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Article

Modeling the Impacts of Urbanization and Industrial Transformation on Water Resources in China: An Integrated Hydro-Economic CGE Analysis

Li Jiang [1,*], Feng Wu [2], Yu Liu [3] and Xiangzheng Deng [4]

[1] School of Economics, Renmin University of China, 59 Zhongguancun Street, Beijing 100872, China

[2] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China; E-Mail: wufeng@igsnrr.ac.cn

[3] Institute of Policy & Management, Chinese Academy of Sciences, Beijing 100190, China; E-Mail: liuyu@casipm.ac.cn

[4] Center for Chinese Agricultural Policy, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; E-Mail: dengxz.ccap@igsnrr.ac.cn

* Author to whom correspondence should be addressed; E-Mail: li.jiang@ruc.edu.cn; Tel.: +86-10-8489-9979; Fax: +86-10-6251-1091.

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Abstract: Pressure on existing water resources in China is expected to increase with undergoing rapid demographic transformation, economic development, and global climate changes. We investigate the economy-wide impacts of projected urban population growth and economic structural change on water use and allocation in China. Using a multi-regional CGE (Computable General Equilibrium) model, TERM (The Enormous Regional Model), we explore the implications of selected future water scenarios for China's nine watershed regions. Our results indicate that urbanization and industrial transformation in China will raise the opportunity cost of water use and increase the competition for water between non-agricultural users and irrigation water users. The growth in water demand for domestic and industrial uses reduces the amount of water allocated to agriculture, particularly lower-value and water-intensive field crops. As a response, farmers have the incentive to shift their agricultural operations from traditional field crop production to higher-value livestock or intensive crop production. In addition, our results suggest that growing water demand due to urbanization and industrial transformation will raise the shadow price of water in all nine river basins. Finally, we find that national economic growth is largely attributable to urbanization and non-agricultural productivity growth.

Keywords: urban population growth; economic structural change; multi-regional CGE model; water accounts; nine river basins; water use and allocation; shadow price

1. Introduction

Water is an essential natural endowment available to mankind and is of high relevance to food production, human livelihoods, and the preservation of life and natural environment on earth. However, partly due to climate change and other anthropogenic factors, water resources are becoming increasingly scarce in many arid and semi-arid regions of the world [1,2]. Urbanization, accelerated industrialization, and increased domestic water use have aggravated the problem. World projection has shown that water consumption for most uses will increase by at least 50% by 2025 compared to the 1995 level [3]. Water resource constraint is a critical issue facing many countries, especially those in the developing world, where rapid demographic transformation and economic development continue to cause growing water demand.

As the most populous country in the world, China sustains 22% of the world population with only 7% of the world fresh water resources [4]. The per capita water availability per annum is 2196 m^3, approximately a quarter of the global average [5]. The imbalance in the spatial and seasonal distribution of water resources has exacerbated the problem of scarcity. While Southern China is relatively abundant with water resources, per capita water availability in Northern China is only 914 m^3, which is 42% of the national average and 12% of the global average. The United Nations defines this as water stress or severe scarcity. Furthermore, in most regions of the country the rainfall received from June to September accounts for 60%–80% of the total precipitation throughout the year [6].

Traditionally, the agricultural sector is the largest consumer of water resources in China—more than 60% of all freshwater withdrawals are used for agriculture, most of which in the form of irrigation [7]. As 80% of the food is produced on irrigated cropland, irrigation water plays an important role in feeding the large population [8]. However, China is transforming from an agriculture-based towards an industrialized and urbanized economy at a fast pace. The proportion of urban population increased from 22% in 1983 to 47% in 2010 [9]. In terms of the structure of the economy, the primary sector now constitutes only 10% of the total GDP of China, compared with 33% in 1983 [9]. During the coming decades, water scarcity is expected to rise due to a rapid increase in the demand for water as a result of urbanization, industrial transformation, and economic development. Water shortage in turn can become one of the bottlenecks that would hamper the further development of the regional economy. Despite the magnitude and scale of socioeconomic changes across the country, to date, there is not an integrated hydro-economic system that can simultaneously examine the national and regional impacts of primary socioeconomic forces, including urban population growth and economic structural change, on water use and allocation, rural livelihoods, and the overall economy in China.

The primary goal of this paper is to investigate the effects of exogenously projected urban population growth and economic structural change on the national and regional economies of China, with a special consideration of water resources. We apply a multi-regional CGE model, TERM (The Enormous Regional Model), which incorporates water accounts linked to each economic activity, to nine major river basins in China. The regional disaggregation approach enables us to track both intra- and inter-regional linkages and interactions between the economy and the hydro-system and to quantify the net effect of potential socioeconomic changes on water use. Particularly, we use the model to assess the economy-wide impacts under two scenarios: (i) an increase in the proportion of urban population; and (ii) non-agricultural productivity growth and water-saving technological change. We present a first attempt to examine the impacts of socioeconomic changes on water use in China at the national scale while capturing multi-regional linkages.

2. A Review on Economic Models of Water Use

Economic models of water use have been widely applied to analyze water-related policies and scenarios and their impacts on the allocation and use of water resources. These generally include partial and general equilibrium models. Partial equilibrium analysis at a catchment or basin scale is best suited for assessing sectoral policies of a region while assuming that the shifts in key parameters under alternative water scenarios will have little impact on other sectors and regions of the economy [10]. For example, Rosegrant *et al.* use the IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) model to estimate demand and supply of water to 2025 at the global scale [3]. While the IMPACT model simulates detailed future outcomes for a range of agricultural products and regions, non-agricultural sectors are excluded. However, efficient water resource management and water policy development require good understanding of inter-sectoral and inter-regional linkages and economy-wide effect of water scenario changes.

A general equilibrium analysis considers all sectors and regions of an economy to determine the economy-wide effect that cannot be captured in partial equilibrium approaches. CGE models distinguish a number of sectors, commodities, and factors of production within the economy, allowing for a complete exploration of the effects and complex feedbacks of many variables throughout the economy [11]. CGE models have been used in many countries to examine the impacts of water scarcity scenarios and water management policies. However, most of these studies rely on data for a single country or region assuming no interlinkages exist between the target country (region) and the rest of the world [12]. Seung *et al.* examined the economic impacts of relocating water from irrigated agriculture to recreational use in rural Nevada [13]. They found that the additional rural income from water rights compensation did not offset the economic losses associated with the reduction in agricultural production. Decaluwe *et al.* assessed the effect of water tariff reforms on water resource allocation and social welfare gains in Morocco [14]. Letsoalo *et al.* explored the water resource management strategies to address water scarcity problems, with a focus on the impacts on water allocation and poverty in South Africa [15]. Watson and Davies investigated the general equilibrium implications of economic and population growth in the context of fixed total supply of available water in Colorado [16]. They identified that the magnitude of increase in municipal water price due to population growth would be significantly smaller by allowing for transfers of water between agricultural and municipal water users.

Given geographic and socioeconomic variations between watershed regions, many water-related questions between economically linked regions can better be answered with multi-regional CGE models.

As multi-regional models allow for separate region-specific supplies, prices, government policies, and production functions, these models can illustrate inter-regional feedbacks and the distribution of economic impacts across space with greater realism [17]. Two of the most popular multi-regional water CGE models are GTAP-W (e.g., [10,18]), which is a multi-country model of the world, and TERM, which is an inter-regional model of a country. To date, most of the applications of TERM on water issues are for Australia. Horridge *et al.* simulated the short-run economic effects of the Australian drought of 2002–2003 [19]. Peterson *et al.* examined the impacts of intra- and inter-regional water trading in the southern Murray Darling basin of Australia [20]. Wittwer and Griffith modeled the economy-wide small regional effects of reduced water supply during periods of severe droughts in the Murray Darling basin [21]. Ejaz Qureshi *et al.* explored the impact of increased population and water demand and reduced water supply on sectoral and regional output and employment in Australia [22].

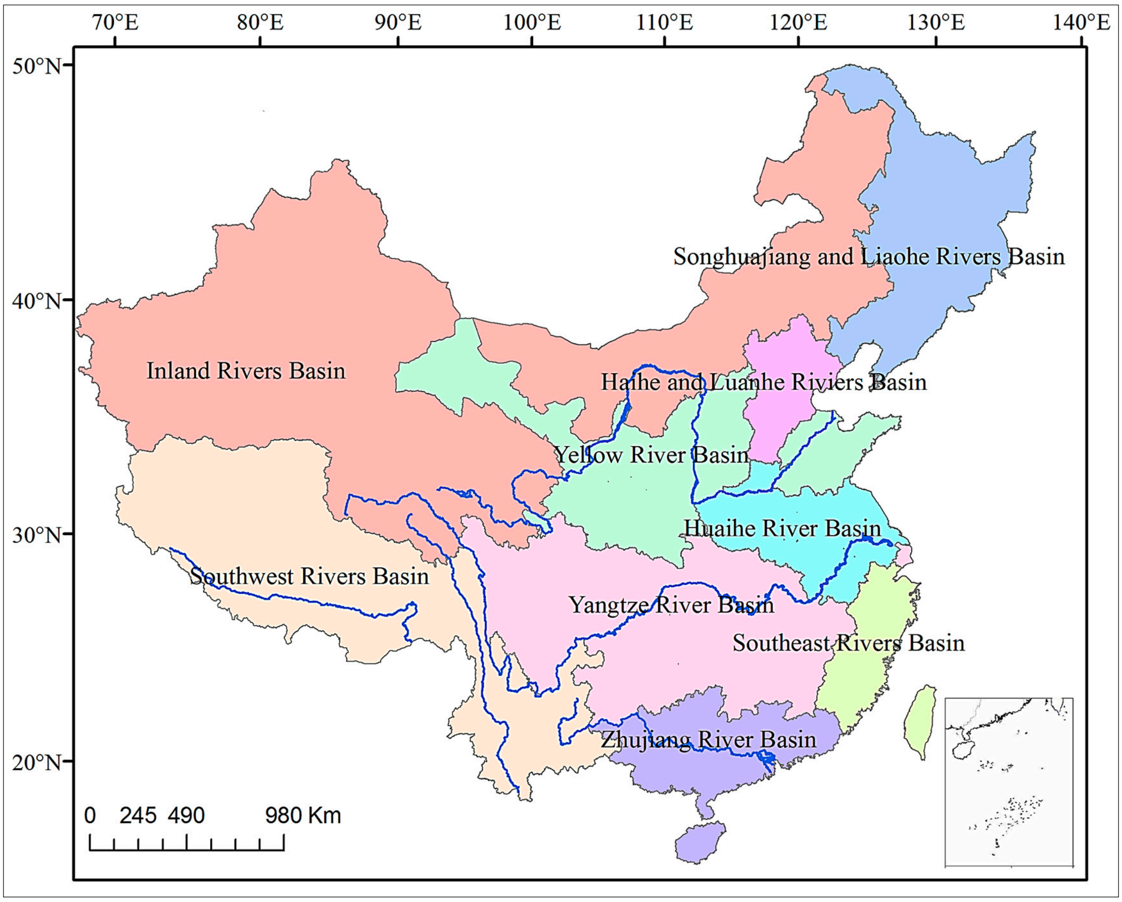
As in Australia, water scarcity is a growing issue in China and China has several important river systems that support economic activities within respective watershed regions. Largely due to data limitation and model constraint, most modeling studies analyzing water issues in China focus on particular regions (e.g., [23–25]). On the contrary, studies about water issues in China at the national scale are scarce. In this case, treating the whole country as a single watershed region has obvious limitations in incorporating important regional variations and inter-regional linkages. Rather, a practical way is to model each watershed region of the country as a separate economy with links to other regions to account for product and factor mobility between regions. Feng *et al.* used a dynamic general equilibrium approach to assess the economic impacts of the South-North Water Transfer (SNWT) project [26]. However, they divided China into only two regions—Beijing and the rest of China, and therefore provided simplified regional detail. The recent development of different versions of TERM for other nations including China, and improved water accounts from the National Bureau of Statistics of China make a more practical and complicated analysis of national water issues possible. This first requires construction and compilation of the multi-regional database that includes water accounts linked to individual economic activities. In this study, we divide the whole country into nine river basins, develop water accounts for individual watershed regions, and explore the implications of selected future water scenarios for China's nine watershed regions.

3. Modeling Framework and Scenarios

3.1. Modeling Framework

In this study, we use a multi-regional CGE model of the Chinese economy, the version of TERM for China, developed by the Centre of Policy Studies at Monash University of Australia, to examine the economic impact of various future water scenarios for nine river basins in China [27]. An essential component of this model is a multi-regional database that contains complete input-output information for 137 sectors and 31 provinces and inter-regional trade relationships between provinces in 2007 [7]. The "bottoms-up" approach of TERM allows for a separate modeling of each region as a distinct economy with links to the other regions of the country and to the rest of the world. We aggregate the multi-regional database to nine watershed regions with a relatively detailed representation of agricultural industries and with a focus on watershed regions. The agricultural sectors include field crops (summer cereals, winter cereals, oil crops and legumes, and cotton), intensive crops (vegetables, fruit, and horticulture), livestock (livestock and dairy), and other agriculture (fishing and forestry). The nine watershed regions are associated with major river basins in China, which are Southeast Rivers Basin (SE), Zhujiang River Basin (ZH), Yangtze River Basin (YT), Southwest Rivers Basin (SW), Huaihe River Basin (HA), Songhuajiang and Liaohe Rivers Basin (SL), Inland Rivers Basin (IL), Yellow River Basin (YE), and Haihe and Luanhe Rivers Basin (HL) (Figure 1) [28]. As TERM works with administrative regions within a country, in practice, we attribute individual provinces to particular river basins using the greatest-area method and aggregate those to form the watershed regions. For the greatest-area method, if a province locates across more than one river basin, the river basin with the greatest area in the province is assigned. In this way, the borders of watershed regions coincide with existing administrative boundaries. Using 2007 water accounts published by the National Bureau of Statistics of China [7], we devise water accounts for each of the nine watershed regions and incorporate the regional hydrological detail into the aggregated multi-regional database to form the final database used for this study.

Figure 1. Location map of nine major river basins in China.



The TERM for China retains a number of main features common to most CGE models. This model includes irrigation water in production as an endowment and the production of irrigation water from raw water is not accounted for in the model. A region's water supply is fixed and is derived from data on the observed use of irrigation water in the base year. Each industry determines the level of output to satisfy demand and selects a particular bundle of inputs to minimize the costs of producing its output. Specifically, agricultural sectors use a combination of irrigation water and non-water inputs for production and have a constant elasticity of substitution (CES) production function. Non-agricultural sectors only use non-water inputs, which consist of intermediate inputs, primary factors, and other costs, in fixed proportions. Water utility sector provides sewerage and drainage services, and delivers non-irrigation (or treated) water, which can be purchased and enter the production process as intermediate inputs. The model distinguishes household consumption for two types of households, rural and urban, by region. The composition of household demand follows the linear expenditure system, while the composition of investment and government demands is held exogenous [19]. For long-run simulations as described in this study, labor and capital are fully mobile between sectors and regions while land endowments are assumed to be mobile between sectors within a region. The "*hukou*" system of residency permits in China has been gradually relaxed since the mid-1980s. Particularly in 2014, the Chinese government formally abandoned the "*hukou*" system to promote urbanization, which meant that the difference between urban residency and rural residency would disappear. We make the assumption about labor mobility to reflect this future trend of demographic changes.

A challenge for incorporating irrigation water in the model is to identify the value of marginal product of water in agricultural production. As water is often not treated as a normal good, water prices do not necessarily reflect the marginal value of water, but may be administratively set and subject to subsidies or regulations. Inferring marginal productivity of water from water consumption levels and prices can be problematic. In this study, we value water as an input to production and use market output prices, output levels, and quantities of water consumed in each sector to determine the marginal productivity of water. The underlying rationale is that producers who use water as a variable input to their production processes choose how much to consume depending on the marginal value of that input to the value of outputs.

Our model has three foreign trade closures. First, there is a trade balance equilibrium constraint. Foreign trade balance is allowed to adjust but should keep fixed in the long run. Second, closure for imports reflects a small-country assumption. China faces perfectly elastic world supply at a fixed import price. Third, closure for exports reflects a large-country assumption. China faces imperfectly elastic world demand and has an impact on the export price.

3.2. Scenarios

The simulation examined in this study is designed to mimic the primary socioeconomic changes projected for China by the year 2030. In order to explore the impacts of urban population growth and economic structural change on water use, we consider a series of scenarios. We specify these scenarios according to the existing policies or demographic and economic forecasts for China. We present the simulation results in decomposition form, so that we can track the contribution to water use made by each scenario. In both scenarios, we allow for transfers of water between agricultural and non-agricultural water users within watershed regions but do not allow water transfers between watershed regions. This is consistent with the undergoing reform in national water policy toward more market-based allocation regimes.

3.2.1. Scenario 1: An Increase in the Proportion of Urban Population

This scenario assumes that the proportion of urban population relative to the total will increase from the current level to 69% by 2030. This demographic change assumption is derived from United Nations' population projections for China [29]. Correspondingly, we introduce different percentage increases in urban population for different watershed regions according to their current levels of urbanization. New migrants adopt urban consumption patterns, allowing us to capture increased demand for water resources caused by urbanization. In addition, in this scenario, we assume that no new water sources are developed to increase the supply of water.

3.2.2. Scenario 2: Economic Structural Change

Much structural shift in an economy over time can be reflected by productivity changes at the industry level [30]. Industrial productivity growth, primarily driven by technological innovations, promotes the industrial transformation of the economy. Average non-agricultural productivity increase in China remained relatively stable over the past two decades, at around 1% per year, although variations existed among different industries [7]. In this scenario, we assume that the annual percentage increase of productivity in non-agricultural sectors remains at 1% between 2007 and 2030. Moreover, we assume that water use efficiency increases as a result of the emergence and adoption of water-saving technologies. According to the 12th National Plan about Water Security, we impose a 30% reduction on irrigation water requirements per unit of output, and a 15% downward shift on per capita household water requirements during the projection period.

4. Results and Discussion

Expected rapid economic development and the relaxation of restrictions on internal migration in China will continue to draw labor from agricultural sectors in the coming decades. The accelerating shift of the economy away from primary sector production towards manufacturing and services represents another critical change being experienced by the country. Both of the two socioeconomic changes have important implications for water usage and water resources allocation at regional and national scales. In Scenario 1, we examine the impacts of increased proportion of urban population. In Scenario 2, we investigate the impacts of economic structural change.

4.1. Scenario 1: An Increase in the Proportion of Urban Population

Table 1 displays changes in the quantity of water usage by sector in all scenarios relative to 2007. Since we assume that no extra water sources are developed and there is no reduction in available water supply, the total water allocated to each column of Table 1 sums to zero. We assume that there is no change in the supply of water because we intend to focus on the impacts of two socioeconomic changes—urbanization and industrial transformation. It is expected that climate change and water pollution both can reduce supply and aggravate water scarcity. Using our study as baseline and adding those other factors can be a direction of future work. Under Scenario 1, all agricultural sectors except livestock have losses in share of national water usage due to urban population growth. On the contrary, households modestly increase their water usage by 10.5 billion m^3 and various manufacturing and service sectors substantially increase their water usage by 28.7 billion m^3. Table 2 shows changes in value of national output in all scenarios relative to 2007. Generally the impacts of urbanization on share of water usage and on value of output are consistent in direction. With urban population growth, sectors that suffer reductions in water usage have declines in output while sectors that experience increases in water usage have growth in output. The value of national output increases strongly in non-agricultural sectors by 15.2%. In terms of agricultural sectors, only livestock gains in value of output.

Table 1. Change in quantity of water usage by sector, all scenarios in 2030 relative to 2007.

	Scenario 1	**Scenario 2**			**Total**
	Urbanization	**Non-agricultural productivity growth**	**Agricultural water saving**	**Household water saving**	
			Absolute change (billion m^3)		
Field crops	−34.2	−38.7	−47.8	3.4	−117.3
Intensive crops	−2.8	8.0	12.5	6.6	24.3
Livestock	8.1	4.7	10.8	5.9	29.5
Other agriculture	−10.3	−17.2	7.2	2.2	−18.1
Household	10.5	5.7	11.9	−21.3	6.8
Industry	28.7	37.5	5.4	3.2	74.8
			Percentage change (%)		
Field crops	−11.2	−12.6	−15.6	1.1	−38.3
Intensive crops	−3.2	8.5	13.4	7.1	25.8
Livestock	24.6	14.3	32.8	17.9	89.7
Other agriculture	−37.9	−63.5	26.6	8.1	−66.7
Household	14.8	8.1	16.8	−30.0	9.7
Industry	19.0	24.8	3.6	2.1	49.5

Table 2. Change in value of national output, all scenarios in 2030 relative to 2007 (%).

	Scenario 1	**Scenario 2**			**Total**
	Urbanization	**Non-agricultural productivity growth**	**Agricultural water saving**	**Household water saving**	
Field crops	−19.4	−21.6	42.3	2.9	4.2
Intensive crops	−1.2	5.8	34.7	2.1	41.4
Livestock	17.5	2.3	21.8	1.2	42.8
Other agriculture	−4.1	−6.6	12.7	0.8	2.8
Industry	15.2	19.6	0.6	0.2	35.6

Our results indicate that urbanization will increase the share of water consumed by domestic households and non-agricultural sectors, thereby raising the opportunity cost of using irrigation water and increasing the competition for water between non-agricultural users and irrigation water users. There are two reasons that can explain this effect of urbanization. First, urban households tend to consume more water per capita than their rural counterparts. Migrants from rural to urban areas adopt urban consumption patterns, which are considerably more water-intensive [31]. Further, urban households are generally smaller in size. It is found that compared to larger households, smaller households consume more water per capita [32]. Second, compared to rural households, urban households spend a larger share of their income on non-agricultural goods and services than on food. Therefore, the shift in household demand composition caused by urbanization may result in the expansion of non-agricultural sectors and an increase of water demand in those sectors. Finally, the positive impacts of urbanization on water usage and value of output in livestock sector may reflect the change in food consumption patterns and increasing demand for livestock products for an urbanized population. It is well documented that urbanization can accelerate the dietary transition, represented by a shift of food consumption away from staple grain and towards meat, seafood, and dairy products [33,34].

Most of the rising competition for water is captured by changes in the domestic price or shadow price of water (Table 3). Our model predicts that with urban population growth, the shadow price of water in all nine river basins will rise. The projected highest shadow price increase due to urbanization is for Haihe and Luanhe Rivers Basin, which is 4.2 CNY per m^3. This region contains Beijing-Tianjin-Hebei urban cluster, a rapidly growing urban cluster with high degree of industrial concentration.

Table 3. Change in shadow price of water, all scenarios in 2030 relative to 2007 (CNY per m^3).

	Scenario 1	**Scenario 2**			**Total**
	Urbanization	**Non-agricultural productivity growth**	**Agricultural water saving**	**Household water saving**	
SE	2.4	1.6	−0.8	−0.6	2.6
ZH	3.6	3.1	−0.9	−1.0	4.8
YT	3.3	2.3	−0.5	−1.4	3.7
SW	0.9	0.4	−0.3	−0.6	0.4
HA	1.4	0.9	−0.5	−0.7	1.1
SL	1.1	0.5	−0.8	−0.1	0.7
IL	1.4	1.0	−1.3	−0.2	0.9
YE	2.5	1.7	−1.6	−0.3	2.3
HL	4.2	2.2	−0.7	−1.1	4.6

Note: Southeast Rivers Basin (SE); Zhujiang River Basin (ZH); Yangtze River Basin (YT); Southwest Rivers Basin (SW); Huaihe River Basin (HA); Songhuajiang and Liaohe Rivers Basin (SL); Inland Rivers Basin (IL); Yellow River Basin (YE); Haihe and Luanhe Rivers Basin (HL). 1 CNY ≈ 0.16 US dollars.

4.2. Scenario 2: Economic Structural Change

Column 2 of Tables 1 and 2 shows the impacts of non-agricultural productivity growth on changes in water usage and value of output respectively. With higher income resulting from productivity growth, households slightly increase their share of water usage by 5.7 billion m^3. Non-agricultural sectors substantially increase their share of water usage by 37.5 billion m^3. For agricultural sectors, field crops and other agriculture have reductions in water usage while intensive crops and livestock experience increases in water usage. Particularly, field crops decrease water usage by 38.7 billion m^3. In terms of value of output, field crops and other agriculture are expected to lose by 21.6% and 6.6%, while intensive crops and livestock are expected to increase by 5.8% and 2.3% respectively. Again, non-agricultural sectors obtain a significant increase of 19.6% in value of output.

Non-agricultural productivity increases, usually via primary-factor saving technological change, raise the shadow price of water. As water becomes more valuable in terms of non-agricultural production, non-agricultural industries increase the share of water consumption at the expense of decreasing water use in agriculture. This has important implications for irrigation water allocation and agricultural operations. First, as shadow value increases and the competition for water grows, field crop production, which is water-intensive but with relatively lower economic values, becomes the marginal water user and is more likely to reduce water use than intensive crop production. This has also resulted in the changes of output associated with different agricultural practices. Particularly, a substantial drop in value of output is observed for water-intensive field crops. Second, the increase in non-agricultural GDP due to productivity growth increases income or expenditures per capita in urban areas, which may lead to higher local demand for livestock and intensive crops such as vegetables, fruit, and horticultural products. Given the two reasons described above, in the long run, farmers have the incentive to shift their agricultural operations from traditional field crop production to higher-value livestock or intensive crop production. Accordingly, more irrigation water and primary factors are diverted to livestock and intensive crop production. On the contrary, field crops such as rice and cotton, which heavily rely on access to low-cost irrigation water, may face shrinking operational scales as well as further reductions in water usage.

Columns 3 and 4 of Tables 1 and 2 demonstrate the effects of water use efficiency improvements in agricultural production and household consumption. As anticipated, agricultural water efficiency improvements have strong negative effects on water usage of field crops and household water efficiency improvements have strong negative effects on water usage of households. Because of these two forms of water savings, more water is diverted from field crops and households and becomes available to other sectors. Further, although agricultural water saving reduces water usage in field crops, it exhibits positive effects on value of output for all industries.

Overall, agriculture is expected to transfer roughly 17.7% of its water to non-agricultural sectors in this simulation. However, all agricultural sectors have increases in value of output (Column 5 of Table 2). The results of our study support the findings of other studies [16,22] that a reduction in agricultural water use does not necessary have a negative effect on agricultural sector profitability. We expect that agricultural water use efficiency improvement plays an important role in counterbalancing the negative effects of reduced water supply in agriculture. In addition, other than the amount of irrigation water use, factors including world market conditions, government strategies, and consumer preferences all contribute to agricultural sector performance.

Column 5 of Table 3 shows the total impacts of urbanization and economic structural change on the change in the shadow price of water. Our results indicate that regions containing rapidly growing urban centers or industrial development zones experience the largest increases in the shadow price of water. Urbanization and industrial transformation raise the opportunity cost of water use for all regions, which is most significant for more developed urban areas. For example, the price increases in Haihe and Luanhe River Basin and in Yangtze River Basin amount to 4.6 and 3.7 CNY per m^3 respectively. The former embraces Beijing-Tianjin-Hebei urban cluster and the latter has Yangtze River Delta urban cluster.

4.3. Macroeconomic Outcomes

Table 4 displays changes in a number of national macroeconomic indicators in all scenarios relative to 2007. From the results we can see that national economic growth is largely attributable to urbanization and non-agricultural productivity growth. Agricultural and household water savings, which promote more efficient water use and allocation, account for a limited portion of the total influence.

Table 4. Change in national macroeconomic outcomes, all scenarios in 2030 relative to 2007 (%).

	Scenario 1	**Scenario 2**			**Total**
	Urbanization	**Non-agricultural productivity growth**	**Agricultural water saving**	**Household water saving**	
Real GDP	16.6	22.3	0.6	0.1	39.6
Real consumption	15.9	21.2	0.5	0.1	37.7
Real investment	20.1	25.0	0.4	0.1	45.6
Export volume	17.2	25.9	0.3	0.1	43.5
Import volume	11.5	15.8	0.1	0.0	27.4
Employment	13.2	4.7	0.0	0.0	17.9

The total increases in real GDP and real consumption due to projected socioeconomic changes vary from region to region (Table 5). Regions including Zhujiang River Basin, Yangtze River Basin, and Haihe and Luanhe Rivers Basin are projected to experience the most significant growth in real GDP and real consumption. This is consistent to our expectation as those are the regions currently undergoing rapid urban expansion or non-agricultural productivity growth. In addition, our results indicate that the regional imbalance of economic growth contributes to the change in spatial patterns of employment. Generally, regions with greater economic growth encounter larger increase in employment, while regions with smaller economic growth have less increase or even decline in employment. Continuing urbanization and industrial transformation within a region prompt regional economic growth and create nonagricultural working opportunities, which in turn reinforces the regional imbalance of the distribution of employment.

Table 5. Total change in regional macroeconomic outcomes, 2030 relative to 2007 (%).

Region	**Real GDP**	**Real consumption**	**Real investment**	**Export volume**	**Import volume**	**Employment**
SE	49.1	47.3	42.1	32.7	22.0	22.7
ZH	64.3	59.4	89.8	61.3	43.7	32.0
YT	59.4	57.2	83.3	66.9	30.8	33.5
SW	17.7	16.8	27.5	37.5	31.4	−2.7
HA	30.7	29.2	38.7	32.4	34.6	15.4
SL	28.2	27.0	24.5	31.9	17.2	12.6
IL	12.3	10.6	12.1	36.4	10.1	−3.4
YE	25.6	24.8	25.0	34.7	33.3	8.6
HL	63.3	64.9	77.7	67.4	32.1	34.4
National	39.6	37.7	45.6	43.5	27.4	17.9

Note: Southeast Rivers Basin (SE); Zhujiang River Basin (ZH); Yangtze River Basin (YT); Southwest Rivers Basin (SW); Huaihe River Basin (HA); Songhuajiang and Liaohe Rivers Basin (SL); Inland Rivers Basin (IL); Yellow River Basin (YE); Haihe and Luanhe Rivers Basin (HL).

The main mechanism by which urbanization affects real GDP is via investment and the growth of capital stocks. As people migrate from rural to urban areas, they tend to spend relatively more on capital-intensive goods such as housing, automobiles, and electrical appliances. A large increase in demand of capital-intensive goods requires the expansion of those non-agricultural sectors, which can stimulate investment and capital accumulation in the country.

Finally, there are several limitations associated with our study. First, without detailed information about crops at the regional level, we are not able to model rainfed and irrigated agriculture separately. As most studies which use TERM-Water to model agricultural water use (e.g., [22]), in this study water is not modeled as being appurtenant to land but is incorporated in the production function as a separate input. In addition, the model used in the study is comparative static and cannot assess progressive demographic change and trade liberalization over time.

5. Conclusions

It is anticipated that pressure on existing water resources in China will become greater with undergoing rapid demographic transformation, economic development, and global climate changes. Increasing water scarcity and rising competition for water from domestic households and non-agricultural industries combined are expected to have important implications for water resources allocation, rural livelihoods, and the overall economy. Our study aims to develop an integrated hydro-economic CGE system to examine the economy-wide impacts of projected urban population growth and economic structural change on water use and allocation in China while accounting for multi-regional linkages and inter-sector feedbacks. This is realized by dividing the whole country into nine river basins, constructing water accounts for individual watershed regions, and modeling each watershed region as a separate economy with links to other regions.

The results indicate that urbanization and industrial transformation in China will increase the share of water consumed by domestic households and non-agricultural industries, thereby raising the opportunity cost of using irrigation water and increasing the competition for water between non-agricultural users and irrigation water users. The growth in water demand for domestic and industrial uses reduces the amount of water allocated to agriculture, particularly lower-value and water-intensive field crops. As a response, farmers have the incentive to shift their agricultural operations from traditional field crop production to higher-value livestock or intensive crop production. In addition, our results suggest that growing water demand due to urbanization and industrial transformation will raise the shadow price of water in all nine river basins. Finally, we find that national economic growth is largely attributable to urbanization and non-agricultural productivity growth.

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Author Contributions

Li Jiang conceptualized and designed the study, designed the model, and wrote the paper. Feng Wu jointly designed the model, collected the data, and analyzed the data. Yu Liu jointly designed the model, and assisted in interpretation of data and analysis. Xiangzheng Deng jointly designed the study, and assisted in interpretation of data and analysis. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Piao, S.; Ciais, P.; Huang, Y.; Shen, Z.; Peng, S.; Li, J.; Zhou, L.; Liu, H.; Ma, Y.; Ding, Y.; *et al*. The impacts of climate change on water resources and agriculture in China. *Nature* **2010**, *467*, 43–51.
2. Shindell, D.; Faluvegi, G.; Lacis, A.; Hansen, J.; Ruedy, R.; Aguilar, E. Role of tropospheric ozone increases in 20th century climate change. *J. Geophys. Res.* **2006**, *111*, Article D08302.
3. Rosegrant, M.W.; Cai, X.; Cline, S.A. *World Water and Food to 2025: Dealing With Scarcity*; International Food Policy Research Institute: Washington, DC, USA, 2002.
4. Oki, T.; Kanae, S. Global hydrological cycles and world water resources. *Science* **2006**, *313*, 1068–1072.
5. Deng, X.; Zhang, F.; Wang, Z.; Li, X.; Zhang, T. An extended input output table compiled for analyzing water demand and consumption at county level in China. *Sustainability* **2014**, *6*, 3301–3320.
6. Zhai, P.; Zhang, X.; Wan, H.; Pan, X. Trends in total precipitation and frequency of daily precipitation extremes over China. *J. Clim.* **2005**, *18*, 1096–1108.
7. National Bureau of Statistics of China (NBSC). *China Statistical Yearbooks (2007)*; China Statistics Press: Beijing, China, 2008
8. Yang, H.; Zhang, X.H.; Zehnder, J.B. Water scarcity, pricing mechanism and institutional reform in northern China irrigated agriculture. *Agric. Water Manag.* **2003**, *61*, 143–161.
9. National Bureau of Statistics of China (NBSC). *China Statistical Yearbooks (2010)*; China Statistics Press: Beijing, China, 2011.
10. Calzadilla, A.; Rehdanz, K.; Tol, R.S. The economic impact of more sustainable water use in agriculture: A computable general equilibrium analysis. *J. Hydrol.* **2010**, *384*, 292–305.
11. Dixon, P.; Parmenter, B.; Sutton, J.; Vincent, D. *ORANI: A Multisectoral Model of the Australian Economy*; North-Holland Publishing Company: Amsterdam, The Netherlands, 1982.
12. Berrittella, M.; Rehdanz, K.; Tol, R.S.; Zhang, J. The impact of trade liberalization on water use: A computable general equilibrium analysis. *J. Econ. Integr.* **2008**, *23*, 631–655.
13. Seung, C.K.; Harris, T.R.; MacDiarmid, T.R.; Shaw, W.D. Economic impacts of water reallocation: A CGE analysis for the Walker River Basin of Nevada and California. *J. Region. Anal. Pol.* **1998**, *28*, 13–34.
14. Decaluwe, B.; Patry, A.; Savard, L. *When Water is No Longer Heaven Sent: Comparative Pricing Analysis in an AGE Model*; Working Paper 9908, CRE´FA 99–05; De´partment d'e´conomique, Universite´ Laval: Québec, QC, Canada, 1999.
15. Letsoalo, A.; Blignaut, J.; de Wet, T.; de Wit, M.; Hess, S.; Tol, R.S.J.; van Heerden, J. Triple dividends of water consumption charges in South Africa. *Water Resour. Res.* **2007**, *43*, Article W05412.

16. Watson, P.S.; Davies, S. Modeling the effects of population growth on water resources: A CGE analysis of the South Platte River Basin in Colorado. *Ann. Region. Sci.* **2011**, *46*, 331–348.
17. Wittwer, G., Ed. *Economic Modeling of Water: The Australian CGE Experience*; Springer: New York, NY, USA, 2012.
18. Berrittella, M.; Rehdanz, K.; Tol, R.S. The economic impact of the South-North Water Transfer Project in China: A computable general equilibrium analysis. Available online: http://dx.doi.org/10.2139/ssrn.952938 (accessed on 15 March 2014).
19. Horridge, M.; Madden, J.; Wittwer, G. Using a highly disaggregated multi-regional single-country model to analyse the impacts of the 2002–2003 drought on Australia. *J. Pol. Model.* **2005**, *27*, 285–308.
20. Peterson, D.; Dwyer, G.; Appels, J.; Fry, J. Water trade in the southern Murray-Darling basin. *Econ. Rec.* **2005**, *81* (Suppl. S1), S115–S127.
21. Wittwer, G.; Griffith, M. Modeling drought and recovery in the southern Murray-Darling Basin. *Aust. J. Agric. Resour. Econ.* **2011**, *55*, 342–359.
22. Ejaz Qureshi, M.; Proctor, W.; Young, M.D.; Wittwer, G. The economic impact of increased water demand in Australia: A computable general equilibrium analysis. *Econ. Pap. J. Appl. Econ. Pol.* **2012**, *31*, 87–102.
23. Guan, D.; Hubacek, K. A new and integrated hydro-economic accounting and analytical framework for water resources: A case study for North China. *J. Environ. Manag.* **2008**, *88*, 1300–1313.
24. Zhao, J.; Wang, Z.; Wang, D.; Wang, D. Evaluation of economic and hydrologic impacts of unified water flow regulation in the Yellow River Basin. *Water Resour. Manag.* **2009**, *23*, 1387–1401.
25. Yuan, R.; Zhu, J.; Tao, X.; Mao, C. Application of shadow price method in calculation of water resources theoretical value. *J. Nat. Resour.* **2002**, *17*, 757–761.
26. Feng, S.; Li, L.; Duan, Z.; Zhang, J. Assessing the impacts of South-to-North Water Transfer Project with decision support systems. *Decis. Support Syst.* **2007**, *42*, 1989–2003.
27. Horridge, M.; Wittwer, G. SinoTERM, a multi-regional CGE model of China. *China Econ. Rev.* **2008**, *19*, 628–634.
28. Liu, X.; Chen, X.; Wang, S. Evaluating and predicting shadow prices of water resources in China and its nine major river basins. *Water Resour. Manag.* **2009**, *23*, 1467–1478.
29. United Nations. *World Urbanization Prospect: The 2011 Revision*; United Nations: New York, NY, USA, 2012.
30. Dixon, P.; Rimmer, M. Dynamic general equilibrium modelling for forecasting and policy: A practical guide and documentation of MONASH. In *Contributions to Economic Analysis*; Blundell, R., Caballero, R., Laffont, J.J., Persson, T., Eds.; North-Holland Publishing Company: Amsterdam, The Netherlands, 2002.
31. Hassan, R.; Thurlow, J. Macro-micro feedback links of water management in South Africa: CGE analyses of selected policy regimes. *Agric. Econ.* **2011**, *42*, 235–247.
32. Domene, E.; Saurí, D. Urbanisation and water consumption: Influencing factors in the metropolitan region of Barcelona. *Urban Stud.* **2006**, *43*, 1605–1623.
33. Pingali, P. Westernization of Asian diets and the transformation of food systems: Implications for research and policy. *Food Pol.* **2007**, *32*, 281–298.

34. Popkin, B.M. Urbanization, lifestyle changes and the nutrition transition. *World Dev.* **1999**, *27*, 1905–1916.