

Chapter 12

Water Subdivision Module and Its Application—Impact of Water Price Reform on Water Conservation and Economic Growth in China



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Abstract Water pricing has been used as an effective way to conserve water and optimize water allocation. However, little is known about how to set a rational and efficient water price and how water pricing impacts economic growth. In this chapter we address this challenge using a dynamic general equilibrium model for China that is augmented by a total water constraint module. We also include a water subdivision module, allowing for substitution between various water sources. These extensions facilitate a comprehensive estimate of the impact that various water price reforms have on water conservation and economic growth. Modelling results confirm that an increase in the water price will lead to a decline in total water usage, a better water-use structure, and enhanced water use efficiency. We conclude with a comparison of multiple scenarios, which suggests an optimal water price system.

Keywords Water pricing · Water constraint · Water subdivision · Water conservation · Economic growth · China

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12.1 Introduction

China's burgeoning economic growth has been accompanied by soaring water use and has generated increasing excess demand for water resources (Huang et al. 2015). Efforts to address potential water scarcity problems have focused on the demand side of water management (He et al. 2007). Water managers and planners in China have given high priority to the allocation and development of water supply and the management of water prices, while the management of demand and improvement of water use patterns have received less attention (Jurian et al. 2013). The growing concern among researchers and policy makers with the continuous growth in global water demand has motivated some analysts, e.g., Calzadilla et al. (2007) and Louw and Kassier (2002), to embrace water demand management as a means of solving the current water crisis. Since the water price is one of the most effective tools to regulate water supply and demand, the Chinese government has continually attached great importance to water pricing (Jiang et al. 2014). However, problems associated with water pricing mechanisms in China still exist, including underpricing and nonstandard pricing in some regions. In addition, water endowments in some areas cannot adapt to economic development (Shen et al. 1999). Since water pricing in China is determined in some regions by top-down administrative commands rather than by a market, many water companies cannot recover their supply costs. The current pricing system is therefore unable to accurately account for the commodity attributes of water, so significant water pricing reform in China is necessary (Yu and Shen 2014).

Recognition of people's response to changes in the water price provides important information for those who are responsible for water policy formulation and water resource planning. However, assessment of the impact of revisions to China's water price policy has stagnated at the stage of qualitative description and rough estimation. Some research systematically investigated water price issues worldwide, but most work involved qualitative analyses (e.g., Eileen et al. 2013; Zuo et al. 2014). In contrast, Espey et al. (1997), Nauges and Thomas (2003) and Grafton et al. (2011) presented quantitative analyses using econometric methods. In general, Computable General Equilibrium (CGE) models have emerged as widely-applied and effective analytical tools in water pricing policy analysis. Since Berck's (1991) first application of a CGE model to water problems, CGE models for water have been continually refined and improved. For example, Chou et al. (2001) used a single-country water resources CGE model—WATERGEM—which included municipal water, surface water and ground water to investigate the double dividend effects of imposing water rights fees. Simulation results demonstrated that a double-dividend effect existed, and that its deduction from corporate taxes had an evident effect. The simulation results also showed that water demand decreased when water rights fees were imposed. Berrittella et al. (2007) developed a GTAP-W model to investigate the role of water resources and water scarcity resulting from reduced availability of groundwater, and identified regional winners and losers. Moreover, the water supply constraints were found to improve allocation and efficiency. Calzadilla et al. (2007) also used the

GTAP-W model to analyze the macroeconomic impacts of enhanced irrigation efficiency. The results indicated that global water conservation was achieved. For water-stressed regions, the effects on welfare and demand for water were generally positive, while for non-water scarce regions the results were mixed and mostly negative. Hassan et al. employed the TACOGE-W model which disaggregated agricultural and nonagricultural water use and contained detailed information on production, trade and consumption to examine the impacts of water-related policy reforms on water use and allocation, rural livelihoods, and the macro economy. The simulation results showed that allowing for water trade between irrigation and non-agricultural users lead to higher water shadow prices for irrigation water, with reduced income and employment benefits to rural households and increased gains for non-agricultural households. Wittwer et al. (2012) used the TERM-H2O model, a special version of the TERM model (The Enormous Regional Model), to analyze water policy issues in the Murray-Darling Basin in Australia. This model recognized 50 regions and 170 sectors. The results did not support the pessimistic view that buybacks worsened the plight of farmers. Conversely, buybacks were shown to increase economic activity, and were of benefit to farmers.

Existing research on the impact of water price reform on water usage and economic growth appears to pay little attention to: (1) Substitution between various types of water sources; (2) differentiated pricing of different types of water sources; and (3) the total water constraint. To fill this gap in this area we extended a dynamic CGE model—SICGE (State Information Centre General Equilibrium) model by introducing a total water constraint module and a water subdivision module with a substitution relationship between different water sources. To investigate the impact of water price reform on water usage among different users, in the water subdivision module, we divide water users into six categories based on the volume of water usage and sector classification. To further investigate the substitution relation between different water sources, water sources are divided into four categories. In this study, our baseline simulation spans a period of 14 years (2007–2020). We implement a water price policy change in 2011, with the resulting policy simulation analysis encompassing the period from 2011 to 2020. Crucial factors for designing pricing policies for water demand management include water conservation, water structure, water use efficiency and economic impact.

The paper is structured as follows. In Sect. 12.1, we provide some contextual background to the study by reviewing the pertinent literature. Section 12.2 outlines the modelling framework and data sources, while Sect. 12.3 describes the baseline scenario. We then discuss policy scenarios and the simulation results in Sect. 12.4, and present a summary of key findings and a discussion of future considerations and extensions in Sect. 12.5.

12.2 Modelling Framework

This study uses the SICGE model, a recursive dynamic CGE model of the Chinese economy. The SICGE model is based on China's 2007 Input–output table and has 42 sectors. As a classical CGE model applied to China, it was created for China's State Information Centre (SIC) by the Centre of Policy Studies (CoPS) in Australia (Li and Zhang 2012; Mai et al. 2014). The SICGE model is the earliest version of CHINAGEM model. The core CGE structure is based on ORANI, a static CGE model of the Australian economy (Dixon et al. 1982, 2005; Horridge et al. 2005; Dixon and Jorgenson 2013). The dynamic mechanism of SICGE is based on the MONASH model of the Australian economy (Dixon and Rimmer 2002; Panida et al. 2013; Khalid and Harald 2014).

12.2.1 SICGE Model

The SICGE model is a set of equations that describe supply–demand balance relations throughout the economic system. They are constrained by a series of optimizing conditions: optimization of producer profit, consumer benefit, import profit as well as export cost. The solution of the equation system yields a set of quantities and relative prices that correspond to an economy-wide general equilibrium. The model includes six economic agents: a single producer, investor, household, government, and foreign country agent (or rest of the world agent), along with an inventory agent/account. Each sector minimizes unit costs subject to given input prices and a constant-returns-to-scale (CRS) production function. Consumer demands are modelled via a representative utility maximizing household. Consumers get paid and use their income to consume goods and services. Subject to budget constraints, consumers achieve the highest possible benefit or utility by choosing the best combination of goods and services. Government revenues come from taxes and fees, while government spending includes various public undertakings, transfer payments and policy-oriented subsidies. The model assumes that the path of total government demand follows the path of household total consumption. The model also adopts flexible linkage mechanisms. A Constant Elasticity of Transformation (CET) Equation is usually adopted to describe the process of optimized allocation of output between domestic commodities, and between the domestic market and exports for ultimately optimizing profits. Imperfect substitutability between imported and domestic varieties of each commodity is modelled using the Armington constant-elasticity-of-substitution (CES) specification (Walras 1969; Johansen 1960; Dixon et al. 1982, 2005; Dixon and Rimmer 2002; Horridge et al. 2005).

There are three primary factors: land, labour and capital. Capital and labour are perfectly mobile domestically, and capital is also mobile internationally, i.e., between China and the rest of the world. In contrast, land is sector-specific. The value of the

elasticity of substitution between factors is based on the findings of Burniaux and Truong (2002).

12.2.2 *The Extension of the SICGE Model*

The existing SICGE model has only one water sector. It does not consider different types of water sources with substitution relations. To achieve the objectives of this study, the China Institute of Water Resources and Hydropower Research (IWHR) and the State Information Center (SIC) have cooperated to develop a water pricing analysis model, which is based on the SICGE model and entitled the WPSICGE (Water pricing SICGE) model. This extended model combines the water subdivision module with the substitution relationship between different types of water sources and the total water constraint module. In WPSICGE, the water sector is subdivided into four sub-sectors; each sub-sector produces one of the four types of water commodities: raw water, tap water, recycled water and desalinated water. In this paper, raw water refers to water that is obtained directly from the surface or underground without disinfection treatment. Tap water refers to water that is produced by water works and needs to be purified and disinfected by successive procedures. Tap water is derived from raw water and must conform to relevant standards for human consumption and production. Recycled water refers to waste water and rain, which after appropriate treatment meets quality standards of recycled water. Desalinated water refers to fresh water generated from sea water. Recycled water and desalinated water are unconventional water sources. Conventional water supply (the total amount of raw water in this model) constitutes an important constraint variable.

Using the WPSICGE model, this study will contribute to several important topics including: (1) control of water consumption under the “red line”¹ by water pricing reform; (2) quantitative evaluation of water conservation and the economic impact of water pricing reform; and (3) recommendation of a more cost efficient water pricing system by comparing multiple scenarios, and indicating a water price reform direction.

(1) Water substitution modules

In order to reflect substitution relationships between different types of water sources, we set a hierarchical structure (from bottom-to-top) shown in Fig. 12.1 using a Constant Elasticity of Substitution (CES) production function to model the producer’s decision regarding alternative water compositions in production.

We apply the CES function to reflect the substitution relationship between various types of water. Firstly, we consider raw water, which is composed of local water and

¹ “Red line” refers to the annual total raw water consumption control target set by the central government of China. It was first announced in the No. 1 Document in 2011 (Chinese State Council 2011, 2012). “Red line” was considered the most stringent water resources management system in China. The annual total raw water consumption in Tianjin must not exceed the “red line” which is 3100 million m³.

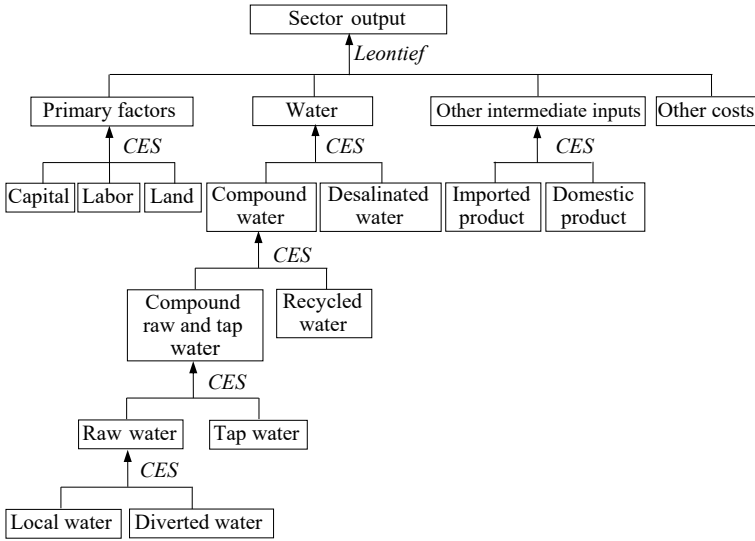


Fig. 12.1 The sectoral production structure in the water subdivision module

diverted water transferred from other regions, and can be represented in CES equation form as follows:

$$X_{\text{raw},j}^{(1)} = \text{CES} \left\{ \frac{X_{(\text{raw},s),j}^{(1)}}{A_{(\text{raw},s),j}^{(1)}}; \rho_{\text{raw},j}^{(1)}, b_{(\text{raw},s),j}^{(1)} \right\} (s = 1, 2; j = 1, \dots, n) \quad (12.1)$$

Equation (12.1) shows that intermediate input raw water $X_{\text{raw},j}^{(1)}$ used in sector j is the CES composite of local and diverted water, where $X_{(\text{raw},s),j}^{(1)}$ represents the different sources of raw water used in sector j , and s represents the source ($s = 1$ is local products; $s = 2$ is diverted products). $A_{(\text{raw},s),j}^{(1)}$ represents technological parameters, $b_{(\text{raw},s),j}^{(1)}$ are the shares different raw water sources in sector j , and $\rho_{\text{raw},j}^{(1)}$ is the constant elasticity of substitution between local water and diverted water.

We next examine the demand for the compound raw and tap water in sector j , $X_{\text{raw_tap},j}^{(1)}$ which is represented by the following CES equation:

$$X_{\text{raw_tap},j}^{(1)} = \text{CES} \left\{ \frac{X_{(\text{raw_tap},s),j}^{(1)}}{A_{(\text{raw_tap},s),j}^{(1)}}; \rho_{\text{raw_tap},j}^{(1)}, b_{(\text{raw_tap},s),j}^{(1)} \right\} (s = 1, 2; j = 1, \dots, n) \quad (12.2)$$

where $X_{(\text{raw_tap},s),j}^{(1)}$ is sector j 's demand for compound water from sources of water ($s = 1$) and tap water ($s = 2$); $A_{(\text{raw_tap},s),j}^{(1)}$ are technological parameters of water sources (raw water and tap water); $b_{(\text{raw_tap},s),j}^{(1)}$ are the shares of raw water and tap

water; and constant elasticity of substitution between raw and tap water. When compared with other sources, these two sources are strong substitutes, with an elasticity of substitution approximately 1 according to Tianjin Municipal Water Affairs Bureau.²

With the rapid development of recycled water, raw and tap water may be replaced by recycled water. The demand for composite water consisting of the compound raw-tap water from Eq. (12.2) and recycled water can be represented in CES equation form as follows.

$$X_{\text{comp},j}^{(1)} = \text{CES} \left\{ \frac{X_{(\text{comp},s),j}^{(1)}}{A_{(\text{comp},s),j}^{(1)}}; \rho_{\text{comp},j}^{(1)}, b_{(\text{comp},s),j}^{(1)} \right\} \quad (s = 1, 2; j = 1, \dots, n) \quad (12.3)$$

where $X_{(\text{comp},s),j}^{(1)}$ is the demand for compound raw-tap water ($s = 1$) and recycled water ($s = 2$) in sector j ; $A_{(\text{comp},s),j}^{(1)}$ represent technological parameters; $b_{(\text{comp},s),j}^{(1)}$ are the shares of the compound raw-tap water and recycled water (respectively); and $\rho_{\text{comp},j}^{(1)}$ is the constant elasticity of substitution between the compound raw-tap water and recycled water. The value of the elasticity of substitution $\rho_{\text{comp},j}^{(1)}$ is approximately 0.5 according to Tianjin Municipal Water Affairs Bureau.

Desalinated water is generally regarded as being weakly substitutable with the aforementioned three water sources. The CES equation for water demand (the second highest level in Fig. 12.1) in sector j is as follows.

$$X_{\text{water},j}^{(1)} = \text{CES} \left\{ \frac{X_{(\text{water},s),j}^{(1)}}{A_{(\text{water},s),j}^{(1)}}; \rho_{\text{water},j}^{(1)}, b_{(\text{water},s),j}^{(1)} \right\} \quad (s = 1, 2; j = 1, \dots, n) \quad (12.4)$$

where $X_{(\text{water},s),j}^{(1)}$ is sector j 's aggregate demand for the aforementioned three types of water ($s = 1$), and the demand for desalinated water ($s = 2$); $A_{(\text{water},s),j}^{(1)}$ represent technological parameters of compound water and desalinated water; $b_{(\text{water},s),j}^{(1)}$ are the shares of compound water and desalination water; and $\rho_{\text{water},j}^{(1)}$ is the constant elasticity of substitution between the compound water and desalination water. This elasticity of substitution is approximately 0.2 according to Tianjin Municipal Water Affairs Bureau.

(2) Later constraints module

To meet the “red line” control target of total water utilization which is the most stringent water resources management in China, the total water constraints module is added to the SICGE model.

Water is used as both an intermediate input to production, and a final consumption good. The value of water use is calculated in the model by:

² <http://www.tjsw.gov.cn/pub/tjwcb/index.html>.

$$V_w = X_w \times P_w \tag{12.5}$$

where V_w is water value, X_w is volume of water and P_w is the water price. In order to more conveniently simulate the impact of water price reform in the SICGE model, we need to transform the specific water tax, WTAX, which is levied on the volume of water, into an ad valorem tax, TAWP, which is based on the value of water.

$$WTAX_{s,j}^{(1)} \times QHY_{s,j}^{(1)} = TAWP_{s,j}^{(1)} \times \left(P_{HY,s,j}^{(1)} \times X_{HY,s,j}^{(1)} \right) \tag{12.6}$$

$$WTAX_s^{(3)} \times QHY_s^{(3)} = TAWP_s^{(3)} \times \left(P_{HY,s}^{(3)} \times X_{HY,s}^{(3)} \right) \quad (s = 1, 2, 3, 4) \tag{12.7}$$

In Eq. (12.6), $QHY_{s,j}^{(1)}$ represents the volume of water by source- s that is used as an intermediate input in production by sector j , where s is used to distinguish between the various sources of water, e.g., $s = 1, 2, 3$ and 4 represent raw, tap, recycled and desalinated water, respectively; the superscript (1) indicates that this relationship is applied to producers; $WTAX_{s,j}^{(1)}$ indicates the tax levied per cubic meter of water by source and sector; $TAWP_{s,j}^{(1)}$ indicates the ad valorem tax levied by source and sector; $P_{HY,s,j}^{(1)}$ indicates the price of water from source- s used by sector j ; and $X_{HY,s,j}^{(1)}$ indicates the amount of water used from source- s in sector j .

In Eq. (12.7), $QHY_s^{(3)}$ represents the volume of water from various sources consumed by households, with the superscript (3) indicating that this relationship applies to household consumption; $WTAX_s^{(3)}$ indicates the tax levied per cubic meter of water consumed by households; $TAWP_s^{(3)}$ indicates the ad valorem tax levied on source s by households; $P_{HY,s}^{(3)}$ indicates the price of water from different sources consumed by households; and $X_{HY,s}^{(3)}$ indicates the amount of water from different sources consumed by households.

In China, water control is applied only to raw water (tap water originates from raw water). Recycled and desalinated water are non-conventional water sources. The Chinese government encourages the use of these types of water by providing subsidies to water plants. The supply of recycled and desalinated water is limited only by production capacity, not by the total amount of water resources. The total amount of raw water consumed can be calculated as:

$$QHY = \sum_{\text{raw},j} QHY_{\text{raw},j}^{(1)} + QHY_{\text{raw}}^{(3)} \quad (j = 1, \dots, n) \tag{12.8}$$

where QHY indicates the total amount of water consumption. It cannot exceed the “red line” control target of total water utilization.

12.2.3 Case Study Area

Tianjin was selected as the case study area. It is one of China's typical coastal municipalities with a comprehensive industrial base and trade center. Per capita GDP of Tianjin ranks third in China, trailing only Shanghai and Beijing. Due to pollution and climate change, Tianjin suffers from a severe water shortage, with its per capita water resources amounting to 160 m³, only 6% of the national average. Even adding inflow and diverted water, its per capita water resources stand at only 370 m³, the lowest level of any municipality in China. Rapid economic development, pollution and climate change have exacerbated Tianjin's water scarcity. Continuing growth in water demand is expected to impart severe constraints on the availability of water resources in Tianjin. This has driven several water conservation initiatives, and the expansion of unconventional water resource industries. As discussed, four distinct sources of water now exist in this region: raw, tap, recycled, and desalinated water. Nevertheless, water is still the binding constraint on economic growth in Tianjin.

The current level of water pricing in Tianjin is still relatively low. Price discrepancies between water users of the same type of water source and the relative prices of water from different types of water sources are too narrow. As a result, the current level of water pricing could not restrain the use of water in water-intensive sector and promote the usage of unconventional water.

12.3 Baseline Scenario

To analyze the economic effects of a policy change, we first develop a baseline scenario that represents business-as-usual without implementation of any water pricing policy reforms. Subsequent to this, we construct various policy scenarios to explore the impact of different policy settings on key measures of welfare. Specifically, the effects of these alternative policies are measured by the deviations of variables from their baseline levels.

12.3.1 Data Sources and Processing

For the baseline scenario, macroeconomic data is divided into two periods: an initial "historical" period from 2007 to 2010 and a second "planned" period from 2011 to 2020. For the first period, we provide realized values for key economic variables, e.g., real GDP growth, real consumption growth, real investment growth, employment, etc., as exogenous shocks to the model. Among these shocks are realized water usage figures for the various water users, and relative prices for the four types of water sources. To develop a suitable baseline forecast over the second period of the baseline simulation, exogenous shocks were developed using economic data from

Table 12.1 Economic growth in the baseline scenario in Tianjin at the basedate year price, 2007

Categories	2008 (%)	2009 (%)	2010 (%)	2011–2015 (%)	2016–2020 (%)
GDP	16	16	16	14	11
Employment	6	5	6	6	4
Household consumption	17	10	11	14	12
Government consumption	30	44	26	17	12
Capital	19	21	26	26	17

Source Authors' calculations based on the statistics yearbook and the “five-year” plan

the Tianjin “twelfth five-year plan and 2020 vision”. In the twelfth five-year plan period, growth of GDP in Tianjin is expected to remain at 14.5% for five years, being driven primarily by investment. During this time, consumer spending is also expected to increase rapidly. The predictions for economic growth are displayed in Table 12.1.

Data used in the baseline scenario come from several sources. As with all CGE models, an initial solution is required. In the SICGE model, we use China's 2007 input–output table. The exogenous shocks for the historical period 2008–2011 are sourced from the China and Tianjin statistical yearbooks. Using the RAS (also called “biproportional scaling” method) method (Bacharach 1970) based on the initial 42 sectors in the input–output table, we obtain a 44-sector input–output table.³ The classification of 42 sectors is based on the classification standards of Classification and Code National Economy Industry (GBT4754-2002) issued by the National Bureau of Statistics. The data for disaggregating water sectors into raw, tap, recycled and desalinated water are from the Tianjin Statistical Information Net⁴ and Tianjin Municipal Water Affairs Bureau. In order to facilitate analysis of the impact of water pricing adjustments, the simulation results of 44 sectors are merged into 6 sectors according to water pricing classification, water use characteristics and industrial characteristics. These 6 sectors are listed in Table 12.2.

12.3.2 Parameters

(1) Water price

From 2007 to 2010, the prices of raw water used by the agriculture sector and desalinated water for all users did not change (Table 12.3). The price of raw water for all other users in 2008 was the same as in 2007. The price in 2009 increased by 0.02 RMB/m³ compared with the preceding year. In 2010, the price increased by a

³ Since values in the metal mining and dressing sector were all 0 we ignored this sector.

⁴ <http://www.stats-tj.gov.cn/>.

Table 12.2 44 sectors merging into 6 sectors

6 sectors	42 sectors base on the National Economy Industry Classification
Agriculture	Agriculture, forestry, husbandry, subsidiary, fishery
General industry	Coal mining and washing sector; oil and gas sector; textile sector; textile clothing, shoes, hats; leather, down and their products; timber processing and furniture manufacturing; metal smelting and rolling processing sector; fabricated metal products; general and special equipment manufacturing; transportation equipment manufacturing; electric machinery and equipment manufacturing; telecommunications equipment; computers and other electronic equipment manufacturing; instrumentation and office machinery manufacturing; handicrafts and other manufacturing sector; gas production and supply sector; water production and supply sector
Water-intensive industry	Other non-metallic mineral ore mining; food production and tobacco processing; paper making or printing, stationery and sporting goods manufacturing sector; oil processing, coking and nuclear fuel processing sector; chemical sector; non-metallic mineral products; electric power; heat production and supply
Construction	Construction sector
General service	Accommodation and catering; household services and other services

further 0.03 RMB/m³. For tap water, the price for all users in 2008 was the same as in 2007. In 2009, the price increased by 0.05 RMB/m³. In 2010, the price increased by a further 0.5 RMB/m³ to reach 7.2 RMB/m³ for industry, construction and general service, 21.1 RMB/m³ for water-intensive service, and 4.4 RMB/m³ for households. For recycled water, the price for all users in 2008 was the same as in 2007. In 2009 the price used in general industry and water-intensive industry increased by 1.9 RMB/m³ (Table 12.3). In the general service sector it increased by 1.5 RMB/m³, while in the water-intensive service sector it increased by 2.2 RMB/m³. The price for all users in 2010 was the same as in 2009.

In the forecast period of 2011–2020, we assume that water prices of all different types remain the same as in 2010.

(2) Water usage

Water usage for the first period is based on actual economic growth. Results are shown in Tables 12.4 and 12.5. The total amount of water usage was 2.33 billion m³ in 2007. Due to the increase in water prices in the initial time period, which was discussed in the previous section, water usage declined. In 2010, total water usage was 2.13 billion m³.

From Table 12.4, we can see that the agriculture sector only uses raw water. The industry sector uses water from all sources, while the service sector mainly use raw water, tap water and recycled water. The construction sector and households use only raw water and tap water. Table 12.5 shows that the share of the agricultural sector in total water usage was 60.24% in 2007, followed by water-intensive industry (14.48%) and households (13.54%). The water usage shares of the agriculture and

Table 12.3 Water pricing of Tianjin from 2007 to 2010 at the baseline year price (2007) (unit: RMB/m³)

Years	Water source	Agriculture	General industry	Water-intensive industry	Construction	General service	Water-intensive service	Households
2007	Raw water	0.2	1.03	1.03	1.03	1.03	1.03	1.03
	Tap water	–	6.2	6.2	6.2	6.2	20.1	3.4
	Recycled water	–	1.2	1.2	–	1.5	1.8	–
	Desalinated water	–	4	4	–	–	–	–
2008	Raw water	0.2	1.03	1.03	1.03	1.03	1.03	1.03
	Tap water	–	6.2	6.2	6.2	6.2	20.1	3.4
	Recycled water	–	1.2	1.2	–	1.5	1.8	–
	Desalinated water	–	4	4	–	–	–	–
2009	Raw water	0.2	1.05	1.05	1.05	1.05	1.05	1.05
	Tap water	–	6.7	6.7	6.7	6.7	20.6	3.9
	Recycled water	–	3.1	3.1	–	3.1	4	–
	Desalinated water	–	4	4	–	–	–	–
2010	Raw water	0.2	1.08	1.08	1.08	1.08	1.08	1.08
	Tap water	–	7.2	7.2	7.2	7.2	21.1	4.4
	Recycled water	–	3.1	3.1	–	3.1	4	–
	Desalinated water	–	4	4	–	–	–	–

Source: Tianjin Water Authority, Tianjin Water Resources communiqué

Table 12.4 The water usage in the baseline scenario in Tianjin (unit: million m³)

User	Resources	2007	2010	2015	2020
Agriculture	Raw water	140,600.00	111,969.00	131,247.78	144,514.05
	Tap water	–	–	–	–
	Recycled water	–	–	–	–
	Desalinated water	–	–	–	–
General industry	Raw water	1310.00	1984.00	3268.61	5240.15
	Tap water	6746.00	12,716.00	20,921.03	33,646.01
	Recycled water	0	1.10	3.42	6.31
	Desalinated water	180.00	270.00	646.11	1324.04
Water-intensive industry	Raw water	18,563.00	19,909.00	26,355.56	33,764.48
	Tap water	14,111.00	12,547.00	14,477.23	16,412.68
	Recycled water	1070.00	801.00	1341.36	2103.44
	Desalinated water	20.00	30.00	52.79	85.53
Construction	Raw water	399.00	399.00	583.00	856.42
	Tap water	1501.00	2061.00	3019.32	4451.81
	Recycled water	–	–	–	–
	Desalinated water	–	–	–	–
General service	Raw water	1291.00	1639.00	3213.28	5737.67
	Tap water	7368.00	8753.00	18,199.02	34,697.49
	Recycled water	282.00	436.00	828.54	1353.85
	Desalinated water	–	–	–	–
Water-intensive service	Raw water	1810.00	1027.00	1387.43	1902.64
	Tap water	6567.00	3225.00	4585.98	6308.11
	Recycled water	0	0.29	0.41	0.58
	Desalinated water	–	–	–	–
Households	Raw water	14,500.00	12,300.00	12,853.05	13,285.96
	Tap water	17,100.00	22,600.00	29,320.85	37,601.42
	Recycled water	–	–	–	–
	Desalinated water	–	–	–	–
Total	Raw water	178,473.00	149,227.00	178,908.71	205,301.37
	Tap water	53,393.00	61,902.00	90,523.43	133,117.52
	Recycled water	1352.00	1238.39	2173.73	3464.18
	Desalinated water	200.00	300.00	698.90	1409.57
Total		233,418.00	212,667.39	272,304.77	343,292.64

Source Tianjin Water Authority, Tianjin Water Resources communiqué and development plan

Table 12.5 The shares of water usage by users in the baseline scenario in Tianjin

Water usage	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2015 (%)	2020 (%)
Agriculture	60.24	62.87	58.71	52.66	48.20	42.07
General industry	3.51	4.90	5.39	7.05	9.10	11.73
Water-intensive Industry	14.48	11.14	14.17	15.66	15.52	15.25
Construction	0.81	0.86	1.13	1.18	1.32	1.54
General service	3.81	3.09	3.67	5.08	8.18	12.19
Water-intensive service	3.60	2.43	2.04	2.02	2.20	2.39%
Households	13.54	14.71	14.89	16.41	15.48	14.81%

Source Authors' calculations based on Tianjin Water Authority, Tianjin Water Resources communiqué and development plan

water-intensive service sectors have declined from 2007 to 2010, while the shares of the construction and general industry sectors have increased steadily (Table 12.5).

Table 12.6 shows the structure of water use by water source. The share of raw water in total water usage was 76.50% in 2007, followed by tap water (22.90%). The share of raw water decreased from 2007 to 2010 while the share of tap water increased.

The assumptions about water usage for the second period (2011–2020) are based on economic growth trends and the Twelfth Five-year Plan of Water Conservancy Development (Tianjin Water Authority). Results are shown in Tables 12.4 and 12.5. In the 12th five-year period, the annual growth rate of total water usage in Tianjin is forecast to be 5.1%. This rate is forecast to fall to 4.7% in the 13th five-year period (Table 12.7).

The growth in general service sector consumption is forecast to be the most rapid, followed by general industry and the construction sector. The agriculture sector will experience the slowest growth, due to forecast efficiency gains via advances in water-saving irrigation technology, e.g., trickle irrigation. As a result, the share of agriculture water usage will decrease. The shares of the general industry and the general service sectors show a faster rate of growth than the water-intensive industry and water-intensive service sectors (Table 12.5). Because of the assumption

Table 12.6 The shares of water usage from different sources in the baseline scenario in Tianjin

Usage structure	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2015 (%)	2020 (%)
Raw water	76.50	73.50	73.40	69.80	65.70	59.80
Tap water	22.90	26.00	25.90	29.50	33.20	38.80
Recycled water	0.60	0.40	0.50	0.60	0.80	1.00
Desalinated water	0.10	0.10	0.10	0.10	0.30	0.40

Source Authors' calculations based on Tianjin Water Authority, Tianjin Water Resources communiqué and development plan

Table 12.7 The growth rate of water in the baseline scenario in Tianjin

Water usage	2008 (%)	2009 (%)	2010 (%)	Average annual growth rate	Average annual growth rate
				2011–2015 (%)	2015–2020 (%)
Agriculture	−6.05	−1.82	−13.65	3.2	1.9
General industry	25.61	15.53	26.05	10.7	10.2
Water-intensive Industry	−30.77	33.76	6.39	4.9	4.4
Construction	−5.26	38.89	0.00	8.0	7.9
General service	−26.97	24.62	33.33	15.5	13.5
Water-intensive service	−39.29	−11.76	−4.44	7.1	6.6
Households	−2.22	6.47	6.08	3.9	3.8
Total	−9.98	5.14	−3.71	5.1	4.7

Source Authors' calculations based on Tianjin Water Authority, Tianjin Water Resources communiqué and development plan

of unchanged water prices from 2011 to 2020, water usage will continue to rise and the total amount of water usage will reach to 3.43 billion m³ in 2020.

From Table 12.6, we can see that the share of raw water in total water usage will continue to decline to 59.80% in 2020, while the share of tap water will continue to rise, reaching 38.80% in 2020. The total usage of recycled water and desalinated water will increase from 2011 to 2020, to 1.0% and 0.4%, respectively.

(3) Other parameters

The labour demand elasticity for all sectors was 0.243 according to the Chinese Academy of Social Sciences (Zheng and Fan 2008). The consumer price elasticity was set at 4 according to the PRCGEM model data of the Chinese Academy of Social Sciences (Zheng and Fan 2008). Per capita income of Tianjin has reached the level of upper middle-income countries, so the Frisch parameter⁵ in the Linear Expenditure System (LES) should be −2 (Dervis et al. 1982). The Armington elasticity is the elasticity of substitution between imports and native commodities. For the present study, its value of 2 was obtained from the Tianjin Statistical Information Net. The elasticity of substitution between primary factors in the CES production function is 0.5, derived from the Tianjin Statistical Information Net.

Values for the CET elasticity (substitution elasticity of domestic commodity exports and sale in domestic market), elasticity of households demand expenditure, etc. were obtained from the China Version of the ORANI-G model of CoPS at Victoria University (Horridge 2006).

⁵ Frisch parameter = $-(x_{\text{total}}/x_{\text{luxuty}})$ in CGE model, where x_{total} indicates total household expenditure, x_{luxuty} indicates luxury expenditure in total household expenditure.

12.3.3 Baseline Forecast Results

The baseline simulation results show that if the water price were to remain at the 2010 level, total water consumption would reach 3.433 billion m³ in Tianjin by 2020 (Table 12.4). This projection is consistent with the estimate of 3.434 billion m³ from water supply planning by the Tianjin Water Bureau. Meanwhile, consumption projections of raw, tap, recycled, and desalinated water are also similar to those of the Tianjin Water Bureau. The baseline scenario developed in this paper is therefore consistent with the forecasts generated by the Tianjin Water Bureau.

12.4 Policy Simulation Results and Discussions

Our policy scenarios focus upon exogenous shocks to the water price. The impact of the water price changes are subsequently measured via deviations of endogenous variables from their baseline levels. We use two main indicators to judge whether a water price system is rational: (1) Whether the amount of water usage is within the bearing capacity of water resources; and (2) Whether the water structure (the share of water used by sources and users) is optimized.

Since the sensitivity or responsiveness of different users to changes in the price of water is different, the effect of water price reform will differ across users and sources. In order to design an optimal water price policy, we first calculate the price elasticity of water demand.

12.4.1 Price Elasticity of Water Demand

Price elasticity of water demand is a measure used in economics to show the *ceteris paribus* responsiveness, or elasticity, of the quantity of water demanded to a change in the water price. More precisely, it gives the percentage change in quantity demanded in response to a one percent change in price.

Based on different water users, we set forty-nine policy scenarios. In these scenarios the water prices of different users using all water sources are increased by 40%, 50%, 60%, 70%, 80%, 90% and 100%, respectively, compared with baseline. The price elasticity of water demand is then calculated by running these policy simulations. The price elasticity of water demand by different users in Tianjin in 2020 is shown in Fig. 12.2. The price elasticity of household water demand is less than that of non-households. Among non-household water users, the water-intensive industry sector has the highest price elasticity of water demand, followed by the water-intensive service sector, the general industry sector, the general service sector and the construction sector. Since an increase in the price of water promotes water saving, price reform for water-intensive industry should be given top priority in order

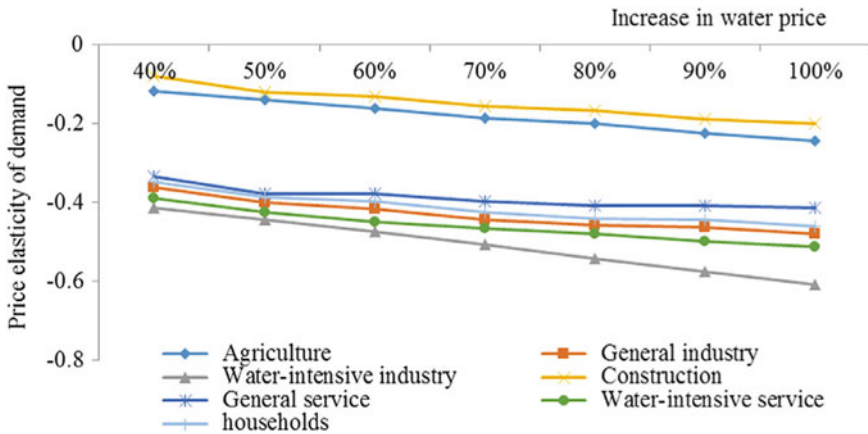


Fig. 12.2 The price elasticity of water demand of different users in 2020

to conserve more water, followed by the water-intensive service, general industry and general service sectors.

Based on different water sources, we set another twenty-eight policy scenarios. In each policy scenario, the water prices of different water types used by all users are increased by 40%, 50%, 60%, 70%, 80%, 90% and 100% relative to the baseline. The price elasticities of water demand by different water types are shown in Fig. 12.3. The price elasticities for recycled and desalinated water are quite low, around -0.1 , which is highly inelastic. The government or administration encouraged consumers to use unconventional water such as recycled water or desalinated water to replace conventional water by applying a price advantage to unconventional water, which was supported by financial subsidies from government. Since the price elasticity of tap water is higher than raw water, the saving rate of tap water will be higher than that for raw water for a given price change. This means that price reform of tap water should be given top priority, followed by raw water.

The price elasticity of water demand is not uniform across price levels, but increases as prices rise. This implies that water pricing can directly promote water-saving. However, results show that even if the existing water price is doubled, the price elasticities of water demand of various users and water types still remain above -1 , which means they are inelastic.

12.4.2 Optimal Scenarios

Based on the forty-nine policy scenarios of different users and twenty-eight policy scenarios of different water types, we obtain the price elasticities of water demand for different users and sources as discussed in the last section. From these elasticities, we conclude that increasing the price of tap water, especially in the water-intensive

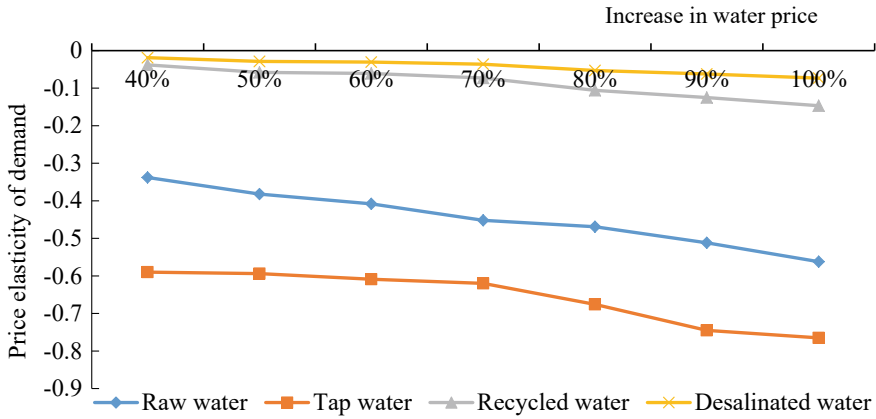


Fig. 12.3 The price elasticity of water demand of different sources in 2020

industry and water-intensive service sectors, should be given top priority when the government reforms the water price. We designed a series of scenarios from which we identified two optimal scenarios which conformed to the following goals: (1) constraints on water volume; (2) promote use of unconventional water, and optimize water structure. Scenario 1 assumes that the prices of recycled and desalinated water stay unchanged, and that by 2020, the raw water price for agricultural use will increase by 40%; prices for other industries will increase by 100%; tap water prices for households, general industry, construction and general service will also increase by 100%; tap water prices for water-intensive industry and service will increase by 200%. In scenario 2 we assume that the recycled water and desalinated water prices stay unchanged, and by 2020, the raw water price for all industries will increase by 100%; tap water prices for households, general industry, construction and general service will increase by 200%; tap water price for water-intensive industry and service will increase by 400% (Table 12.8).

12.4.3 Policy Results and Discussion

(1) Water conservation and utilization structure

The introduction of market-oriented pricing will reduce water wastage and the inefficient use of water. Both scenarios will produce tangible water saving results. The aggregated water saving rate will be 12.20% in scenario 1, or 420 million m³. In scenario 2, the water saving rate is 16.30%, with 560 million m³ of water conserved. In general, three factors initiated by water price adjustments contribute to overall water saving: first, the amount of water used decreases due to rising costs; second, all sectors adopt water-saving measures, therefore water use efficiency improves;

Table 12.8 Scenarios of water pricing reform (unit: RMB/m³)

Scenario	Sources	Users						
		Agriculture	General industry	Water-intensive industry	Construction	General service	Water-intensive service	House-holds
Scenario 1	Raw water	0.28	2.16	2.16	2.16	2.16	2.16	2.16
	Tap water	–	15.00	30.00	15.00	15.00	87.60	8.80
	Recycled water	–	3.10	3.10	–	3.10	4.00	–
	Desalinated water	–	4.00	4.00	–	–	–	–
Scenario 2	Raw water	0.40	2.16	2.16	2.16	2.16	2.16	2.16
	Tap water	–	22.50	37.50	22.50	22.50	109.50	13.20
	Recycled water	–	3.10	3.10	–	3.10	4.00	–
	Desalinated water	–	4.00	4.00	–	–	–	–

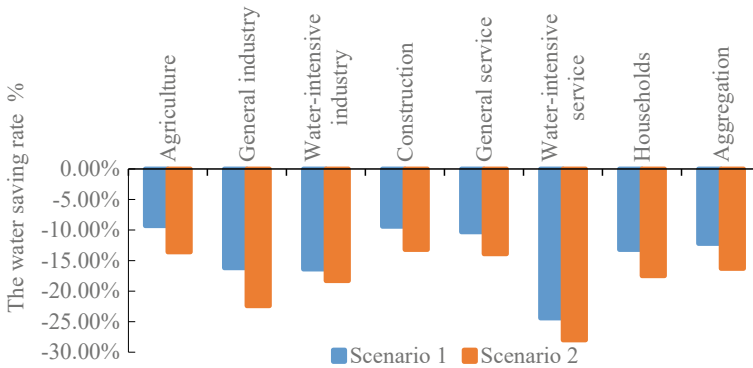


Fig. 12.4 The deviation of water usage by different users from the baseline scenario in 2020

third, the increase in the cost of water leads to industrial adjustment towards less intensive water use.

The adjustments on the demand side will differ across sectors. The water price for water-intensive services increases most, bringing the greatest proportionate decrease in water usage of circa 24% relative to baseline in scenario 1 (Fig. 12.4). The water usage by general industry in scenario 1 will be 16% lower than in the baseline scenario, since the tap water sector belongs to general industry. Water use by the general service industry and construction sector also declines (Fig. 12.4). The cost of water for households shows a continued increase, which enhances the motivation for water saving. In scenario 1, water used by households falls by 13% relative to the baseline scenario (Fig. 12.4).

Figure 12.5 shows that in scenario 1 the increase in the price of raw water reduces the demand for raw water by 9.60% by 2020 relative to the baseline scenario. There are two main reasons for this reduction. First, the increase in the price of water will reduce its demand. Second, because all tap water comes from raw water, the decline in tap water usage will lead to a decrease in raw water demand. In Scenario 1, the prices of recycled and desalinated water are assumed to remain unchanged. Their relative prices fall compared to raw and tap water, which drives a substitution towards these two types of water. The demand for recycled and desalinated water increases by 10.43% and 12.65%, respectively by 2020, relative to the baseline scenario. The shares of recycled and desalinated water in total water utilization increase by 0.6% and 0.3%, respectively, from the baseline in Scenario 1. The share of raw water is 1.7% higher than baseline while the share of tap water is 2.3% lower than baseline. This suggests that water price reform directed at the level and structure of relative water prices promotes the use of unconventional water and the conservation of conventional water. As a result, the water utilization structure is improved.

(2) Efficiency of water utilization

Water price reform has significant effects on efficiency of water utilization. As water prices increase, both water usage and sectoral output decrease because of the

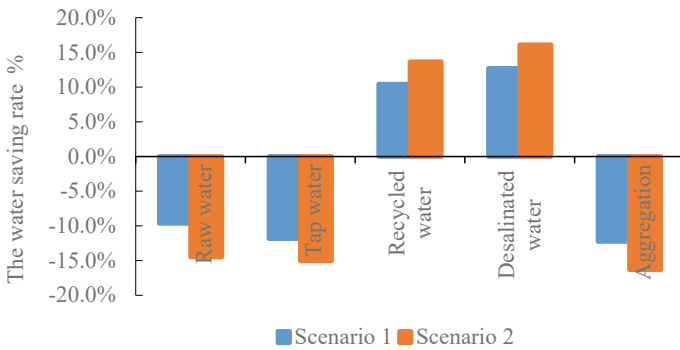


Fig. 12.5 The deviation of water supplied by different sources from the baseline scenario in 2020

increased cost. Since the proportionate decrease in water usage is greater than that of total output, water usage per 10,000 yuan of GDP declines. The water-intensive service sector shows the largest decrease. In 2020 water usage per 10,000 yuan of GDP is 32% lower in scenario 1 and 37% lower in scenario 2 than in the baseline scenario. In comparison, general industry and water-intensive industry also experience a reduction, though of smaller magnitude (Fig. 12.6). Additionally, aggregate water usage of 12.9 m³/per 10,000 yuan of GDP in the baseline scenario falls by 14% to 11.1 m³/per 10,000 yuan of GDP in scenario 1. In scenario 2, aggregate water usage falls by 16% to 10.6 m³/per 10,000 yuan of GDP, in 2020. These adjustments confirm that an increase in the price of water causes a significant increase in the efficiency of water utilization.

Both scenarios 1 and 2 show that as the price of tap water increases, total water usage decreases. Specifically, total water usage in scenario 2 stands at 2,873 million m³ by 2020, which implies that 140 million m³ water is conserved compared with

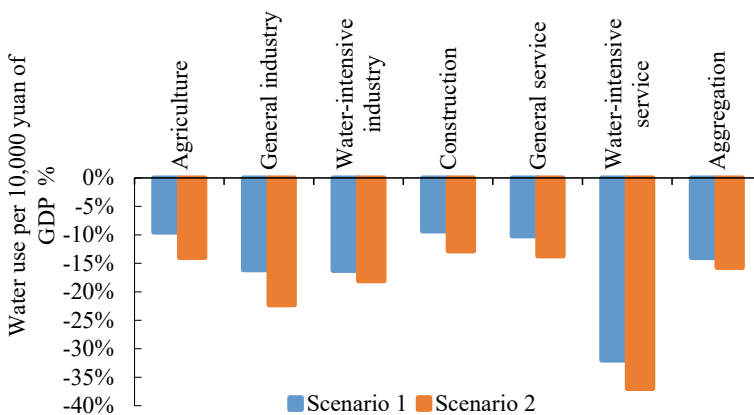


Fig. 12.6 The deviation of water usage per 10,000 yuan of GDP from the baseline scenario in 2020

scenario 1. The water-saving rate in scenario 2 is 16.3%, while in scenario 1 it is 12.1%. However, real GDP is 0.18% lower relative to baseline in scenario 1, while in scenario 2 it is 0.27% lower. Employment is 0.19% lower in scenario 1, while in scenario 2 it is 0.32% lower. Of the two scenarios presented, scenario 1 minimizes the impact of water price policy reform on GDP and unemployment, suggesting that scenario 1 is the better policy for economic outcomes. In the next section, we will focus our analysis on scenario 1. In scenario 1 the prices of tap, recycled and desalinated water are 27.35, 3.41 and 4.40 times higher than the price of raw water, respectively (Table 12.8).

(3) Economic impacts

Figure 12.7 shows the macroeconomic impacts of the water pricing reform captured in scenario 1. We can regard an increase in water prices here as being equivalent to a reduction in Government subsidies on water use, which flows through to producers and consumers as an increases in production costs and living expenses. All else being equal, we would therefore expect GDP to fall via a reduction in household consumption. We define GDP (Y) as a function of underlying technology A , capital K and labour L , $Y = \frac{1}{A}F(K,L)$. GDP in 2020 will be 0.18% lower than in the baseline scenario. This reduction reflects the combined effects of factor use and labour productivity adjustments (the percentage change in L is -0.194% , that in K is -0.31%). From the expenditure side of GDP, a higher water price will cause an increase in output prices. The CPI (consumer price index) will be 2.49% higher in 2020 than in baseline due to the effects of the water price increase. As a result, household real consumption will be 0.17% lower and investment will be 0.48% lower than in the baseline scenario in 2020.

A rational water price adjustment is regarded as one that minimizes the negative impact on the macro economy, causing small (if any) economic fluctuations and social instability. Water price adjustments will reduce water demand in water-intensive

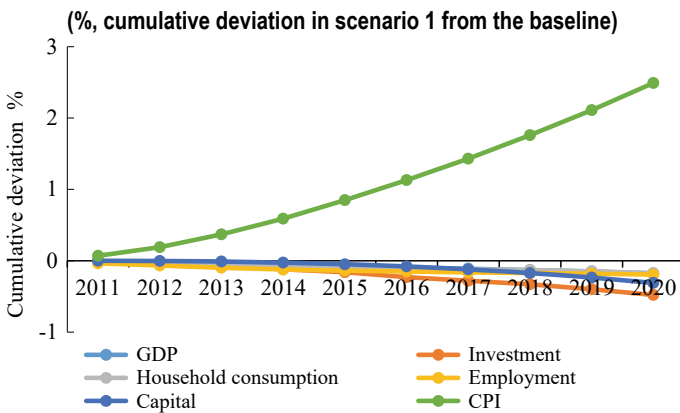


Fig. 12.7 The macroeconomic impact (% , cumulative deviation in scenario 1 from the baseline)

industries where output will decrease. Therefore, water resources will flow to sectors that use water relatively efficiently. These adjustments will lead to a better industrial structure and an improved efficiency of water utilization.

12.4.4 Application of This Study

Based on the findings of this study, the Tianjin government increased the water price in May 2015. Specifically, water prices for both general industry and service sectors were increased by 0.35 RMB/m³, those for households were increased by 0.5 RMB/m³, and those for water-intensive industry and service sectors by 1.15 RMB/m³. The recycled water and desalinated water prices remained unchanged. Past and present water prices are shown in Table 12.9. By June and July total water consumption had fallen by 1.2% and 1.1%, respectively, compared to the same period in the preceding year. Water consumption of households decreased by 2.3% and 2.1%, respectively in June and July. The general industry and general service sectors showed a small decline, and water-intensive industry showed the biggest drop of 3.0% and 2.9% (according to Tianjin Water Authority). The recommended scenario which was applied in Tianjin has produced positive impacts on water conservation. Encouragingly, the practical application of the policy described herein drove changes in consumption patterns which were similar to those in the simulation results presented.

12.5 Conclusions

Many policy designers are afraid to implement reform of water pricing systems because of a perceived threat to social conditions. To date, the responses of people and the economy to changes in water pricing are unclear. Earlier studies using CGE water models did not distinguish between different water sources and different users. Therefore they could not analyze the effects of water price reform with sufficient granularity. Here, we present a computable general equilibrium model of the Chinese economy with raw water, tap water, recycled water and desalination water as independent sectors. This differentiation between four different types of water sources provides a deeper insight into the implications of different water policies and their respective economic implications.

The model used in this study captured the detailed characteristics of water users and water sources, and simulated the effect of water pricing reform. By looking at the impacts across different water users and sources, their different price responses could be explored. Among water users, we found that priority of water pricing reform should be given to water-intensive industry, followed by households and general industry and general service sectors. From the perspective of water sources, priority of water price reform should be given to tap water. We explored two specific pricing policy reforms. Our recommended policy was scenario one, in which the relative

Table 12.9 Past and present water pricing at the basedate year price (2007) (unit: RMB/m³)

Years	Water source	Agriculture	General industry	Water-intensive industry	Construction	General service	Water-intensive service	Households
2007	Raw water	0.2	1.03	1.03	1.03	1.03	1.03	1.03
	Tap water	-	6.2	6.2	6.2	6.2	20.1	3.4
	Recycled water	-	1.2	1.2	-	1.5	1.8	-
	Desalinated water	-	4	4	-	-	-	-
2008	Raw water	0.2	1.03	1.03	1.03	1.03	1.03	1.03
	Tap water	-	6.2	6.2	6.2	6.2	20.1	3.4
	Recycled water	-	1.2	1.2	-	1.5	1.8	-
	Desalinated water	-	4	4	-	-	-	-
2009	Raw water	0.2	1.05	1.05	1.05	1.05	1.05	1.05
	Tap water	-	6.7	6.7	6.7	6.7	20.6	3.9
	Recycled water	-	3.1	3.1	-	3.1	4	-
	Desalinated water	-	4	4	-	-	-	-
2010	Raw water	0.2	1.08	1.08	1.08	1.08	1.08	1.08
	Tap water	-	7.2	7.2	7.2	7.2	21.1	4.4
	Recycled water	-	3.1	3.1	-	3.1	4	-
	Desalinated water	-	4	4	-	-	-	-
2015	Raw water	0.2	1.43	2.23	1.43	1.43	2.23	1.58
	Tap water	-	7.55	8.35	7.55	7.55	22.25	4.9
	Recycled water	-	3.1	3.1	-	3.1	4	-
	Desalinated water	-	4	4	-	-	-	-

Source Tianjin Water Authority, Tianjin Water Resources communiqué

price in terms of raw water, tap water, recycled water and desalinated water was increased by 27.35, 3.41 and 4.40 times, respectively. In this scenario, an aggregate water saving rate of 12.20% was achieved. Water-intensive industry and service sectors showed the greatest decrease in water usage. The shares of recycled and desalinated water in total water utilization increased, while the share of tap water fell by 2.3%. The water pricing reform promoted the use of unconventional water and the conservation of conventional water, while improvements in water utilization structure were also observed. Water usage decreased proportionately more than total output, and water use per 10,000 yuan of GDP declined by 14%. This scenario had significant positive effects on water utilization efficiency, whilst driving smaller negative impacts on the level of economic activity than that observed in scenario two. The present investigation of water pricing reform has clearly demonstrated that pricing is an effective tool for policymakers to manage water consumption.

It should be noted that this study has several limitations. Specifically, a perfect water market was assumed, where various types of water could flow freely between various sectors. Additionally, we did not recognize differences in water quality between different water sources. We also assumed that water was used efficiently and no water was wasted. Nevertheless, the results of this study provide a promising start in the area of water pricing reform. The present limitations will be addressed in future investigations.

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