2020 with respect to 2007 emission levels, and emission permits cannot be traded amongst polluters;

S-30%N: 30 percent reduction in emissions needed by the year 2020 with respect to 2007 emission levels, and emission permits cannot be traded amongst polluters.

In addition, total emission reduction targets are extended to all pollutants in all plausible simulations. The first 10 percent of emission reductions should be achieved before the year 2010 in all scenarios, with the remaining reductions required by 2020. The total emission reduction paths for all six simulations are shown in Figure 5.2.

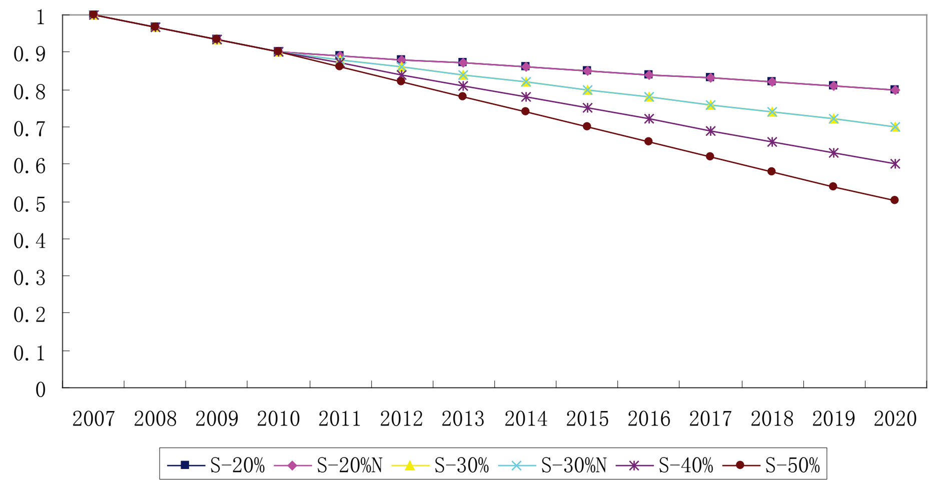

Figure 5.2 Total emission reduction paths in China

5.5 Policy simulations and key findings

5.5.1 Macroeconomic results

Changes in the main macroeconomic variables for each simulation scenario (see Table 5.5) are compared with the benchmark projections. Through analyzing the development of Gross Domestic Product (GDP), Net National Income (NNI) and GDP growth rate over time, we can gain insights into the economic transition paths induced by the total emission reduction policy. The percentage changes in GDP and NNI over time are presented in Figures 5.3 to 5.5. The changes in trend for GDP and NNI are very similar. The results reflect that limited emission reduction targets can be met at limited macroeconomic costs, producing limited GDP and NNI losses for China's economy. The 20 to 30 percent emission reduction targets will lead to an accumulated GDP loss in 2020 of 0.29-1.34 percent, and an NNI loss of 0.32-1.49 percent. The annual GDP growth rate is projected to reach 7.86-7.98 percent in 2020 which is very close to the 8 percent benchmark GDP growth rate. If a total emission reduction of 40 to 50 percent is implemented, the estimates of GDP and NNI loss compared with the benchmark projections are 4.28-8.83 percent and 4.64-9.63 percent respectively in 2020. The GDP growth rate would also be reduced to less than 6 percent in 2020 for a reduction target of 50 percent or greater. These results lead to the important insight that the increase in economic cost as the total emission reduction target increases is faster than linear. On one hand, the producers first select the cheapest options for reducing emissions, and further reductions lead to substantial increases in abatement costs. On the other hand, consumers prefer to keep their original consumption style, which also contributes to raising the cost of economic restructuring. When both the marginal abatement cost and the cost of economic restructuring are higher than the value-added foregone, producers will prefer to reduce their economic activities, resulting in greater GDP and NNI losses. This is especially true if the required emission reduction target is set at a more ambitious level.

The GDP and NNI results also suggest that implementation of tradable emission permits could reduce the macroeconomic costs of a total emission reduction policy. From Figures 5.3 and 5.4 we see that if emission permits are not allowed to be traded amongst producers and consumers, a 20 to 30 percent emission reduction target can lead to a GDP loss of 1.11 to 2.46 percent and an NNI loss of 1.11 to 2.58 percent in 2020, which are both much higher than with the tradable emission permits. This is because different producers have different abatement costs for the same pollutants. Producers who have a low abatement cost can abate more pollutants than required by the reduction proportion, and producers who have a high abatement cost but with higher economic gains can achieve the emission permits at a price that allows them to enlarge their production. In this way, the macroeconomic costs of emission reduction are lower than when all producers reduce their emissions proportionately.

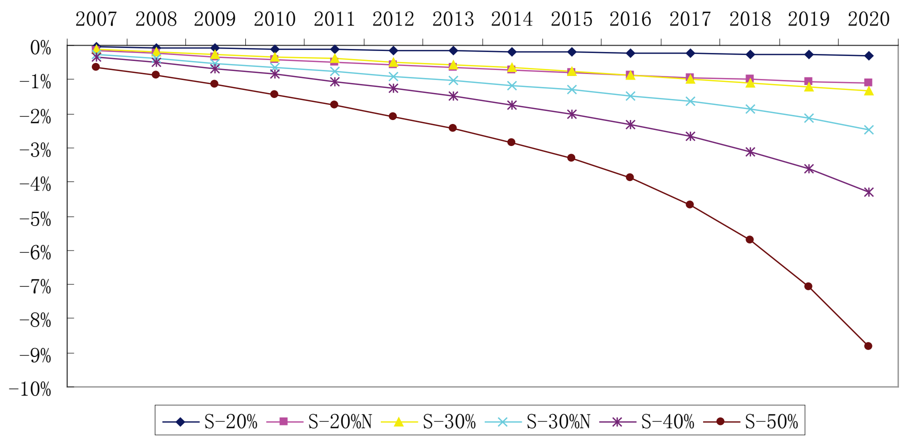

Figure 5.3 Impact of total emission control policy on GDP (%-change compared to benchmark projection)

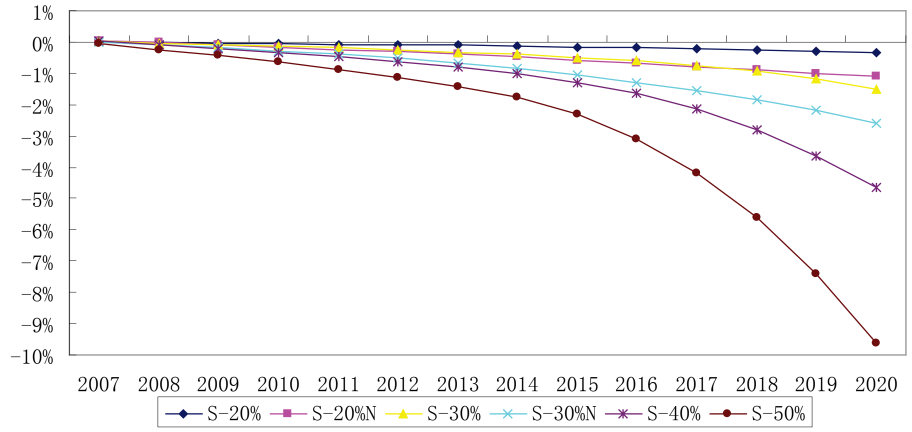

Figure 5.4 Impact of total emission control policy on NNI (%-change compared to benchmark projection)

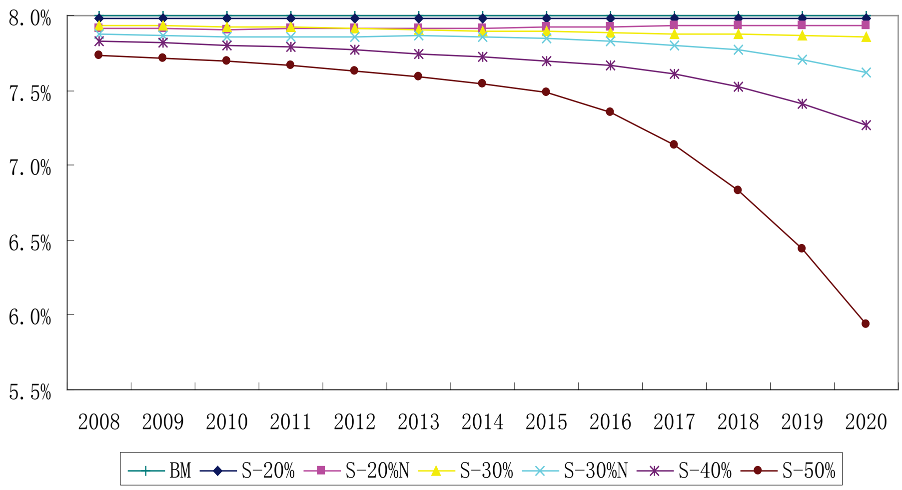

Figure 5.5 Impact of total emission control policy on growth rate

In addition, from Figures 5.3 and 5.4 we note that GDP and NNI changes can already be seen in the first year. This is because the private households are modelled to have perfect foresight in anticipating stricter future environmental policy. Increasing production costs caused by environmental policy will lead to rising commodity and service prices. Consumers also need to increase their expenditure on abatement services for their domestic water use. To reduce their welfare losses, they would spend more on current consumption, the cost being lower consumption levels in later years. Figure 5.6 shows that 20 to 50 percent emission reduction targets can result in a 0.16 to 1.82 percentage increase in consumption levels for private households in the first year, whereas in the year 2020 their consumption levels are 0.58 to 14.35 percent lower than the benchmark projection. The results indicate that private households would increase their consumption substantially in the short term rather than saving if environmental policy becomes stricter, because this has a positive effect on household welfare. However, lower savings will translate into lower investments in the long term (see Figure 5.7). Lower investment levels will in turn lead to a lower rate of economic growth, and consumption, production and income are all well below the long term benchmark projections.

In this study, we use the Hicksian equivalent variation (EV) to analyze the impact of water charges on household welfare. The above analysis indicates that environmental policy lowers consumption levels in the long run and hence results in a downward welfare trend. Emission reduction targets of 20 to 30 percent can lead to a 0.65 to 2.60 percent decrease in welfare, while 40 to 50 percent emission reduction targets can decrease welfare by 7.41 to 15.66 percent. This indicates that the rate at which reductions in household welfare caused by emission reduction targets increase is faster than linear with respect to the stringency of environmental policy. However, we must keep in mind that these welfare losses are only induced by changes in consumption, because the benefits of environmental improvements are not taken into consideration in the household utility function. If emission permits are not permitted to be traded among producers and consumers, 20 to 30 percent emission reduction targets can lead to a reduction of 1.47 to 3.86 percent in purchasing power. This indicates that tradable emission permits not only alleviate the negative impacts on production caused by implementing total emission reduction targets, but also reduce negative impacts on the welfare of private households.

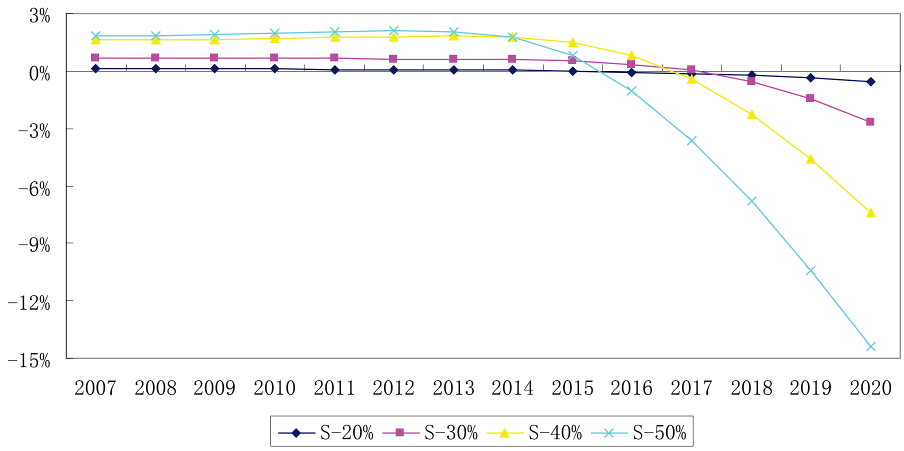

Figure 5.6 Impact of total emission control policy on total consumption of private households (%-change compared to benchmark projection)

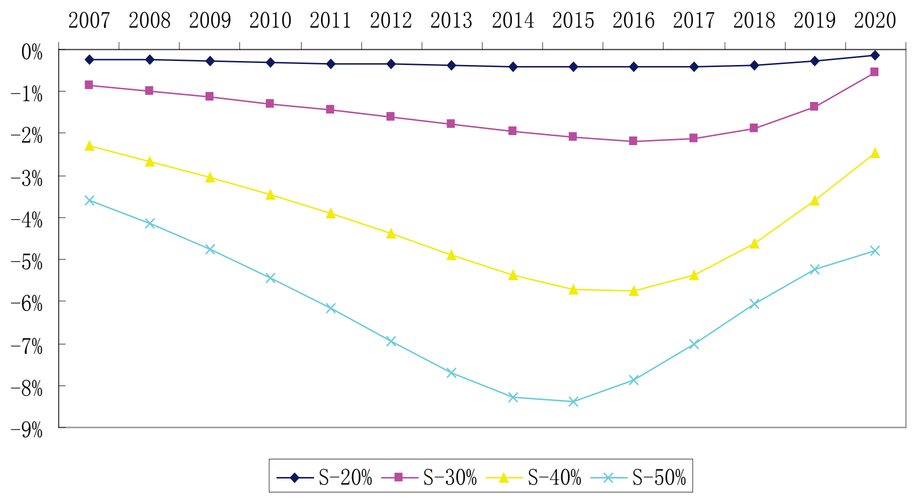

Figure 5.7 Impact of total emission control policy on investment (%-change compared to benchmark projection)

5.5.2 Sectoral results

The multi-sectoral structure of the environmental CGE model used in this study allows a detailed analysis of the impact on different sectors in the economy. Because different sectors have different emission intensities and abatement costs, the implementation of a total emission reduction policy will lead to diverse impacts on production, consumption, and trade in different sectors.

Figure 5.8 shows the impact of total emission reduction targets on sectoral production in 2020. Compared with the benchmark projections, the impact of environmental policy on production differs substantially between sectors. While the implementation of a total emission reduction policy can lead to increases in production costs for all sectors, this does not mean that all production sectors will be negatively affected by the policy. Some production sectors with high emission intensities and abatement costs are severely affected, whereas other sectors that provide relatively clean goods and services can actually benefit from stricter environmental targets. From Figure 5.7, we see that the sectors with substantial reductions in production are agriculture, food and tobacco processing, textile, clothing, sawmills and furniture, paper and printing industry, chemical industry, artwork and other manufacturing sectors.

One of the sectors that should receive more attention is the agriculture sector, which is characterized by relatively large emissions and relatively small contributions to GDP. Agriculture contributed 49 percent of total COD emission and 46 percent of NH3-N emission in 2007. To achieve the emission reduction targets, it is vitally important to reduce the emissions (most of which are non-point source) discharged by the agriculture sector. On the other hand, food security is very important for China due to the size of the population. In addition, the agriculture sector employs many farmers and provides a primary income source for agricultural households. Reductions in agricultural production induced by environmental policy would substantially affect China's food security and lead to welfare losses for agricultural households.

To maintain the stability of agricultural production and reduce the negative impacts on the welfare of agricultural households when implementing stricter environmental policies, the government should provide subsidies for farmers to invest in abatement measures and adopt cleaner production technologies. The increased expenditure can be balanced by the income the government receives from selling emission permits.

Another important point we must keep in mind is that the impact of environmental policy on production sectors can be induced not only directly by high emission intensities and abatement costs, but also indirectly due to increased production costs in related sectors that provide production inputs (Qin et al., 2011b). A major advantage of the multi-sectoral environmental CGE model used in this study is that it helps us capture both direct and indirect effects of implementing a total emission reduction policy. For example, production in the food and tobacco processing, textile and clothing sectors is likely to be indirectly influenced by the agricultural sector, because the main inputs into these three sectors are agricultural products. Implementation of emission reduction targets will substantially increases the production costs in the agricultural sector and lead to increased prices of agricultural products.
At the same time, the environmental policies being discussed create opportunities for other production sectors, such as metal smelting and pressing, metal products, industrial machinery, electric equipment, especially electronic & telecom equipment sector. Stricter total emission

reduction targets increase production values in these sectors, and consequently total emission reduction policies may lead to an important shift in emphasis from dirty sectors to relatively clean sectors. Actually, the implementation of environmental policy can result in a reallocation of resources (labour and capital) and not just an economic decline.

Comparing the results in Figure 5.8, we see that changes in sectoral production levels are much more substantial when emission permits are not allowed to be traded among producers. When tradable emission permit schemes are implemented, sectors with relatively high abatement costs can obtain more emission permits at a proper price, which not only reduces the average abatement costs for all sectors, but also avoids the partial costs of economic restructuring. Therefore, the macroeconomic costs of implementing total emission reduction targets decrease due to adaptation of the tradable emission permits system as shown in the above macroeconomic analysis.

To reduce the negative impacts on welfare, private consumers increase consumption levels initially but reduce their consumption in the long run. Compared with the benchmark projection, private consumption demand in most sectors for 2020 is reduced as shown in Figure 5.9. However, the impacts of consumption caused by the total emission control policy differ across sectors, because environmental policy has different impacts on production costs in different sectors due to their differing emission intensities and abatement costs. As with changes in production structure, sectoral consumption demand also increases with the stringency of environmental policy. Figure 5.9 shows that, in 2020, there is a substantial reduction in demand from private households for products provided by the agriculture, food and tobacco processing, textile, clothing, sawmills and furniture, paper and printing, chemical, artwork and other manufacturing sectors. This is because strict total emission reduction targets raise the prices of these products more than those of other products, and hence it is beneficial for private households to substantially reduce their consumption demand on these sectors. This means that a total emission reduction policy can not only lead to an important shift in production structure, but can also induce a shift in future consumption structure from dirty to relatively clean sectors.

Moreover, as noted above, environmental policy has the greatest impact on consumption demand for agriculture and its related sectors. It can be concluded that this affects the purchasing power of poor households more than that of other households. Therefore, when the total emission reduction target is made stricter, policy makers should pay attention to this effect on poor households and put in place corresponding poverty reduction measures, such as food and clothing subsidies funded by the revenue from emission permit sales.

Based on the Heckscher-Ohlin (HO) theorem (Heckscher, 1919 and Ohlin, 1933) for international trade, the comparative advantage of different countries is dependent on their relative factor endowments. A country usually exports products with a high comparative advantage and imports products with low comparative advantage. A country may have a comparative advantage if it is endowed with certain resources or if it can produce a product with relatively low cost to the environment (Guan and Hubacek, 2007). Because environmental policy has a different impact on production costs for different sectors, there will also be different impacts on the comparative advantage of each sector. Sectors with high emission intensities and abatement costs will see their comparative advantage in international trade reduced and their exports will decline substantially as total emission reduction policy becomes stricter.

However, some sectors that provide relatively clean goods and services can benefit from stricter environmental targets and gain opportunities to increase exports of their products. This is because on one hand, they have relatively low emission intensities or abatement costs; and on the other the implementation of environmental policy can result in a reallocation of resources between sectors. This reallocation affects the comparative advantage of international trade in each sector differently and alters the trade structure.

Figure 5.10 shows that the sectors for which exports in 2020 are substantially lower than the benchmark projections are agriculture, food and tobacco processing, textile, clothing, sawmills and furniture, paper and printing, chemical, artwork and other manufacturing sectors. The major sectors that benefit from the opportunities that environmental policy creates for export are mining, machinery and equipment sectors.

Because the supply of some products declines substantially as a result of environmental policy, imports of these products from other countries will increase to satisfy domestic demand. These sectors include agriculture, food and tobacco processing, paper and printing, electronic and telecom equipment (see Figure 5.11). Most of these sectors have relatively high emission intensities or abatement costs, or are indirectly affected by related sectors. Thus a total emission reduction policy can allow for a shift in trade structure for China's economy and significantly reduce domestic emissions at a relatively small macroeconomic cost.

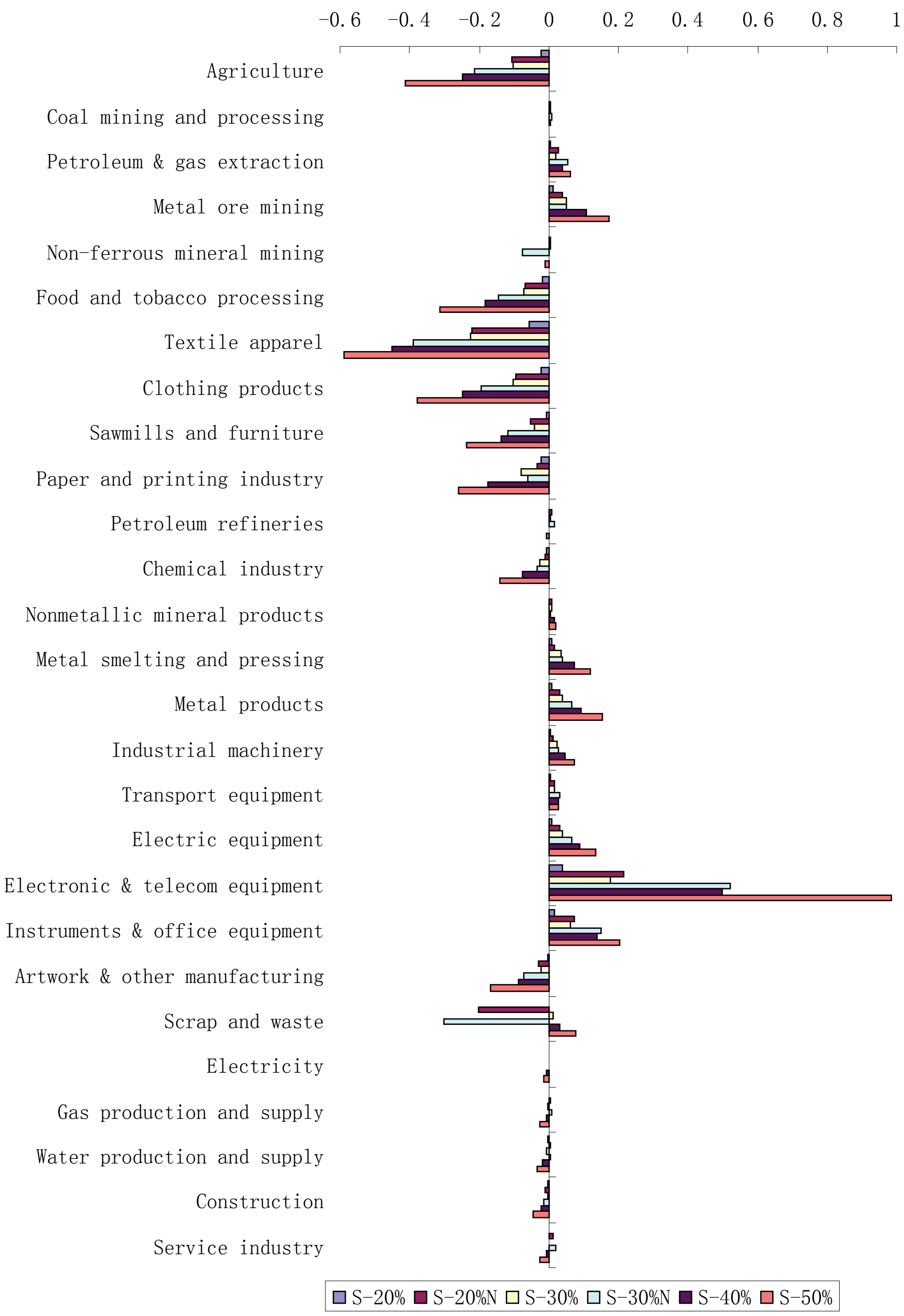

Figure 5.8 Impacts of the total emission control targets on sectoral production in 2020 (%-change compared to benchmark projection)

Figure 5.9 Impacts of the total emission control targets on consumption of private households in 2020 (%-change compared to benchmark projection)

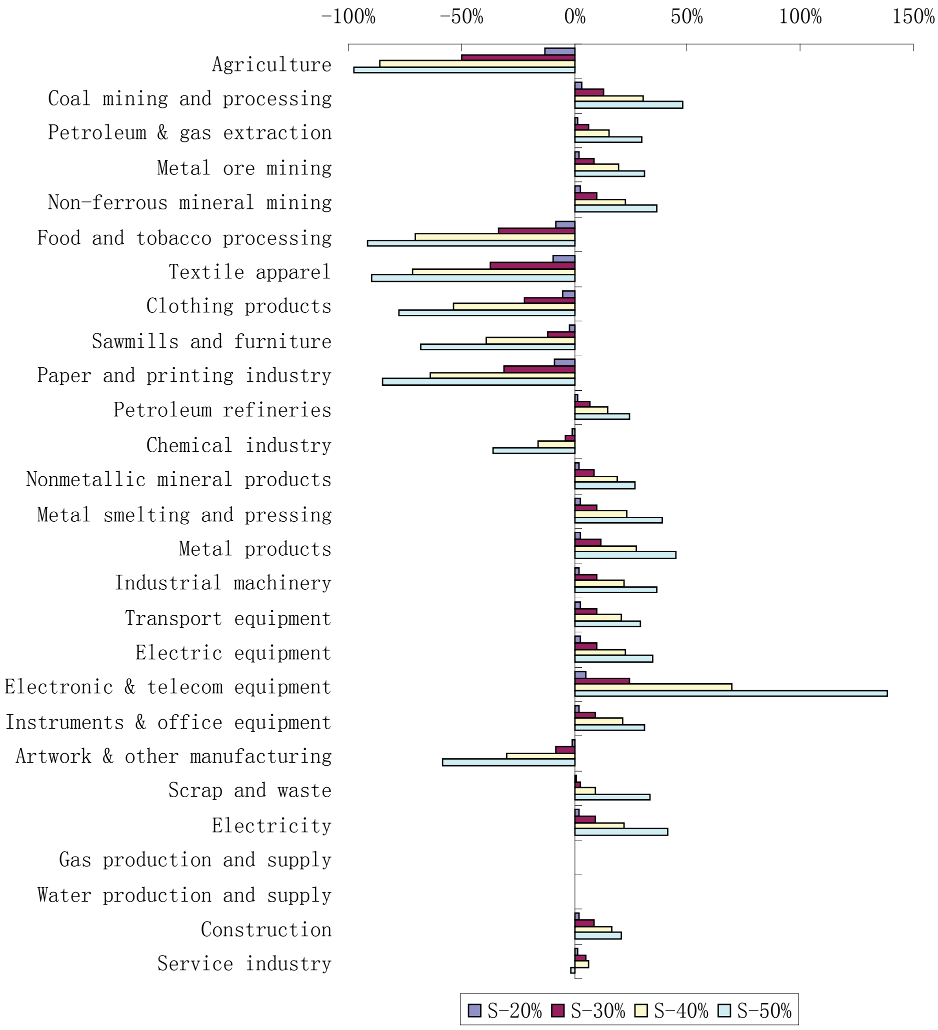

Figure 5.10 Impacts of the total emission control targets on exports in 2020 (%-change compared to benchmark projection)

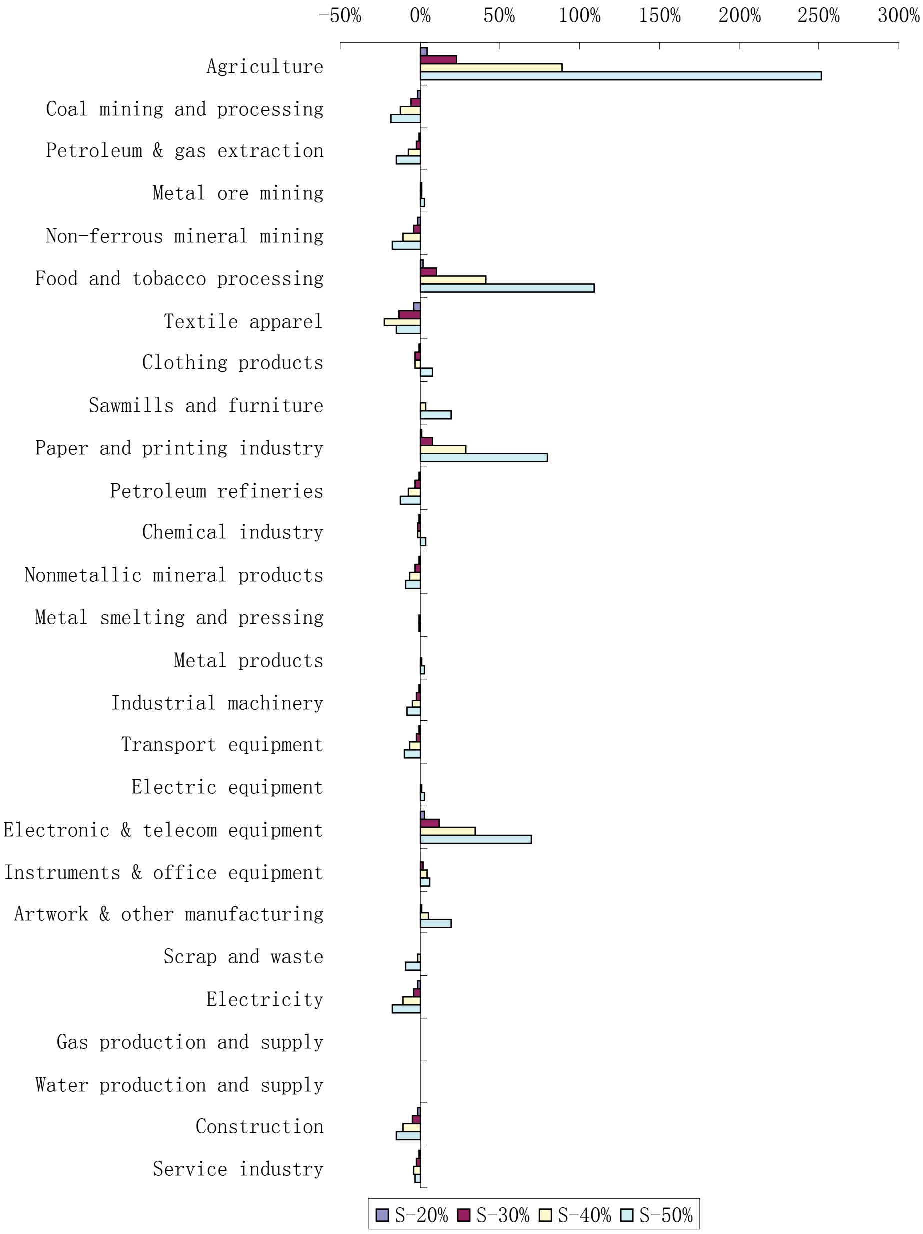

Figure 5.11 Impacts of the total emission control targets on imports in 2020 (%-change compared to benchmark projection)

5.5.3 Abatement and environmental results

The tradable permit prices for emissions in Table 5.6 are given as the price of one kilogram of emissions for COD and NH3-N, and one kilogram of pollution equivalents for other pollutants. The rate of increase of permit prices over time is faster than linear when total emission reduction targets are implemented gradually in China's rapidly growing economy. There is also a greater than linear increase in the price of permits with respect to the stringency of environmental policy.

Table 5.6 Prices of tradable emission permits (CNY/kilogram in constant 2007 prices)

Year	S-20% reductions			S-30% reductions			S-40% reductions			S-50% reductions		
	COD	NH3-N	OHP	COD	NH3-N	OHP	COD	NH3-N	OHP	COD	NH3-N	OHP
2007	0.7	0.875	0.7	0.7	0.875	0.7	0.7	0.875	0.7	0.7	0.875	0.7
2008	1	1.24	0.96	1	1.24	0.96	1.01	1.24	0.96	1.01	1.24	0.95
2009	1.47	1.79	1.34	1.48	1.8	1.33	1.48	1.81	1.32	1.49	1.81	1.31
2010	2.24	2.68	1.88	2.25	2.69	1.87	2.27	2.71	1.84	2.29	2.73	1.81
2011	2.88	3.45	2.34	3.17	3.75	2.45	3.53	4.13	2.54	3.95	4.55	2.64
2012	3.74	4.49	2.92	4.57	5.36	3.24	5.78	6.57	3.54	7.45	8.17	3.91
2013	4.89	5.89	3.65	6.8	7.87	4.3	10.1	11.1	5.01	16	16.2	5.91
2014	6.48	7.83	4.56	10.5	11.9	5.74	19.3	20	7.17	39.9	36	9.19
2015	8.69	10.5	5.72	16.9	18.9	7.71	40.4	39.1	10.4	105	83	14.7
2016	11.8	14.4	7.18	28.6	31.2	10.4	88.3	79.4	15.4	239	178	24.5
2017	16.3	20.1	9.03	50.4	53.7	14.3	181	157	23.3	458	357	43.2
2018	22.9	28.4	11.4	90.3	95.2	19.6	328	298	36.2	774	704	83
2019	32.6	41.2	14.4	157	169	27.3	538	554	58.4	1197	1422	186
2020	47.1	60.9	18.3	257	295	38.6	812	1035	99.4	1712	3043	570

When emission permits become more expensive the demand for abatement efforts increases, calling for higher environmental expenditure. As a result abatement sectors will benefit from strict environmental policy and will develop rapidly. Figure 5.12 shows the development of abatement services over time assuming a 30 percent reduction in total emissions for each pollutant. Under this reduction target, the demand for abatement services would increase 8.4 times for COD, 6.0 times for NH3-N and 3.0 times for other pollutants (OHP) by 2020, whereas in the same period total output only increases by a factor of 2.7. As environmental targets become stricter, both environmental expenditure and marginal abatement costs will increase until a new equilibrium is achieved when marginal abatement costs are equal to the price of environmental permits (Dellink et al., 2003).

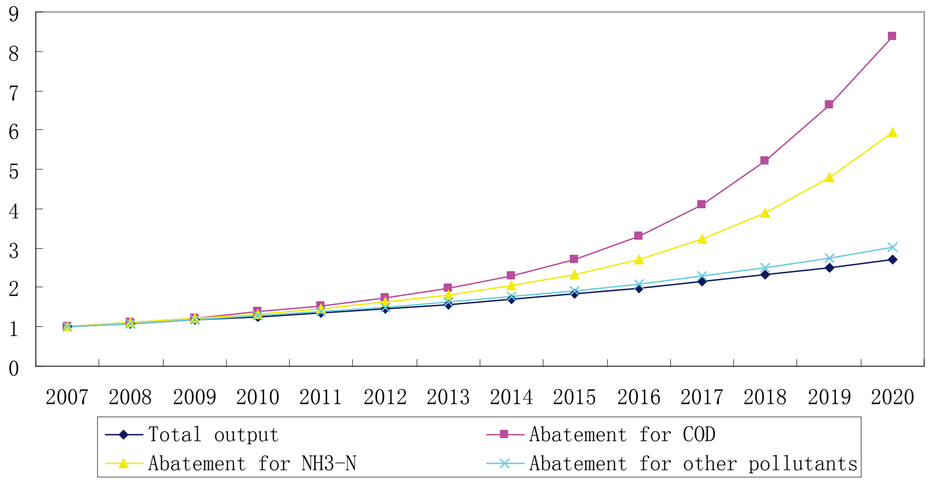

Figure 5.12 Development of abatement services over time with a 30 percent reduction of total emission permits (Benchmark index = 1)

Due to diversity in pollution intensities and marginal abatement costs, polluters choose the cheapest option between buying more emission permits and demanding more abatement services. A key advantage of the extended model in this study is that the multi-sectoral abatement structure allows us to capture more detailed changes in abatement service demand for specific pollutants. Table 5.7 shows the changes in demand for abatement services by production sectors and changes in emissions from different production sectors in 2020 when a 30 percent reduction target is implemented. The results show significant differences in the rate of increase of demand for abatement services across the sectors for different pollutants.

In sectors with relatively high emission intensity or marginal abatement cost for one pollutant, demand for abatement services for that pollutant will increase more than in other sectors. If emission permits are not allowed to be traded, the polluters will have to either reduce their emission levels via abatement measures or reduce their production levels. If tradable emission permit schemes are implemented, sectors with high emission-intensity or marginal abatement cost for one pollutant can buy more emission permits for that pollutant to reduce their expenditure for abatement services. This has a positive impact on their production level, avoiding the macroeconomic cost caused by non-tradable permits.

Since both marginal abatement costs and the prices of tradable permits increase at a faster than linear rate, sectors with high emission intensity or marginal abatement cost will reduce their emission levels by reducing their production level. However, production levels in some sectors with lower emission intensities and marginal abatement costs will also be substantially reduced by the environmental policy. For example, the textile sector has both low emission intensity and low marginal abatement costs, but production is substantially reduced (see Figure 5.8) when strict emission reduction targets are implemented. The reason for this is that agricultural products are the main production inputs for the textile industry, and so the effects of the environmental policy on the agriculture sector indirectly impact production levels in the textile sector.

Table 5.7 Changes in demand for abatement services and sectoral emissions in 2020 with a 30 percent of emission reduction in China (benchmark index = 1)

Sectors	Abatement services				Emissions		
	COD	NH3-N	OHP	Total	COD	NH3-N	OHP
Agriculture	**16**	**16.7**	**N/A**	**16.1**	**0.83**	**0.82**	**N/A**
Coal mining and processing	5.2	6.6	3.3	5.1	0.5	0.49	0.71
Petroleum & gas extraction	4.2	4.4	3	3.2	0.47	0.41	0.68
Metal ore mining	4.4	14.2	3.2	3.9	0.49	0.77	0.71
Non-ferrous mineral mining	5	15.8	2.9	4.7	0.5	0.81	0.68
Food and tobacco processing	7.4	3.6	4.4	6.3	0.55	0.36	0.78
Textile apparel	4.5	2.7	2.3	3.8	0.41	0.29	0.52
Clothing products	5	5	2.6	4.7	0.46	0.4	0.6
Sawmills and furniture	7.6	8.7	2.9	7	0.57	0.55	0.65
Paper and printing industry	8.1	5.7	2.8	7.8	0.57	0.43	0.63
Petroleum refineries	6.5	3.4	3	3.5	0.54	0.37	0.68
Chemical industry	6.2	4.7	2.9	4.9	0.53	0.41	0.66
Nonmetallic mineral products	5.5	4.6	3	4.7	0.51	0.42	0.68
Metal smelting and pressing	7.3	3.6	3	3.5	0.58	0.39	0.69
Metal products	6.6	6.7	3	3.3	0.56	0.5	0.7
Industrial machinery	5.9	6.8	3.2	4.8	0.53	0.5	0.71
Transport equipment	5	4.2	3.1	4.1	0.5	0.4	0.69
Electric equipment	4.3	4.2	3.1	4	0.49	0.41	0.71
Electronic & telecom equipment	4.2	4.5	3.4	3.9	0.53	0.45	0.79
Instruments & office equipment	4.3	3.3	3.1	3.6	0.49	0.38	0.71
Artwork & other manufacturing	7.9	10	2.8	4.7	0.58	0.6	0.65
Scrap and waste	7.3	N/A	2.9	5.2	0.57	N/A	0.68
Electricity	3.9	4	3.1	3.8	0.46	0.39	0.69
Gas production and supply	11.1	7.3	3.5	7	0.69	0.51	0.72
Water production and supply	6.7	3.9	2.9	5	0.55	0.39	0.67
Construction	12.4	9.3	2.9	8.6	0.74	0.58	0.67
Average of industry	**6.2**	**4**	**3**	**4.7**	**0.55**	**0.41**	**0.7**
Service industry	**10.9**	**12.6**	**N/A**	**11**	**0.69**	**0.7**	**N/A**
Private households	**9.9**	**11.5**	**N/A**	**10**	**0.65**	**0.65**	**N/A**
Total	**8.4**	**6**	**3**	**6.6**	**0.7**	**0.7**	**0.7**

5.5.4 Sensitivity analysis

In order to investigate the robustness of the model, we do a brief sensitivity analysis on the crucial parameters which are directly related to the newly introduced pollution/abatement mechanism. Table 5.8 presents the results for the base specification and for the alternative values of the PAS-elasticity, technical potential and APEI for the 30% reduction scenarios.

As a key parameter in the model, the PAS-elasticity is increased or decreased with 0.05 for one pollutant a time. The results of sensitivity analysis indicate that the higher the PAS-elasticity, the lower the GDP losses and EV losses. This is because the higher elasticity implies the better substitution possibilities between buying emission permits and adopting abatement measures. The PAS-elasticity for COD shows the largest impact on GDP and EV. But for other pollutants, the elasticity has a very minor impact on the economic costs of total emission control policy.

In the sensitivity analysis, the technical potential for emission reduction is increased and decreased with 0.05 for one pollutant at a time. Compared with other parameters, changes in technical potential have a relative smaller impact on the results. The results of sensitivity analysis indicate that a higher technical potential will reduce the economic costs of emission reduction policy. The largest impact on GDP and EV is also caused by the technical potential change for COD.

Another key parameter of the model is autonomous pollution efficiency improvements. Therefore, APEI is increased or decreased with 0.003 for one pollutant at a time in the sensitivity analysis. The results of sensitivity analysis indicate that changes in APEI values for COD influence GDP and EV substantially. Increasing the autonomous pollution efficiency improvements of COD will substantially reduce the costs of environmental policy and COD is the dominant pollutant for the total emission control policy.

Table 5.8 GDP and EV losses in the 30% reduction scenario for alternative values of main parameters

	GDP losses in 2020				EV losses			
Parameter change	Base	COD	NH3N	OHP	Base	COD	NH3N	OHP
PAS elas.+0.05	-1.34	-1.14	-1.31	-1.34	-2.60	-2.32	-2.55	-2.59
PAS elas.-0.05	-1.34	-1.58	-1.43	-1.34	-2.60	-2.93	-2.81	-2.60
Tech. potential +0.05	-1.34	-1.23	-1.33	-1.34	-2.60	-2.39	-2.57	-2.59
Tech. potential -0.05	-1.34	-1.46	-1.36	-1.34	-2.60	-2.84	-2.64	-2.60
APEI +0.003	-1.34	-0.92	-1.31	-1.34	-2.60	-1.96	-2.54	-2.59
APEI -0.003	-1.34	-1.92	-1.43	-1.34	-2.60	-3.48	-2.83	-2.60

5.6 Conclusion and remarks

Economic success in China has come at the expense of over exploitation of natural resources and has had huge impacts on the environment and water resources especially. To mitigate water pollution and reduce environmental damage, the government has begun to implement a total emission control policy by distributing a restricted number of emission permits to polluters. This study examines the effectiveness of total emission control policy in China and assesses the economic impacts of implementing 20 to 50 percent total emission reduction targets by 2020 through an extended environmental dynamic computable general equilibrium (CGE) model. We calibrate the model by constructing an environmentally extended social accounting matrix (ESAM) for China economy in 2007 and use this model to investigate the dynamic relationships between production, consumption, abatement and pollution. Moreover, we study a multi-abatement-sector extension to the model which captures more detailed dynamic interactions between the costs of abatement and the price of emission permits.

We simulate the economic consequences for different emission reduction scenarios, ranging from 20 percent to 50 percent emission reduction by 2020 with respect to emission levels in 2007. Because marginal abatement costs for small amounts of emission reduction are relatively cheap, a modest emission reduction target can almost be achieved with low macroeconomic cost through the implementation of technical measures and economic restructuring. As the stringency of the environmental policy increases, the macroeconomic impacts increase at an increasing rate, and therefore setting the policy target at a more ambitious level would result in huge macroeconomic losses.

However, emission reduction can improve water quality, providing more safe water. This has a positive effect on welfare, but welfare gains caused by improvements in environmental quality are not included in the welfare function used in our CGE framework. Once the benefits of clean, safe water are taken into account, the economic costs of a stringent environmental policy might be very worthwhile and actually contribute to the overall welfare of the Chinese people. With continual technical improvements, we conclude that in the future emission abatement will be possible at a lower macroeconomic cost. Therefore, policy makers need to balance the considerations of macroeconomic costs and environmental benefits when setting environmental policy targets.

Stringent environmental policy can lead to an important shift in production, consumption, and trade patterns from dirty sectors to cleaner sectors, because the implementation of environmental policy can result in a reallocation of resources in China’s economy rather than just a decrease in economic growth. Production levels in some sectors with low emission intensities or abatement costs will decrease, whereas others may benefit from the implementation of total emission reduction policy and increase their production.

To alleviate negative impacts on welfare, private households will need to reduce consumption of products from sectors with high emission intensity or abatement costs rather than from cleaner sectors. The reallocation of resources induced by policy targets has a different effect on the comparative advantage of international trade for different sectors. Sectors that provide clean goods and services benefit from stricter environmental targets and gain opportunities to increase exports of their products, while reductions in the production levels from other sectors will lead to increased imports to satisfy domestic demand.

Results from our simulations indicate that, with a total emission reduction policy in China, tradable emission permits can reduce macroeconomic cost and negative impacts on welfare through reducing the average cost of abatement services. Therefore, local governments should be encouraged to permit the trading of emission permits, and a tradable emission permit system for more pollutants should be developed throughout the country.

Chapter 6. Main findings, policy implications and research issues

6.1 General summary

The main objective of the study is to develop an environmental input-output model and environmental computable general models, and apply them to investigate the inter-relationships between environment and economy, and assess the economy-wide effects of water management and pollution control strategies/mechanisms for mitigating China's water scarcities and pollutions. This study should be viewed as a research contribution to the efforts to address the issue of natural resource degradation and environmental pollution generated by both climate change and human activities.

In the general introduction the study makes an overview of the problems of water scarcity and pollution in China, the threats and challenges posed by these problems and the main water management and pollution control strategies adopted by Chinese government to mitigate water scarcity and pollution. Such water and environmental policies could not only lead to environmental benefits, but also impact economic growth, household welfare and income distribution. Based on different problems and corresponding mitigation measures, several different environmental economic models are developed to investigate the inter-relationship between environment and economy and analyze the impacts of each different measure/policy on the economic, social and environmental variables.

In chapter two, the study developed a hybrid input-output accounting and modelling framework to investigate the inter-relationship between economy and water consumption/pollution in the Haihe River Basin. First, based on Leontief's input-output technology, two coefficients (total water consumption intensity and total wastewater discharge intensity) are quantified, which not only include direct water consumption and pollution in the process of production, but also include indirect water consumption and pollution due to purchasing goods and services from other sectors as their production inputs. Second, virtual freshwater and wastewater footprints are calculated using input-output techniques, which can help us track water consumption and wastewater discharge indirectly generated due to consumption and trade of goods and services. Third, backward and forward linkage indices are developed based on the input-output model. These two indices can help us determine the key sectors with the highest impacts on water consumption and wastewater discharge in the Haihe River Basin.

In chapter three, an econometric-driven, multi-regional, multi-sectoral computable general equilibrium model is developed with water as an explicit factor of production. The study adopts the marginal value of water to represent the equilibrium price of water. An econometric model is used to estimate the marginal value of water. The study uses the computed marginal value of water and the amount of water use to estimate the total return of water in the economy (total economic value of water) and then the economic account of water is extracted from the corresponding factor endowment accounts. The gravity model of trade is used to estimate the regional trade across Beijing, Tianjin and Hebei. The study also estimates the elasticity across production factors in the CES production function through an econometric analysis. In the study, the model is used to analyse the effectiveness of measures and policies for mitigating North China's water scarcity issues through three different scenario groups – reducing over-exploitation of groundwater, constructing a South to North Water Transfer project and reallocating water from low-value sectors to relatively high-value sectors.

In chapter four, the study presents a comparative-static computable general equilibrium model of the Chinese economy with water as an explicit factor of production. At first, the study develops a social accounting matrix for the Chinese economy in 2007. Based on the average sale price of water, sectoral expenditures for water are estimated and then extracted from the traditional social accounting matrix. Then, a with the factor water extended computable general equilibrium model is formulated, which captures the information of the sectoral water price as well as the amount of sectoral water use with each physical unit. So the model is suitable to analyse the impacts of water price policy. In the study, this model is used to assess the broad economic impact of a policy based on water demand management mechanisms, using water resource fee charges as a policy tool.

In chapter five, the study extends a dynamic environmental computable general equilibrium model through disaggregating the abatement sector into a multi-abatement-sector structure to provide pollution abatement services for each different pollutant. In the modelling framework, emission permits are controlled by the government, who sets the total emission reduction targets exogenously by issuing a restricted number of emission permits. Producers and households have the endogenous choice between paying for their emissions and investing in pollution abatement, and will always strive for an optimal combination with the least cost. Based on the environmental accounts of NAMEA and the abatement activity accounting of Xie's EESAM framework, the study also presents an environmentally extended social accounting matrix (ESAM) for China's economy in 2007, which serves as a consistent dataset for calibrating the model. In the study, the model is used to assess the economic consequences of implementing the total emission control strategy and establishing emission permit trading mechanism through simulating different emission reduction scenarios ranging from 20 to 50 percent emission reduction up to the year 2020 with respect to emission levels in 2007.

6.2 Research findings and policy recommendations

It was found that the input-output technique is useful to analyze the inter-relationships between economy, resources and environment, because it can capture the interrelations and interdependencies among production, consumption, trade, resource use and environmental pollution through linking input-output tables with resource and environmental accounts. Results indicated that agriculture is the highest water consumer and polluter with high rates of water consumption and pollution, though only showing low rates of indirect water consumption and pollution. On the other hand some industrial and service sectors show low rates of direct consumption and pollution and high rates of indirect water consumption and pollution. It means that if policy-makers intend to reduce water consumption and pollution through economic restructuring, they need not only consider direct water consumption and pollution in the process of production, but also need consider indirect water consumption and pollution due to purchasing goods and services from other sectors as their production inputs.

Assessment results of backward and forward linkage indices indicated that agriculture, electricity, and water production and supply are key sectors for water consumption, while agriculture, paper & printing, petroleum & nuclear fuel processing, electricity, as well as water production and supply are key sectors for wastewater discharge in the Haihe River Basin. These outcomes mean that the expansion of the final demand in these sectors can lead to a great increase in water demand and pollution for the whole regional economy, and that the expansion of the final demand in the whole regional economy can result in a great increase in water demand and pollution in these sectors. Considering the limited water availability and severe environmental pollution, it is recommended to reduce proportions of these sectors' final demand or improve the efficiencies of water consumption and pollution in these sectors.

Using the input-output technique, results of virtual freshwater and wastewater indicated that the Haihe River Basin is exporting relatively more water-intensive and pollution-intensive products and services than it imports. This means that due to in this respect unreasonable trade patterns a great amount of local water resources are consumed and a lot of wastewater is also discharged into the local water-body. Based on the Heckscher-Ohlin (HO) theorem (Heckscher, 1919 and Ohlin, 1933) for international trade, a country or a region should export more products and services based on their relatively well available factor endowments as production inputs, while satisfy their final demand on products and services with their limited factor endowments as inputs. Considering limited water availability and severe water pollution, it is therefore recommended for policy-makers to readjust the trade structure and produce more products with low water consumption and pollution intensities.

A simple scenario analysis in chapter two (assuming a 20% increase in the final demand of the food & tobacco processing sector) indicated that the input-output model can demonstrate how the level of resources consumption and pollution will adapt to the changes in production, final demand and trade patterns. However, it usually overestimates the impact of such changes, due to the limitations of input-output techniques, such as their lack of market mechanisms stimulating optimization processes, their fixed coefficients that impose fixed relative prices, and their poor substitution possibilities among inputs. Prices, mobility of factors and substitution between inputs have a strong impact on the level of production, consumption and trade, etc. It is important to explicitly incorporate these mechanisms into the environmental economical modelling framework in order to portray a real economy. That is why the CGE model with extensions of resource and environmental constraints was developed to overcome this shortcoming in the following chapters.

Through the Cobb-Douglas production function approach, an important research finding is that marginal values of water vary with both region and sector. Compared with industrial and service sectors, the agriculture sector has the highest output elasticity for water input, but its water use has the least marginal value. These findings generally suggest that water use in the agriculture sector has the least marginal contribution to the whole economy, but water as an input is relatively more important for agricultural production than other sectors. Water use in Beijing has the highest marginal value in the entire economy, because the service sector in Beijing contributes to value-added in a greater proportion than those in Tianjin and Hebei. These results indicate that the marginal values of water vary from one sector to the other and from one region to the other. These variations have the important policy implications that water can be considered to be reallocated from low-value sectors to high-value sectors to improve water use efficiency, but some negative impacts must also be considered, especially on agricultural production and rural residential income.

In North China, extreme water shortages have led to over-exploitation of groundwater and severe threats on environment. If this situation is not reversed and the security of water supply guaranteed, it would severely threat sustainable development of economy, social and environment. Experimental results of the scenario group for reducing groundwater exploitation show that reduction in the water supply level has a severe negative impact on the economy and household welfare. These finding means that once groundwater is exhausted, the water supply crisis will result in huge GDP, welfare, and environmental losses. Thus, the Chinese government should adopt effective measures to mitigate North China’s water scarcities.

To mitigate a severe water crisis in North China, several large-scale projects have been proposed. Some have already been launched. The east and middle routes of the South to North Water Transfer project will play important roles in supplying freshwater for the region, although the project inevitably has some negative impacts, especially on the region from which water is transferred. Considering the extremely uneven distribution of population, economy, land and water resources, it is however in the author's vision necessary to construct the project. Experimental results of the scenario group for the South-to-North Water Transfer project indicate that construction of the project has a positive impact on economic development, household welfare, and environmental sustainability of North China. However, it is also recommended to adopt corresponding measures to alleviate the negative impacts of the project. Actually, the Chinese government has already taken some measures to solve the problems, i.e., providing compensation for donor provinces through transfer payments.

However, due to complex technical, economic, social, and environmental issues, such solutions to rising water demands *via* supply-side mechanisms would gradually become less viable due to resource constraints and increasing marginal costs of such engineering solutions. Therefore, demand-side management policies have already been considered by Chinese government to solve the water problems facing China. Experimental results of the scenario group for reallocating water from agriculture to the industrial and service sectors indicate that transferring water from low-value sectors to high-value sectors can result in a positive impact on the macro-economy and household welfare, and promote economic restructuring from low water efficiency sectors to relatively high water efficiency sectors. It is therefore suggested that reallocation of water should be based on the marginal value of water. However, this would inevitably impact agricultural production and utilities of fragile rural residents who mainly receive their income from the sale of agricultural products. To avoid these negative impacts, the government is recommended to provide subsidies to them to invest in water saving technologies.

Another important water demand policy in China is to reform the water price formulation mechanism. Now according to China's Water Law, local governments are increasing water prices and water resource fees. Scenario analysis of charging water resource fees indicates that imposing water resource fee can redistribute sectoral water use, and lead to shifts in production, consumption, value-added gains, and trade patterns. Sectors not imposing water levies are nonetheless affected by the introduction of water resource fee from other sectors. Specifically for China, water resource fees imposed on the agricultural sector drives most of the effects on sectoral water reallocation, shifts in production, consumption and trade patterns as well as welfare changes. However, the charge of water resource fee would increase the cost of production, which would lead to adverse effects on economic growth and household welfare. To mitigate the negative effects of water taxes, it is recommended to pay more attention to revenues collected from water taxes that can lower the economic cost of the environmental tax, i.e., subsidy schemes and the lowering of other taxes, etc.

To mitigate the impact of water pollution, a series of pollution control policies have been also adopted in China. Controlling the total amount of emissions is the most important environmental policy to alleviate the water pollution crisis facing in China. The results indicate that a modest total emission reduction target in 2020 can be achieved at a low macroeconomic cost. With the stringency of policy targets, macroeconomic cost (e.g., GDP loss, NNI loss and welfare loss) will increase more than linear. Another important finding is that stringent environmental policy can lead to an important shift in production, consumption, and trade patterns from dirty to relatively clean sectors. Some sectors can benefit from their relatively low marginal abatement cost and the reallocation of resource endowments caused by the policy. It is suggested that policy-makers should make a balanced consideration between macroeconomic costs and environmental benefits when setting the environmental policy target. A relatively high emission reduction target should be gradually achieved because with technical improvements and gradual optimism of economic structure, it is empirically concluded that due do technological improvements more emissions can be abated at a relatively low macroeconomic cost in the future.

In order to reduce the macroeconomic cost of total emission control policy, some local governments attempt to adopt tradable emission permit systems to trade emission rights. Simulation results show that macroeconomic cost can be reduced via the trading of emission permits. So emission permit trading experiments taken by local governments should be further encouraged. It is highly recommended to take efforts to establish emission permit trading mechanisms at the national level.

Alterations in the current water management and pollution control strategies may have consequences for agricultural output and lead to rural households' welfare losses. Agriculture is characterized by relatively large water consumption and emission of pollutants, while it provides a relatively small contribution to GDP. Food security is on the other hand very important for China due to the size of the population. The agricultural sector also employs many farmers and provides a primary income source for agricultural households. It is therefore important to adopt other measures to avoid the shrink of agricultural production and maintain the welfare of the vulnerable population against the possible consequences of water and environmental policies, i.e., providing subsidies for farmers to invest in water-saving equipment and technologies, abatement measures and adopt cleaner production technologies.

6.3 Some limitations and future research prospects

The discussion in this thesis shows that some research topics still remain to be investigated and there are several recommendations for future research that aim at improving the knowledge and understanding of the inter-relations among economy, society, resource use and environmental protection in China.

In this thesis, the CGE models are used to evaluate the socio-economic effects of a series of water management and pollution control measures. The incorporation of water use account, pollution abatement sector and emission account have provided useful insights in the modelling of computable general equilibrium for resource and environmental issues. However, it is usually difficult to account expenditures of producers and consumers for water use, abatement services and emission permits due to the lack of data. Therefore, integrated economic, resource use and environmental accounting should receive more attention in the future.

The CGE models used in chapter three and four are comparative-static in nature, which cannot allow it to account for accumulation effects over time. On one hand, long run impacts may be largely different from short run effects. On the other hand, such measures and policies cannot be realized overnight. It is therefore necessary to develop a dynamic CGE model to investigate long run effects and capture accumulation impacts of these policies.

In chapters four and five, the regional differences cannot be captured adequately by a single country model. China is a big country and has huge regional differences in economic structure, water availability and environmental endowments. Modelling the Chinese economy as a whole would overestimate or underestimate the impacts of these policies on different regions. Therefore, in the future study the regional disaggregation should be incorporated into the modelling framework to make more detailed investigations on the impacts of these policies.

Implementation of water management and pollution control measures would result in changes of water consumption and pollution emission, which would have positive or negative ecological and environment effects. These ecological and environmental effects would inevitably lead to benefits or losses for the production and households' utilities. However, the CGE models in this thesis cannot capture these effects because it is difficult to estimate these benefits or losses. In future studies, how to incorporate these benefits or losses into the production function and utility function should become an important research direction for integrated environmental and economic modelling.

China is a big country with many river basins. Each part of the country has its distinctively climatic, hydrologic, agronomic, ecological and socio-economic characteristics. Therefore, water management and pollution control strategies should not only reflect these hydrologic characteristics of each basin, but also consider socio-economic characteristics of each region. However, water bodies, watersheds and basins usually are just geographical units, which are usually inconsistent with administrative boundaries of a region (county, province) or a country as a whole. It is difficult to construct basin level SAMs within a short period. Analysis at the administrative boundary may overestimate or underestimate basin level situations. To recommend plausible water management and pollution control policies at the basin level, there is a need to construct basin level social accounting matrices in the country.

Scenario analysis of water management and pollution control measures in this thesis indicates that the implementation of these policies may generate adverse effects on output and household welfare, especially on agricultural output and the vulnerable population. To eliminate these negative impacts and achieve sustainable development of economy, society and environment, several policy recommendations have already been made in the above discussion, i.e., subsidies, lowering other taxation, recycling the tax or permit income, etc. However, these policy recommendations would also result in multiple effects on economic, social and environmental variables. In the future investigations, it is therefore necessary to develop corresponding CGE models to assess the effectiveness of these policies.

This study focuses two main research topics – water scarcities and water pollutions. In China, the Ministry of Water Resources (MWR), as the main institution of water resources management, is responsible for water quantity management, while the Ministry of Environmental Protection (MEP), as the main institution of environmental management, is responsible for water quality management. Due to the institutional fragmentation, many water policies are implemented separately in China. However, decreasing the level of minimum environmental flows has already reduced the assimilation capacity of water bodies. On the other hand, discharge of pollutants has also polluted a great amount of water resources. Due to severe pollution, even southern parts of China with their relatively well-stocked resources face shortages of safe and clean drinking water. Therefore, severe water shortages and pollutions, especially in North China, call for integrated water quantity and quality management. To provide policy recommendations for the integrated water quantity and quality management, it is important for future studies to incorporate water accounts, abatement services, emission permits as well as other mechanisms into an integrated environmental and economic modelling framework to investigate the impacts of different combinations of policies.

Bibliography

Agudelo, J.I., 2001. The Economic Valuation of Water: Principles and Methods. Value of Water Research Report no 5. IHE Delft

Allan, J.A., 1998. Virtual water: a strategic resource. Global solutions to regional deficits. *Ground Water* 36 (4), 545–546.

Allan, J.A., 2002. The Middle East Water Question: Hydropolitics and the Global Economy. Tauris Publishers, London.

Armington, P. A. (1969). A theory of demand for products distinguished by place of production. *IMF Staff Papers*, 16(1), 159–178.

Aronson, J., Blignaut, J., Milton, J., et al., 2006. Natural capital: the limiting factor. *Ecological Engineering*, 28:1–5

Ashton P.J., Seetal A.R., 2002. “Challenges of Water Resources Management in Africa”. In Rebirth of Science in Africa – A shared vision for Life and Environmental Sciences. (Himansu Baijnath and Yashica Singh, ed.): 133-148. Pretoria: Umdaus Press.

Ashton, P. J., Haasbroek, B., 2002. Water demand management and social adaptive capacity: a South African case study. In: Turton A R and Henwood R, eds., Hydropolitics in the Developing World: A Southern African Perspective. African Water Issues Research Unit (AWIRU) and International Water Management Institute (IWMI), 24

Barro, R.J. and Sala-i-Martin X., 1995. Economic growth. New York, McGraw-Hill, Inc.

Bergman, L., 1988. Energy Policy Modelling: A Survey of General Equilibrium Approaches. *Journal of Policy Modelling* 10:377–399.

Bergman, L., Jorgenson, D.W., and Zalai, E., 1990a. General Equilibrium Modelling and Economic Policy Analysis. Basil: Blackwell.

Bergman, L., 1990b. Energy and Environmental Constraints of Growth: A CGE-Modelling Approach. *Journal of Policy Modelling* 12:671–691.

Bergman, L., 1991. General Equilibrium Effects of Environmental Policy: A CGE-Modelling Approach. *Environmental and Resource Economics* 1: 43–61.

Brand, S., 1997. On the appropriate use of location quotients in generating regional input–output tables: a comment. *Regional Studies* 31, 791–794.

Brown, L. and Halweil, B., 1998. China’s Water Shortage Could Shake World Food Security. *World Watch*, No. 7/8 (www.worldwatch.org).

Browning, E.K. and Zupan, M.A., 2006. Microeconomics: Theory and Application. (9e) Willey, Sussex, UK

CAEP (Chinese Academy for Environmental Planning), SIC (State Information Center), 2008. Environmental and economic trends of China 2008-2020: analysis and forecast. Beijing: China Environmental Science Press.

Calzadilla, A., Rehdanz, K., Tol, R., 2010. The economic impact of more sustainable water use in agriculture: a computable general equilibrium analysis. *Journal of Hydrology* 384: 292-305.

Che, H.J., 2007. Investigation Report on the Reuse of Wastewater after Treatment http://hrwp.hwcc.gov.cn/zhuanti_content.asp?NewsId=763

Chen B., Chen G.Q., 2006. Ecological footprint accounting based on energy - a case study of the Chinese society. *Ecological Modelling* 198:101–14.

Chen B., Chen G.Q., Yang Z.F., Jiang M.M., 2007. Ecological footprint accounting for energy and resource in China. *Energy Policy* 35:1599–609.

Chen, X., Zhang, D., and Zhang, E., (2002). The South to North Water Diversions in China: Review and Comments. *Journal of Environmental Planning and Management*, 45(6): 927-932.

Chen, X.K., 2000. Shanxi water resource input–occupancy–output table and its application in Shanxi Province of China. In: Thirteenth International Conference on Input–Output Techniques, Macerata, Italy.

Cobb, C. and Douglas, P., 1928. A theory of production. *American Economic Review*, 18. 139-165.

Conrad, S., Drennen, T., Engi, D., Harris, D., Jeppesen, D., and Thomas, R., (1998). Modelling the Infrastructure Dynamics of China - Water, Agriculture, Energy, and Greenhouse Gases, Sandia Report SAND98-1715, Sandia National Labouratories, Albuquerque, NM.

Cumberland, J.H., 1966. A regional inter-industry model for analysis of development objectives. Papers of the Regional Science Association 17, 65–95.

Daly, H.E., 1968. On economics of a life science. *Journal of Political Economy* 76 (3), 392–406.

Decaluwé, B., Patry, A., Savard, L., 1999. When water is no longer heaven sent: comparative pricing analyzing in a AGE model. Working paper 9908. CRÉFA 99-05. University of Laval.

Dellink, R. and Van Ierland E., 2004. Pollution Abatement in the Netherlands: A Dynamic Applied General Equilibrium Assessment, Nota di Lavoro 74, CCMP –Climate Change Modelling and Policy, Environmental Economics and Natural Resources Group, Wageningen University.

Dellink, R., 2000. Dynamics in an applied general equilibrium model with pollution and abatement, Global Economic Analysis Conference, Melbourne, Australia.

Dellink, R., 2005. Modelling the costs of environmental policy: a dynamic applied general equilibrium assessment, Cheltenham: Edward Elgar.

Dellink, R., Hofkes, M.W., van Ierland, E. and Verbruggen, H., 2003. Dynamic modelling of pollution abatement in a CGE framework. *Economic Modelling*, Volume 21, Issue 6, December 2004, Pages 965-989

Dervis, K., de Melo, J., Robinson, S., 1982. General Equilibrium Models for Development Policy [M]. Cambridge University Press, 1982.

Diao, X., Dinar, A., Roe, T., Tsur, Y., 2008. A general equilibrium analysis of conjunctive ground and surface water use with an application to Morocco. *Agricultural Economics* 38, 117-135.

Diao, X., Roe, T., 2003. Can a water market avert the “double-whammy” of trade reform and lead to a “win-win” outcome? *Journal of Environmental Management and Economics* 45, 708-723.

Diao, X., Roe, T., Doukkali, R., 2002. Economy-wide Benefits from Establishing Water User-right Markets in A Spatially Heterogeneous Agricultural Economy. Working Paper, Department of Applied Economics, University of Minnesota.

Diao, X., Roe, T., Doukkali., R., 2005. Economy-wide gains from decentralized water allocation in a spatially heterogeneous agricultural economy, *Environment and Development Economics*, 10:249-269.

Duchin, F., Lange, G.-M., 1994. The Future of the Environment: Ecological Economics and Technological Change. Oxford University Press, New York.

Dufournaud, M.C.,Harrington, J., and Rogers, P., 1988. Leontief’s ‘Environmental Repercussions and the Economic Structure. . .’

Revisited: A General Equilibrium Formulation. Geographical Analysis 20: 318–327.

Espinosa, J.A., and Smith, V.K., 1994. Measuring the Environmental Consequences of Trade Policy: A Non-Market CGE Analysis. presented on the 1995 ASSA meeting, Washington, D.C.: January 7–9, 1995.

Fang, X., Roe, T., Smith, R., 2006. Water shortages, water allocation and economic growth: the case of China. Conference paper at the 10th Joint Conference on Food, Agriculture and the Environment, Duluth, Minnesota, August 27-30, 2006.

Flegg, A.T., Webber, C.D., 1997. On the appropriate use of location quotients in generating regional input–output tables: reply. *Regional Studies* 31, 795–805.

Flegg, A.T., Webber, C.D., 2000. Regional size, regional specialisation and the FLQ formula. *Regional Studies* 34, 563–569.

Flegg, A.T., Webber, C.D., Elliott, M.V., 1995. On the appropriate use of location quotients in generating regional input–output tables. *Regional Studies* 29, 547–561.

Forsund, F.R., and Strom, S., 1988. Environmental Economics and Management: Pollution and Natural Resources. London: Croon Helm.

Fraiture, C. de, Cai, X., Amarasinghe, U., Rosegrant, M. and Molden, D., 2004. Does international cereal trade save water? The impact of virtual water trade on global water use. Comprehensive Assessment Research Report 4, Colombo, Sri Lanka.

GAC (General Administration of Customs), 2008. *Customs Statistics Yearbook 2008.* Beijing: China Customs Press.

Gay, P., Proops, J.L.R., 1993. Carbon-dioxide production by the UK economy: an input–output assessment. *Applied Energy* 44, 113–130.

Global Environmental Facility (GEF), 2008. GEF Project Report: Integrated Water Resources and Environmental Management (IWEM).

Guan, D, Hubacek, K., 2007. Assessment of regional trade and virtual water flows in China. *Ecological Economics* 61(1):159–70.

Gunning, J. W., Keyzer, M. A. (1995). Applied general equilibrium models for policy analysis. In J. Behrman & T. N. Srinivasan (Eds.), *Handbook of development* economics, vol. 3A (pp. 2025-2107). Amsterdam: North-Holland.

Hartman, L.M. 1965. The Input-Output Model and Regional Water Management, *Journal of Farm Economics*, 47(5), pp. 1583-1591.

Hazilla, M., Kopp, R., 1990. Social Cost of Environmental Quality Regulations: A General Equilibrium Analysis. *Journal of Political Economy* 98: 853–873.

He, Y.X., Zhang, S.L., Liu, S., Tao, W.J., Wang, Y.J., 2009. Analysis on impact of electricity price adjustment in China based on input–output method. *Journal of North China Electric Power University* 2, 94–99.

He, Y.X., Zhang, S.L., Yang, L.Y., Wang, Y.J., Wang, J., 2010. Economic analysis of coal price–electricity price adjustment in China based on the CGE model. *Energy Policy*, doi:10.1016/j.enpol.2010.06.033

Heckscher, E.F., 1919. The effect of foreign trade on the distribution of income. Ekonomisk Tidskrift 21, 1–32.

Heggedal, T.-R., Jacobsen, K., 2008. Timing of innovation policies when carbon emissions are restricted: an applied general equilibrium analysis, Discussion Paper 536, Statistics Norway.

Hoekstra A.Y., Chapagain A.K., 2007. "Water footprints of nations: water use by people as a function of their consumption pattern". *Water Resources Management* 21 (1): 35–48.

Hoekstra, A.Y., Hung, P.Q., 2002. Virtual Water Trade: A Quantification of Virtual Water Flows Between Nations in Relation to International Crop Trade, in: UNESCO-IHE (Ed.), Value of Water Research Report Series. Institute for Water Education, Delft.

Horridge, M., Dixon, P., Rimmer, M., 1993. "Water Pricing and investment in Melbourne: General Equilibrium Analysis with Uncertain Stream Flow," Centre of Policy Studies/IMPACT Centre Working Papers ip-63, Monash University, Centre of Policy Studies/IMPACT Centre

Hou, H., 1991. Resolving Problems of Water Shortage in China. *International Journal of Social Economics*, 18(9): 167-73.

Huang J., Pray, C., & Rozelle, S., 2002. Enhancing the crops to feed the poor. *Nature* 418, pp. 678-684.

Hubacek, K., Sun, L., 2005. Economic and societal changes in China and its effects on water use. *Journal of Industrial Ecology* 9, 187–200.

Hueting, R., 1996. Three persistent myths in the environmental debate. *Ecological Economics* 18: 81-88.

Intriligator, M., 1965. Embodied technical change and productivity in the United Kingdom, 1929-1958. *Review of Economics and Statistics* XLVII. 65-60.

Isard, W., 1972. Ecological–Economic Analysis for Regional Development. The Free Press, New York.

Jenerette GD, Wu W, Goldsmith S, Marussich WA, Roach J., 2006. Contrasting water footprints of cities in China and the United States. *Ecological Economics* 57:346–58.

Johansen, L., 1960. A Multi-sectoral Study of Economic Growth. Amsterdam: North-Holland.

Juana, J.S., Strzepedk, K.M., Kirsten, J.F., 2009. The economic consequences of the impact of climate change on water resources in South Africa. Conference paper at the International Association of Agricultural Economists Conference, Beijing, China, August 16-22, 2009.

Keuning, S.J.,Dalen, J.V.,Haan,M.D.,1999. The Netherlands' NAMEA: presentation, usage and future extensions. *Structural Change and Economic Dynamics* 10, 15–37.

Kremers, H., Nijkamp, P., Wang, S., 2002. A comparison of computable general equilibrium models for analyzing climate change policies. *Journal of Environmental Systems* 28 (3), 41– 65.

Kumbarôglu, G.S., 2003. Environmental taxation and economic effects: a computable general equilibrium analysis for Turkey. *Journal of Policy Modelling* 25 (2003) 795-810.

Lau, L. Yotopoulos, P., 1971. A test for relative efficiency and an application to Indian agriculture. American Economic Review, 61. 94-109.

Leistrtz, F.L., Leitch, J.A., Bangsund, D.A., 2002. Regional economic impacts of water management alternatives: the case of Devils Lake, North Dakota, USA. *Journal of Environmental Management* 66, 465–473.

Leontief, W., 1970. Environmental repercussions and the economic structure: an input–output approach. *Review of Economics and Statistics* 52 (3, August), 262–271.

Leontief, W., Ford, D., 1972. Air pollution and economic structure: empirical results of input–output computations. In: Brody, A., Carter, A.P. (Eds.), Input–Output Techniques. American Elsevier, New York, pp. 9–30.

Lesher, M., Nordas, H., 2006. Business services, trade and costs. OECD Trade Policy Working Paper No.46.

Letsoalo, A., Blignaut, J., de Wet, T., de Wit, M., Hess, S., Tol, R.S.J., van Heerden, J., 2007. Triple dividends of water consumption charges in South Africa. *Water Resources Research*, VOL. 43, W05412, doi:10.1029/2005WR004076, 2007.

Li, J.C.-I, 2002. A 1998 Social Accounting Matrix (SAM) For Thailand. International Food Policy Research Institute, Washington, D.C., U.S.A.

Li, S., 2010. China's Regional Input-Output Table 2002: Compilation and Application. Economic Science Press: Beijing, China

Liu, C., and He, W., 1996. Zhongguo 21 shiji shui wenti fanglue (Strategies for China's Water Problems in the 21st Century), Beijing: Kexue Chubanshe House.

Loisel, R., 2009. Environmental climate instruments in Romania: A comparative approach using dynamic CGE modelling. *Energy Policy* 37 (2009) 2190-2204.

Mansur, A., Whalley, J., 1984. Numerical specification of applied general equilibrium models: Estimation, calibration and data. In H. E. Scarf & J. B. Shoven (Eds.), Applied general equilibrium analysis (pp. 69-126). Cambridge: Cambridge University Press.

Mayer, W., Pleeter, S., 1975. A theoretical justification for the use of location quotient. *Regional Science and Urban Economics* 5, 343–355.

McCann, P., Dewhurst, J.H., 1997. Regional size, industrial location and input–output expenditure coefficients. *Regional Studies* 32, 435–444.

MEP (Ministry of Environmental Protection), 2008. Annual Statistic Report 2007 on Environment in China. Beijing: China Environmental Science Press.

MEP (Ministry of Environmental Protection), 2008. China Environment Bulletin 2007. June 2008.

MEP (Ministry of Environmental Protection), NBS (National Bureau of Statistics) and MOA (Ministry of Agriculture), 2010. The First National Pollution Census, February 6, 2010.

MEP (Ministry of Environmental Protection), (2011), Twelfth Five-Year Planning for Heavy Metal Pollution Comprehensive Prevention, February 2011.

Miller, R.E. and P.D. Blair. 1985. Input–Output Analysis: Foundations and Extensions. New Jersey: Prentice-Hall, Inc., Englewood Cliffs

Ministry of Water Resources (MWR), 2004. Water Resources in China; www.mwr.gov.cn/english1/20040802/38161.asp.

Ministry of Water Resources (MWR), 2007. China Water Resources Bulletin 2006. China Water Resources and Hydropower Press: Beijing, 2007.

Ministry of Water Resources (MWR), 2008. China Water Resources Bulletin 2007. China Water Resources and Hydropower Press: Beijing, 2008.

MOF (Ministry of Finance), 2008. Finance Yearbook of China 2008. Beijing: China Finance Press.

NBS (National Bureau of Statistics), 2008. China statistical yearbook 2008. Beijing: China Statistics Press.

Nijkamp, P., Wang, S., Kremers, H., 2005. Modelling the impacts of international climate change policies in a CGE context: The use of the GTAP-E model. *Economic Modelling* 22 (2005) 955-974.

O'Ryan, R., de Miguel, C.J., Miller, S., 2003. THE ECOGEM-CHILE MODEL: A CGE MODEL FOR ENVIRONMENTAL AND TRADE POLICY ANALYSIS. Central Bank of Chile Working Papers, December 2003.

O'Ryan, R., Miller, S., de Miguel, C.J., 2003. A CGE framework to evaluate policy options for reducing air pollution emissions in Chile. *Environment and Development Economics* 8, 285– 309.

Ohlin, B., 1933. Interregional and International Trade. Cambridge, MA.

Okadera, T., Watanabe, M., Xu, K.Q., 2006. Analysis of water demand and water pollutant discharge using a regional input-output table: an application to the City of Chongqing, upstream of Three Gorges Dam in China. *Ecological Economics* 58, 221-237.

Phuwanich, L., and Tokrisna, R., 2007. Economic policies for efficient water use in Thailand. *Soc. Sci.* 28: 367-376.

Pietroforte, R., 1995. An input-output analysis of the Italian construction sector, 1959-1958. *Construction Management and Economics*, 13, 253-262.

Proops, J.L.R., 1988. In: Ciaschini, M. (Ed.), Energy Intensities, Input–Output Analysis and Economic Development, pp. 201– 215.

Qin, C., Jia, Y., Su, Z.,Bressers, H., Wang, H., 2011a. The Economic Impact of Water Tax Charges in China: A Static Computable General Equilibrium Analysis. *Water International* (In review).

Qin, C., Su, Z., Jia, Y., Bressers, H., Wang, H., 2011b. An analysis of water consumption and pollution with a hybrid input-output accounting and modelling framework in the Haihe River Basin, China. *Water and Environment Journal* (In review).

Qin, C.C., 2007. Study about balance of social accounting matrix. *Quantitative & Technical Economics* 1, 31–37.

Rees, W, Wackernagel, M., 1994. Ecological footprints and appropriated carrying capacity: measuring the natural capacity requirements of the human economy. In: Jansson A, Hammer M, Folke C, Costanza R, editors. Investing in natural capital. Washington DC: Island Press.

Rees, W., 1992. Ecological footprint and appropriated carrying capacity: what urban economics leaves out. *Environment and Urbanization* 4(2):121–30.

Renault, D., 2003. Value of virtual water in food: principles and virtues. Value of Water Research Report Series No. 12. UNESCO-IHE, Delft, the Netherlands.

Richardson, H.W., 1972. Input–Output and Regional Economics. Redwood Press Limited, Wiltshire.

Robinson, S., 1990. Pollution, Market Failure, and Optimal Policy in an Economy-wide Framework. Working Paper no. 559, Department of Agricultural and Resource Economics. Berkeley: University of California.

Robinson, S., El-Said, M., 2000. GAMS code for estimating a Social Accounting Matrix (SAM) using cross entropy (CE) methods. IFPRI, TMD Discussion Paper, 64. Retrieved from: http://www.ifpri.org.

Robinson, S., El-Said, M., 2000. GAMS code for estimating a Social Accounting Matrix (SAM) using cross entropy (CE) methods. IFPRI, TMD Discussion Paper, 64. Retrieved from: http://www.ifpri.org.

Robinson, S., et al., 1999. From stylized to applied models: building multi-sector CGE models for policy analysis. The North American Journal of Economics and Finance 1, 5–38.

Robinson, S., Yúnez-Naude, A., Hinojosa-Ojeda, R., Lewis, J.D., Devarajan, S., Y., 1999. From stylized to applied models: building multi-sector CGE models for policy analysis. The North American Journal of Economics and Finance 1, 5–38.

Rosegrant, M.W., Cai, X. and Cline, S.A., 2002. World water and food to 2025: Dealing with scarcity. International Food Policy Research Institute, Washington.

Round, I., 1983. Nonsurvey techniques: a critical review of the theory and the evidence. *International Regional Science Review* 8, 189–212.

Rutherford, R.T., 1998. Economic Equilibrium Modelling with GAMS: An Introduction to MS/MCP and GAMS/MPSGE. Draft monograph. www.gams.com/doc/solver/mpsge.pdf.

Rutherford, R.T., 1998. Economic Equilibrium Modelling with GAMS: An Introduction to MS/MCP and GAMS/MPSGE. Draft monograph. www.gams.com/doc/solver/mpsge.pdf.

Sánchez-Chóliz, J., Duarte, R., 2005. Water pollution in the Spanish economy: analysis of sensitivity to production and environmental constraints. *Ecological Economics* 53, 325-338.

SAT (State Administration of Taxation), 2008. Tax Yearbook of China 2008. Beijing: China Taxation Press.

SCCG (The State Council of the Chinese Government), (2006), The Eleventh Five-Year Plan for National Social and Economic Development. Beijing: People’s Publishing House.

SCCG (The State Council of the Chinese Government). 2006. The Eleventh Five-Year Plan for National Social and Economic Development. Beijing: People’s Publishing House.

SCCG (The State Council of the Chinese Government). 2011. The Twelfth Five-Year Plan for National Social and Economic Development. Beijing: People’s Publishing House.

SEPA (State Environmental Protection Administration – now MEP) and NBS (National Bureau of Statistics). 2006. Study Report on Green National Accounting 2004. Beijing: China Academy of Environmental Planning.

Seung, C, Harris, T., Englin, J., Netusil, N., 2000. Impacts of water reallocation: a combined computable general equilibrium and recreation demand model approach. *Annals of Regional Science*, 34: 473-487.

Shi, P., 1997. China’s water crisis: difficulties and policies. *Strategy and Management* (6), pp. 40-47.

Susangkarn, C., Kumar, R., 1997. A computable general equilibrium model for Thailand incorporating natural water use and forest resource accounting. *Asian-Pacific Economic Literature*, 12 (2): 196-209.

Tinbergen, J., 1962. *Shaping the World Economy: Suggestions for an International Economic Policy*. New York: The Twentieth Century Fund. The first use of a gravity model to analyze international trade flows.

UN (United Nations), 1993. System of National Accounts.

UN (United Nations), 1997. China: Water Resources and Their Use, New York, United Nations.

UN (United Nations), 2006. System of Integrated Environmental and Economic Accounting for Water. United Nations, New York. Draft available from the website of the UN Statistical Division, www.un.org.

Velázquez, E., 2005. An input–output model of water consumption: analyzing intersectoral water relationships in Andalusia. *Ecological Economics* 56 (2006), 226-240.

Wackernagel. M., Rees W., 1996. Our ecological footprint: reducing human impact on the earth. Gabriola Island, British Columbia: New Society Publishers.

Wang H. Lall S., 2002. Valuing Water for Chinese Industries: A Marginal Productivity Analyses. *Applied Economics*, 2002 (34): 759-765.

Wang, Y., Xiao, H.L., Lu, M.F., 2009. Analysis of water consumption using a regional input-output model: Model development and application to Zhangye City, Northwestern China. *Journal of Arid Environments* 73, 894-900.

WHO (World Health Organization),2005. World Summit Outcome Document. 15 September 2005.

Willenbockel, D., 2006. Structural Effects of a Real Exchange Rate Revaluation in China: A CGE Assessment. MPRA Paper 920, University Library of Munich, Germany.

World Bank, 2001. China: Agenda for Water Sector Strategy for North China. World Bank Report No. 22040-CHA, Washington, DC, World Bank.

World Bank, 2009. Addressing China's Water Scarcity: Recommendations for Selected Water Resource Management Issues.

Wu, Y. J., Xuan, X. W., 2002. The economic theory of environmental tax and its application in China. Beijing: Economic Science Press, 440 pp.

Xia, J., Deng, Q., Sun, Y., 2010. Integrated water and CGE model of the impacts of water policy on the Beijing's Economy and Output. *Chinese Journal of Population, Resources and Environment* 8(2): 61-67.

Xue, X. M., 1998. Calculation and comparison study of CO2 emission from China's energy consumption. *Environmental Protection*, 4, 27–28.

Yang, H., Zehnder, A., 2001. China's Regional Water Scarcity and Implications for Grain Supply and Trade. *Environmental and Planning* A, 33(1): 79-95.

Yu, Y., Hubacek, K., Feng, K.S., Guan, D.B., 2010. Assessing regional and global water footprints for the UK. *Ecological Economics* , doi: 10.1016/j.ecolecon.2009.12.008

Yue, D., Xu, X., Li, Z., Hui, C., Li, W., Yang, H., et al., 2006. Spatiotemporal analysis of ecological footprint and biological capacity of Gansu, China 1991–2015: down from the environmental cliff. *Ecological Economics* 58, 393–406.

Zhai, F., Hertel, T., 2005. Impact of the Doha Development Agenda on China: The Roel of Labour Markets and Complementary Education Reforms [R]. Washington, D.C.: World Bank Policy Research Working Paper 3702, 2005.

Zhao, S., Li, Z., Li, W., 2004. A modified method of ecological footprint calculation and its application. *Ecological Modelling* 185, 65–75.

Zheng, Y., & Fan, M., 1999. Chinese CGE Model and Policy Analysis [M]. Beijing: Social Sciences Academic Press (China), 1999.

Zhuang, J., 1996. Estimating Distortions in the Chinese Economy: A General Equilibrium Approach [J]. *Economica*, 1996, 63 (252): 543-568.

Author's biography

Background

Qin Changbo began to pursue a Ph.D degree in the Faculty of Geo-Information Science and Earth Observation (ITC) and Twente Centre for Studies in Technology and Sustainable Development, University of Twente, Enschede, The Netherlands since March 2007. Qin Changbo earned an M.Sc degree in Environmental Science from Chinese Research Academy of Environmental Sciences (CRAES) in Beijing, China and a B.Sc degree in Environmental Engineering from Southeast University in Nanjing, China.

Qin Changbo works in Environmental Strategy Institute, Chinese Academy for Environmental Planning since June 2011. Qin Changbo's current research focuses on environmental planning, environmental economics, computable general equilibrium (CGE) modelling, application of input-output techniques, water management, environmental and trade policy analysis.

Publications

ISI Journal Articles (published and in review)

Qin, C., Jia, Y., Su, Z., Zhou, Z., Qiu, Y., and Shen, S., 2008 Integrating remote sensing information into a distributed hydrological model for improving water budget predictions in large-scale basins through data assimilation. *Sensors*, 8, 4441–4465, doi:10.3390/s8074441, 2008.

Jia, Y., Ding, X., **Qin, C.,** Wang, H., 2009. Distributed modeling of land surface water and energy budgets in the inland Heihe river basin of China. *Hydrol. Earth Syst. Sci.*, 13, 1849–1866.

Qin, C., Bressers, H.J.A., Su, Z., Jia, Y., Wang, H., 2011. Economic impacts of water pollution control policy in China: A dynamic computable general equilibrium analysis. *Environmental Research Letters* (Under revision and will be resubmitted for acceptance).

Qin, C., Jia, Y., Su, Z., Bressers, H.J.A., Wang, H., 2011. The Economic Impact of Water Tax Charges in China: A Static Computable General Equilibrium Analysis. *Water International* (Under editorial and will be resubmitted for publication).

Qin, C., Su, Z., Jia, Y., Bressers, H.J.A., Wang, H., 2011. Assessing the Economic Impact of Mitigating North China's Water Scarcity Strategy: an Econometric-Driven Water Computable General Equilibrium Analysis. *Journal of Environmental Planning and Management* (Under review).

Qin, C., Su, Z., Jia, Y., Bressers, H.J.A., Wang, H., 2011. An Analysis of Water Consumption and Pollution with an Input-output Model in the Haihe River Basin, China. *Water and Environment Journal* (Under review).

Other Refereed Journal Articles (published and in review)

Qin, C., Zheng, B., Qin, Y., Lei, K., Yu, T., 2006. Gray Correlation Assessment of Water Environment Quality for Tianjin Coastal Zone in Bohai Bay. *Research of environmental Scicences* (in Chinese), 2006, 19 (6).

Shen S., Jia, Y., Yang, G., **Qin, C.,** 2008. Application Study of Crop Growth Model in Hydrology and Water Resources. *Water Resources and Power* (in Chinese) 2008, 26 (5).

Zhang, Z., **Qin, C.,** Jia, Y., Xie, J., Niu, C., 2011. Comparative Analysis of the Economic Value of water in Water Deficient Areas with a Different Development Level – Case Study of Beijing and Shanxi, China. *China Population Resources and Environment* (in Chinese) (Accepted).

Summary

The economic success in China has come at the expense of over exploitation of natural resources and huge impacts on the environment and especially water resources. Environmental and ecological losses are increasing as a consequence of water scarcity and pollution due to humans overindulging in their increasingly prosperous lifestyles afforded by industrialization. Considering the complex issues involving water, environment, food security, population growth and economic development, sustainable development in China has been facing unprecedented challenges. To mitigate China's water scarcity and pollution, several water management and pollution control strategies were adopted by Chinese government.

The main objective of the study is to develop the environmental input-output model and environmental computable general models, and apply them to investigate the inter-relationships between environment and economy, and assess the economy-wide effects of water management and pollution control strategies/mechanisms for mitigating China's water scarcities and pollutions.

First, the study developed a hybrid input-output accounting and modelling framework to investigate the inter-relationship between economy and water consumption/pollution in the Haihe River Basin. Within the environmental IO framework, a series of assessment indicators is calculated to assist in tracking both direct and indirect effects of freshwater consumption and wastewater discharge in the economic sector, as well as to distinguish the economic sectors that have greatest influence on water demand and pollution.

Second, an econometric-driven, multi-regional, multi-sectoral water extended computable general equilibrium model was presented to analyze the effectiveness of measures and policies for mitigating North China's water scarcity issues with respect to three different scenario groups. Experimental results of the scenario for reducing groundwater indicate that a reduction in the water supply level has a severe negative impact on the economy and household welfare. Experimental results of the scenario for the South-to-North Water Transfer project indicate that

construction of the project has a positive impact on economic development, household welfare, and environmental sustainability. Experimental results of the scenario for reallocating water from agriculture to the industrial and service sectors show that transferring water from a low-value sector to high-value sectors has a positive impact on the macro-economy and household welfare, and promotes economic restructuring from a low water efficiency sector to relatively high water efficiency sectors.

Third, a comparative-static computable general equilibrium model with a water extension was presented to investigate the economy-wide impacts of charging water resource fee in China. It was found that imposing water taxes can redistribute sectoral water use, and lead to shifts in production, consumption, value-added gains, and trade patterns. Sectors not imposing water levies are nonetheless affected by the introduction of taxes from other sectors. Specifically for China, water taxes imposed on the agricultural sector drives most of the effects on sectoral water reallocation, shifts in production, consumption and trade patterns as well as welfare changes.

Fourth, an extended environmental dynamic computable general equilibrium model was applied to assess the economic consequences of implementing total emission control policy by simulating different emission reduction scenarios, with reductions ranging from 20 to 50% of the emission levels in 2007 by the year 2020. The results indicated that a modest total emission reduction target can be achieved at a low macroeconomic cost. With the stringency of policy targets, macroeconomic cost (for example, GDP loss, NNI loss and welfare loss) will increase at an increasing rate. It was also found that stringent environmental policy can lead to an important shift in production, consumption, and trade patterns, from dirty sectors to relatively clean sectors. To certify the positive impact of tradable emission permits, a second version of the model with a non-tradable emission permits system is also developed. Comparative results showed that macroeconomic cost can be reduced via the trading of emission permits, and thus emission permit trading experiments by local governments should be further encouraged. It is highly recommended that efforts are

made to establish emission permit trading mechanism at the national level.

In this thesis, based on different problems and corresponding mitigation measures, several different environmental economic models were developed to investigate the inter-relationship between environment and economy. It was found that the input-output techniques and computable general equilibrium models are useful tools to analyze the impacts of each different measure/policy on the economic, social and environmental variables. They can draw important policy implications and provide policy recommendations to decision-makers. This study could be viewed as a research contribution to the efforts to address the issue of natural resource degradation and environmental pollution generated by both climate change and human activities.

Keywords: Water scarcity; Water shortage; Water tax; Virtual water; Water management; Environmental policy; Total emission control; Water transfer; Emission permit trading; Input-output technique; Computable general equilibrium.

Samenvatting

Het economische succes van China is gepaard gegaan met overexploitatie van natuurlijke hulpbronnen en met enorme inbreuken op het milieu en speciaal op het grond- en oppervlaktewater. De aanslagen op natuur en milieu nemen toe als gevolg van watertekorten en vervuiling die weer het gevolg zijn van de menselijke neiging om zich over te geven aan de steeds welvarender levensstijlen die men zich door de industrialisatie kan veroorloven. Gegeven de complexe problematiek van water, milieu, voedselzekerheid, bevolkingsgroei en economische ontwikkeling, staat duurzame ontwikkeling in China voor grotere uitdagingen dan ooit. Om China's watertekorten en vervuiling te beperken, heeft de Chinese regering diverse watermanagement en anti-vervuiling strategieën in stelling gebracht.

Het hoofddoel van dit onderzoek is om een milieugerichte input-output model en een milieugericht doorrekenbaar algemeen evenwichtsmodel te ontwerpen en deze te gebruiken om de relaties tussen milieu en economie te onderzoeken en om de economie-brede effecten in te schatten van deze watermanagement en anti-vervuiling strategieën, gericht op het beperken van China's watertekorten en vervuiling.

Allereerst heeft de studie een hybride input-output accounting- en modeleringskader ontworpen om de relatie tussen economie en waterconsumptie en -vervuiling in het Haihe rivierbekken te onderzoeken. Binnen het milieugerichte IO kader is een serie waarderingsindicatoren berekend om te helpen om zowel directe als indirecte effecten van de consumptie van zoet water en afvalwaterlozingen van economische sectoren op te sporen alsook om de economische sectoren te onderscheiden die de grootste invloed hebben op de vraag naar water en op de vervuiling ervan.

Ten tweede is een econometrisch, multiregionaal, multisectoraal en met water aspecten verrijkt doorrekenbaar algemeen evenwichtsmodel gepresenteerd om de effectiviteit te analyseren van maatregelen en beleidsinstrumenten om Noord China's watertekorten te beperken met betrekking tot drie verschillende scenario's. De resultaten van dit model voor het scenario van het reduceren van grondwatergebruik laten zien dat een reductie van het niveau van het aanbod van water een ernstige negatieve invloed heeft op de economie en op de welvaart van huishoudens. De resultaten van het Zuid-naar-Noord Water Transfer project laten zien dat de bouw van dit project een positieve invloed heeft op economische ontwikkeling, welvaart van huishoudens en milieu en duurzaamheid. De resultaten van het scenario waarin water wordt herverdeeld van landbouw naar industriële en dienstensectoren tonen dat het overbrengen van wateraanbod van laagwaardige naar hoogwaardige sectoren een positieve invloed heeft op de macro-economie en op de welvaart van huishoudens en ook de herstructurering bevordert van sectoren met een lage mate van waterefficiëntie naar sectoren met een verhoudingsgewijze hoge mate van waterefficiëntie.

In de derde plaats werd een vergelijkend statisch doorrekenbaar evenwichtsmodel met een uitbreiding met water aspecten gepresenteerd om de invloeden op de economie als geheel te onderzoeken van het invoeren van een waterheffing in China. Het bleek dat het opleggen van waterbelastingen kan leiden tot de herverdeling van watergebruik tussen de sectoren en tot veranderingen in de productie, consumptie, toegevoegde waarde en handelspatronen. Sectoren waarop geen waterheffingen worden geheven worden desondanks toch beïnvloed door de introductie van belastingen bij andere sectoren. Speciaal in China zijn het vooral de belastingen die bij de landbouwsector worden opgelegd die de veranderingen in productie, consumptie en handelspatronen, alsmede de veranderingen in welvaart veroorzaken.

In de vierde plaats werd een uitgebreid milieugericht dynamisch doorrekenbaar algemeen evenwichtsmodel toegepast om de economische consequenties van het toepassen van beleidsmaatregelen voor emissiebeperking in te schatten. Het gaat om verschillende emissiebeperking scenario's, met reducties tot 2020 van 20 tot 50% ten opzichte van de uitstootniveaus in 2007. De resultaten lieten zien dat een matige emissiereductiedoelstelling kan worden bereikt tegen lage macro-economische kosten. Bij een toenemende strengheid van de beleidsdoelen zullen de macro-economische kosten (bijvoorbeeld verlies aan GDP en NNI en welvaart) meer dan evenredig toenemen. Ook werd gevonden dat een streng milieubeleid kan leiden tot een belangwekkende verandering in productie, consumptie en handelspatronen, van vuile sectoren naar relatief schone sectoren. Om de positieve effecten van verhandelbare emissierechten vast te stellen werd er ook een modelvariant met niet-verhandelbare emissievergunningen ontwikkeld. Een vergelijkende analyse liet zien dat de macro-economische kosten beperkt kunnen worden door middel van de handel in vervuilingsrechten en dat derhalve experimenten met emissiehandel door lokale overheden verder aangemoedigd zouden moeten worden. Het is ten zeerste aanbevolen dat er pogingen worden gedaan om ook op het nationale niveau mechanismen voor emissievergunningenhandel tot stand te brengen.

Uitgaande van de verschillende problemen en de daaraan gekoppelde mogelijke beleidsmaatregelen, werden in dit proefschrift verschillende milieugerichte economische modellen ontwikkeld om de relaties tussen milieu en economie te bestuderen. De input-output technieken en de doorrekenbare algemene evenwichtsmodellen bleken bruikbare hulpmiddelen om de invloeden van verschillende beleidsmaatregelen op economische, sociale en milieu variabelen te analyseren. Ze kunnen belangrijke beleidsimplicaties duidelijk maken en beleidsaanbevelingen aan besluitvormers opleveren. Deze studie kan worden beschouwd als een bijdrage vanuit het wetenschappelijk onderzoek aan de pogingen om de problematiek te bestrijden van de achteruitgang van natuurlijke hulpbronnen en milieuvervuiling, die door zowel klimaatverandering als door menselijke activiteiten wordt veroorzaakt.

ITC Dissertation List

http://www.itc.nl/Pub/research_programme/Graduate-programme/Graduate-programme-PhD_Graduates.html