Water Policy 23 (2021) 397–416

Water policy and regional economic development: evidence from Henan province, China

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Abstract

With the rapid advance of industrialization and urbanization and the intensified impact of global climate change, the contradiction between the global water shortage and economic growth has become prominent. This paper, taking Henan province as an example, analyzed the influence of water resource policy on regional economic growth through a calculable general equilibrium model and further discussed the relevant policy recommendations. The results showed that the improvement of water supply, water efficiency and water technology could promote the growth of the regional economy and result in a positive effect on regional GDP, employment and resident income. However, the rise of water price has a negative impact on regional economic development, mainly reflected in regional GDP, employment and household income. The improvement of water price, water efficiency and water conservancy technology would lead to a decrease in regional water consumption, while only the increase of the water supply would lead to an increase in water consumption. Accordingly, the paper puts forward policy suggestions, such as accelerating the improvement of water conservancy facilities, establishing a reasonable water price mechanism and actively exploring experience in water conservation and emission reduction.

Keywords: CGE model; Henan province; Policy adjustment; Regional economy; Water policy

Highlights

- The quantitative analysis method is used to simulate the impact of four policy changes of water supply, water price, water-use efficiency and water conservancy technology on the main regional economic indicators.
- The aim of this move is to reflect the effect and potential impact of future policy changes and put forward policy suggestions for appropriate adjustment of relevant policy programs.

doi: 10.2166/wp.2021.167

1. Introduction

In the context of global climate change and rapid economic and social development, the contradiction between supply and demand of water resources and conflict over water resource rights are increasingly intensified (Kanakoudis *et al.*, 2016). The sustainable use of water resources has become an important factor affecting the harmonious development of global economy and society (Boudmyxay *et al.*, 2019). In addition, the water shortage is also a serious challenge to global food security (Hanjra & Qureshi, 2010). Hence, the United Nations recognized ensuring water security as one (Goal 6) of the 17 sustainable development goals. According to the United Nations goals, Asia and Africa are the key areas where water policies need to be adjusted (Gain *et al.*, 2016). In recent years, the Chinese government has issued several significant documents to raise water resource management to the national strategic level. It is expected to achieve the goal of changing the waste and inefficient water-use behavior formed in the long history and building a water-saving society in all respects through the implementation of macro-policy regulation (Zhong *et al.*, 2017).

To achieve the goal of effective water-saving, the first condition is to make reasonable water resource management policy design and policy choice. However, water resource management is not simply a natural science issue, but also a social science issue (Llop & Ponce-Alifonso, 2012). Water resource management policy will have a variety of complex effects on macro-economy, resources and environment, and policy stakeholders. The adaptive management of water resources believes that it is necessary to make reasonable institutional arrangements and policy choices on the basis of considering the comprehensive impact of system vulnerability and water resource management policies (Yin, 2002; Turner *et al.*, 2003; Pahl-Wostl, 2007; Li *et al.*, 2013; Kanakoudis *et al.*, 2017) and balance the conflicts of interest among heterogeneous multi-subjects related to water resource management (Kanakoudis & Tsitsifli, 2010; Wang & Tong, 2011). Only in this way can water users be effectively guided and encouraged to change their inefficient water-use behavior and achieve human–water harmony. China has a vast territory, and there are differences in economic and social development, natural endowments and the level of water resource management in different regions, so the policy adjustment of water resource management should be tailored according to local conditions. Therefore, the quantitative simulation and evaluation of the possible economic and social impacts of water resource management policies are an important basic step for the government to adjust and make decisions on water resource management policies (Damania, 2020).

As the computable general equilibrium (CGE) model can quantitatively simulate the direct and indirect impact of policy changes on the overall national economy, it is widely used in the evaluation of trade policy, fiscal and financial policy, and energy policy (Arikana, 2001; Chen *et al.*, 2010; Liu & Fu, 2011). In recent years, many scholars have begun to use a CGE model to analyze water resource problems, including water price policy, water resources allocation, and water market. For example, Nechifor & Winning (2017) discussed the impact of income and population growth on crop yields and the resulting changes in the amount of freshwater required for irrigation. Van *et al.* (2019) used a CGE model to simulate the impact of water shortage on agricultural production and economy in Uganda. Touitou *et al.* (2020) used a dynamic CGE model to analyze the management of water resource sector in response to climate shocks in Algeria. Zhang *et al.* (2016) simulated and analyzed the economic impact of water resource policy changes in Zhejiang province based on a CGE model. Ma & Li (2019) constructed an environmental CGE model suitable for the study of water pollution tax to evaluate the effect of water pollution control policies in Jiangsu province. Deng (2020) studied the influence of

China's import and export trade policy adjustment on the water resource environment and economic system by building a multi-regional CGE model. Li *et al*. (2020) introduced the dynamic CGE model into disaster comprehensive economic loss assessment to measure the impact trajectory of annual rainstorm and flood disasters on the whole economic system.

Although there is a large body of literature examining the links between different water policies and economic growth, such as technological advances, water pollution taxes, water supply and other policy changes (e.g. Berrittella *et al*., 2007; Choliz & Sarasa, 2019; Kyei & Hassan, 2019), little has been done to explore the relationship between multiple policy changes and major economic indicators. To sum up, scholars have done a great deal of research on water resource policy, but there are still some deficiencies. First, part of the research uses the external method of water resources, which cannot reflect the impact of price changes and supply changes of water resources as a factor of production on the main economic indicators (Ferrarini *et al*., 2020). Second, in a general sense, Henan province is not considered to be an arid area, there is a lack of understanding of the grim situation of water resources in the province and there is little research on the simulation of water resource policy effects in Henan. Based on this, this study took Henan province as an example, based on the social accounting matrix (SAM) compiled comprehensively, and the quantitative analysis method is used to simulate the impact of four policy changes of water supply, water price, water-use efficiency and water conservancy technology on the main regional economic indicators. The aim of this move is to reflect the effect and potential impact of future policy changes and put forward policy suggestions for appropriate adjustment of relevant policy programs.

2. Research area and data source

2.1. Summary of water resources in Henan province

Henan province, situated in the North China Plain, belongs to the central and eastern parts of China, spanning four major basins: the Huanghe River, the Huaihe River, the Haihe River, and the Yangtze River. The annual average precipitation is 778 mm, increasing from 600 to 1,200 mm from north to south. Henan province is in the Central Plains and has a humid and semi-arid climate. The average annual total amount of water resources in the province is 40.353 billion cubic meters (the maximum total water consumption used for the domestic sector contains surface water and groundwater), which is less than 400 cubic meters per capita. Depending on the internationally recognized standard of 500 cubic meters per capita at the edge of a serious water shortage, Henan province is a province with a serious water shortage. In terms of the regional distribution of total water resources (Figure 1), the aggregate distribution of water resources in Henan province is extremely uneven. The three cities in southern Henan (Xinyang, Zhumadian and Nanyang), with a total population of 24.7% of the province, have 52.6% of its water reserves but consume only 22.2% of its water resources. This shows that the distribution and consumption of water resources in Henan province are very unbalanced.

In 2015, Henan province lacked 6.4 billion cubic meters of water, including 1.5 billion cubic meters for domestic and industrial water and 4.9 billion cubic meters for agriculture[1]. As far as the province is

[1] Data source: press conference of the Henan Water Resources Department on 2015-11-09.

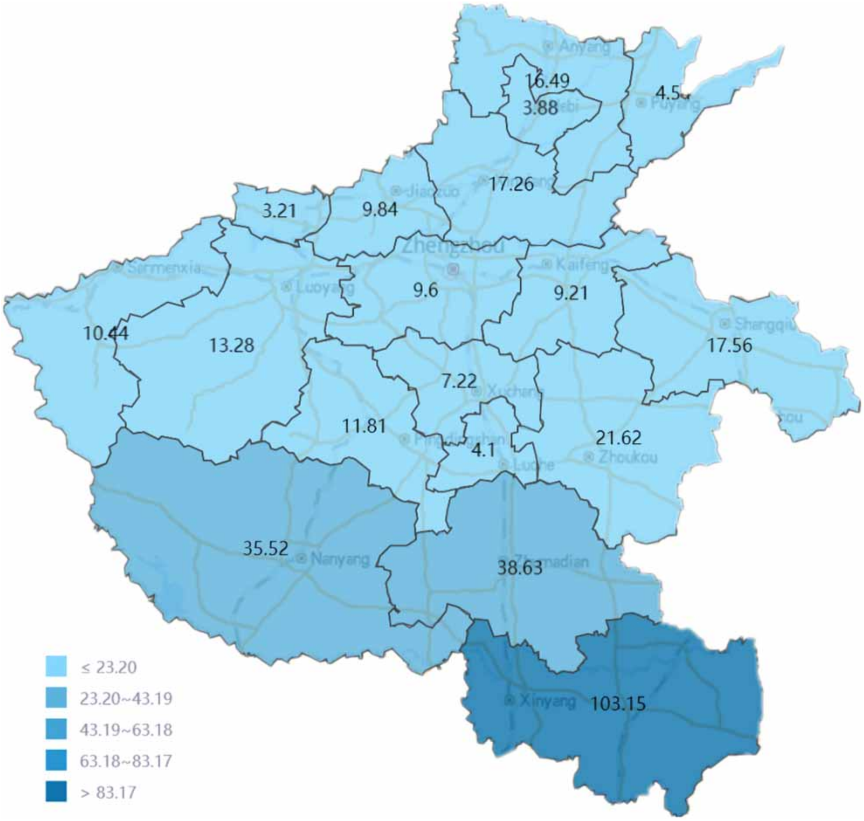

Fig. 1. Regional distribution of total water resources in Henan province. *Source*: Henan Water Resources Bulletin 2016.

concerned, the water shortage is mainly in Anyang, Puyang, Jiyuan, Kaifeng, Pingdingshan, Shangqiu, Zhumadian and other places. In recent years, with the implementation of the national central and western development strategy and the transfer of manufacturing to the central and western regions, the implementation of the Central Plains Economic Zone strategy, the Zhengzhou Airport Comprehensive Experimental Zone strategy and the strategy of a strong industrial province in Henan province, as well as the acceleration of industrialization, urbanization and new rural areas in Henan province, the rigid demand for water in Henan province continues to grow, and the gap between supply and demand of water resources is further enlarged. At present, the acute shortage of water resources has become the main factor restricting economic and social development. If we do not take administrative, economic, technological and other effective measures to save water, not only economic and social development will be difficult to sustain, people's health and quality of life will also be seriously affected.

2.2. Data source

As the data basis of the CGE model, the SAM table describes the flow relationship of macro variables in monetary units, which can clearly reflect the circular relationship within the economy, including the production and nonproductive accounts in the national economy, as well as the distribution process of the added value generated by economic activities in the cycle (Gao & Li, 2008). The SAM table contains the two major production factors of labor and capital. The 42 production departments of the national economy are merged into four industrial departments of agriculture, industry, construction and service. The main body of the organization is further merged into residents, enterprises, governments and other regions outside the province. Taking the input–output table of Henan province in 2017, the Financial Yearbook (2015–2018) and the Water Resources Bulletin (2012–2018) as the data sources of the SAM table, the Henan SAM table is made after a comprehensive calculation. Due to the different statistical sources, the SAM table is usually unbalanced at first, so the direct cross-entropy method is used to balance the SAM table.

The parameters in the CGE model are mainly composed of share parameters and elastic parameters. The share parameters can be comprehensively calculated through the data in the SAM table and the CGE model, which mainly include the input–output consumption coefficient of intermediate inputs, tax rates and factor income distribution shares. Elasticity parameters can be obtained by estimating departmental information and related statistical data through Bayesian parameter estimation methods (Huang *et al*., 2003), which mainly include the elastic parameters of production function, value-added function, Armington function and export transfer function. Among them, the elastic parameter calibration refers to the existing elastic parameter values in some documents (Zhou *et al*., 2002; Zhao & Wang, 2008), and the measured department elastic parameters are weighted. Under normal operation conditions, calibrated parameters enter the CGE model, and the initial equilibrium data can still be returned after re-tuning.

3. Theoretical construction of the CGE model of water resources

The CGE model is precisely an ideal tool for taking the whole economic system as the research object and simulating the effects of economic policies. There is a general correlation among the components of the real economic system. The CGE model can capture the dependence and conductivity of the elements through the transaction information between the production sector and the economic entity. The change of any part will make other components have a linkage reaction. The structure of the model is given in Figure 2. First, the model can get the total output through the joint input of labor, capital elements and composite products in the commodity market. Second, the total output enters the commodity market; on the one hand, it is used for consumption and investment by the domestic government, residents and enterprises; on the other hand, it is exported abroad. Finally, obtained elements and intermediate inputs once again synthesize the total output. Such a cycle is repeated; in the process of economic operation, the government can grasp and regulate the whole system through macro policies.

3.1. Theoretical hypothesis of CGE model

The CGE model includes four industrial sectors: agriculture, industry, other service industries (including domestic water and ecological environment water), construction industry, two production factors of labor and capital, and eight main factors, such as production, investment, residents, enterprises, government, foreign countries and inventory. It can create a multi-scenario simulation to analyze the impact of water resource policy changes on the Henan economy and water resource use. Under the guidance of general equilibrium theory, this paper sets basic assumptions. (1) Production hypothesis: each functional

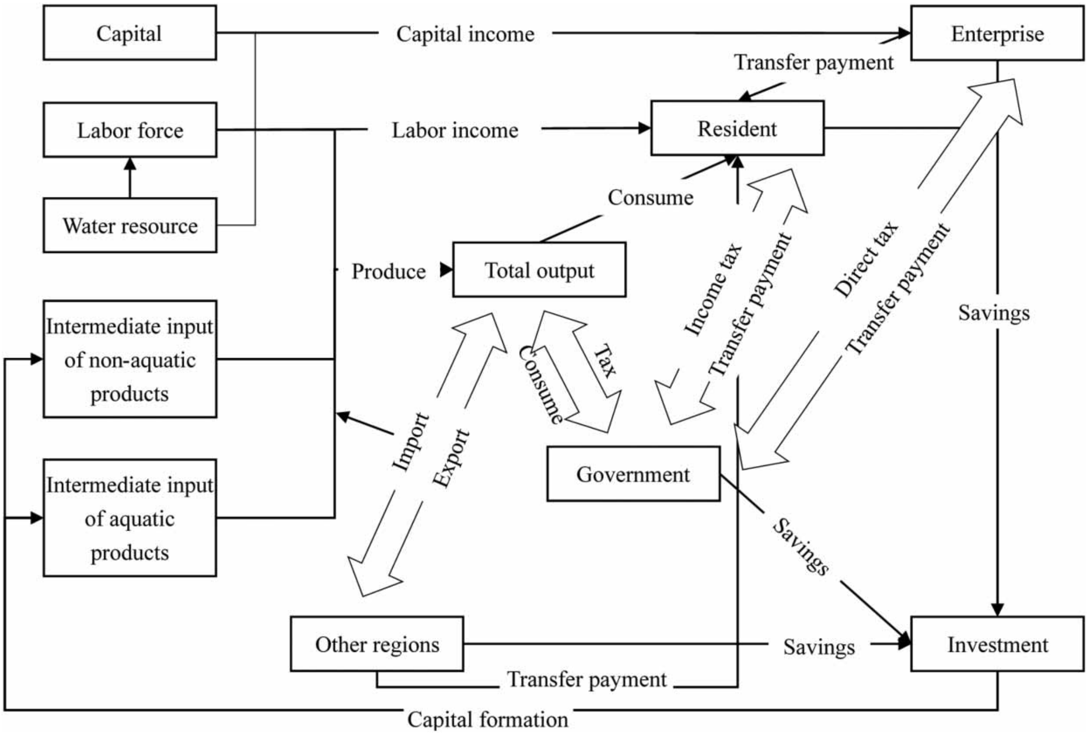

Fig. 2. Economic system described by the CGE model.

department produces only one commodity and has the same characteristic of scale reward, and the optimization conditions are cost minimization and profit maximization. (2) Consumption hypothesis: it uses the nested constant elasticity of substitution (CES)/Leontief function to achieve utility maximization. (3) Trade hypothesis: it consists of two parts: one is the small country assumption that under the given international price, the transaction price will not change due to the change of import and export demand, and the other is the Armington Assumption, that is, the relationship between domestic products and imports is not completely substituted. (4) Market hypothesis: it ensures the clearing of the commodity market and the factor market. (5) The mode of closure: it is assumed that the market is fully employed, the exchange rate system is fixed and the perfect competition model is adopted in the closed mode of neoclassicism.

3.2. CGE model structure of water resource policy

Assuming that the set of all production departments is S, the set of all commodity departments is C, and the production of all departments has the same technical characteristics of scale reward (Zhao & Wang, 2008); then five modules are constructed according to the order of input–output-subject-system constraint-water policy. Among them, two major modules of input and output constitute the production activities of the system. The production function is represented by the most basic double-layer-nested CES function in the CGE model, and its production structure is shown in Figure 3.

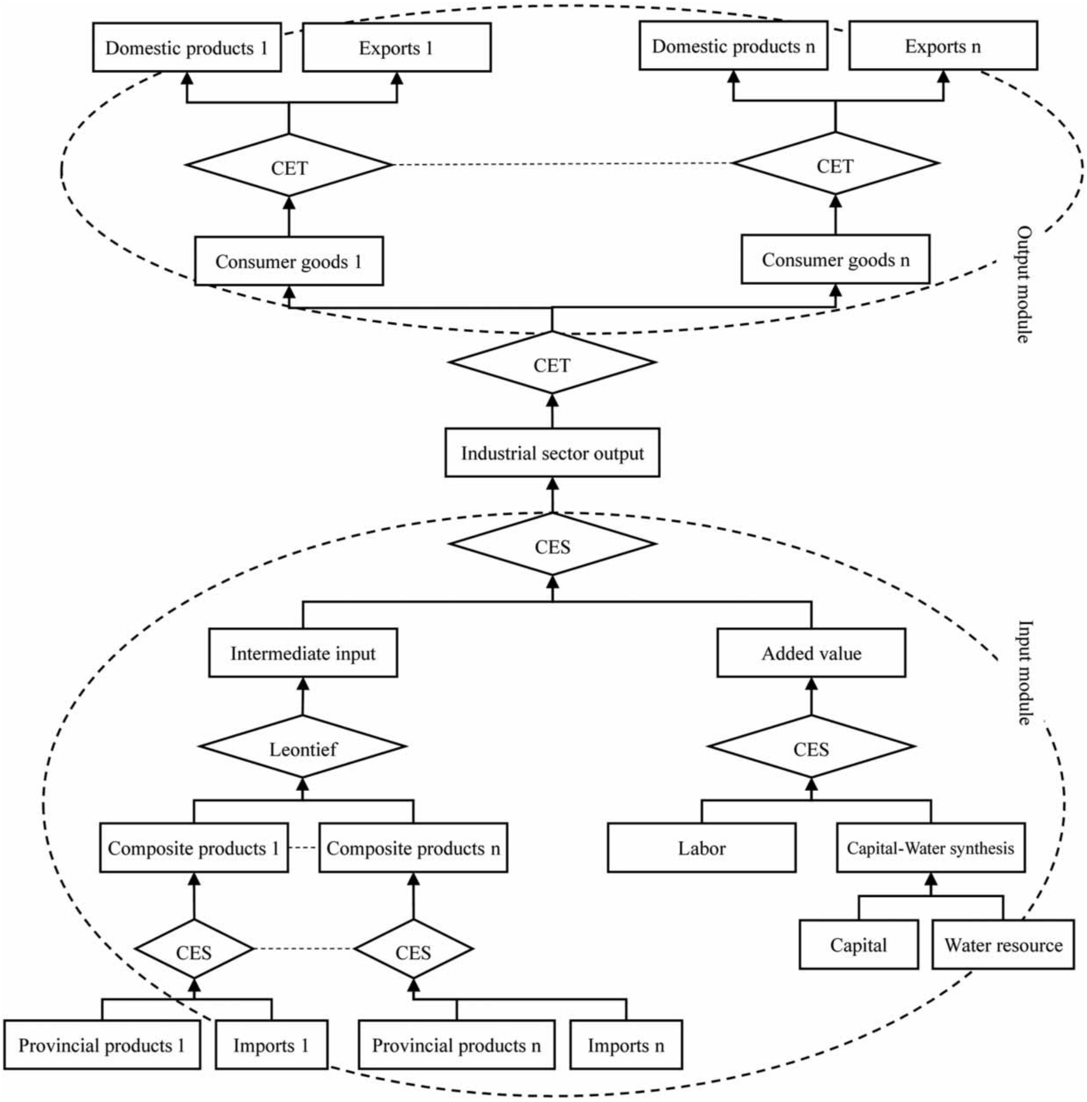

Fig. 3. Production structure of the CGE model.

3.2.1. Production input module. The input module in this paper is mainly divided into three levels with three CES functions. According to the research of Arrow *et al*. (1961), the basic format of the CES function is as follows:

$$q = f(x_1, x_2) = A\left[\delta_1 x_1^{\rho_0} + (1 - \delta_1)x_2^{\rho_0}\right]^{\frac{1}{\rho_0}} \quad (1)$$

Equation (1) is a constant substitution elastic function for the production function. The parameter q stands for the department input. x_1 and x_2 are the outputs of different departments. A is the total factor productivity, and δ_1 is the share parameter. The parameter ρ_0 is related to the constant substitution elasticity coefficient. In the subsequent equation, we use CES to abbreviate this relationship.

The first layer is the total output of each industrial department, which is a CES production function composed of the added value and the intermediate input of each industrial department (Equation (2)). The second layer is the intermediate input and the added value of each industrial sector, in which the added value adopts the CES production function of labor and capital hydration (Equation (3)). The intermediate input is the Leontief production function of each composite product based on the fixed input proportion theory (Equation (4)). The third layer is based on Armington's intermediate input composite product supply theory, which is composed of CES functions of provincial products and imported products (Equation (5); Zhao & Wang, 2008). The products produced are divided into provincial consumption and export, and the distribution share varies with the fluctuation of the international market price and exchange rate. The function expression is shown in Equation (6). Among them, capital–water synthesis is composed of capital and water through function (Equations (7) and (8)).

$$\mathrm{QA_s} = \mathrm{CES}(\mathrm{QVA_s},\ \mathrm{QINTA_s}) \tag{2}$$

$$\mathrm{QVA_s} = \mathrm{CES}(\mathrm{QLD_s},\ \mathrm{QKTD_s}) \tag{3}$$

$$\mathrm{PINTA_s} \times \mathrm{QINTA_s} = \sum_{\mathrm{c} \in \mathrm{C}} \mathrm{PQ_c} \times \mathrm{QINT_{cs}},\ s \in S,\ c \in C \tag{4}$$

$$\mathrm{QQ_c} = \mathrm{CES}(\mathrm{QDC_c},\ \mathrm{QM_c}) \tag{5}$$

$$\mathrm{PM_c} = \mathrm{pwm}(1 + \mathrm{tm_c})\mathrm{EXR},\ c \in C \tag{6}$$

$$\mathrm{QKTD_s} = \alpha(\delta \mathrm{QKD_s^{\rho}} + (1 - \delta)\beta \mathrm{QTD_s^{\rho}})^{\frac{1}{\rho}} \tag{7}$$

$$\frac{\mathrm{WK}}{\mathrm{WT}} = \frac{\delta}{(1 - \delta)} \left(\frac{\beta \mathrm{QTD_s}}{\mathrm{QKD_s}} \right)^{1-\rho} \tag{8}$$

Among them, $\mathrm{QA_s}$ is the total output of the industrial sector; $\mathrm{QVA_s}$ is the added value of the department. $\mathrm{QLD_s}$ and $\mathrm{QKTD_s}$ are the demand of labor and capital–water synthetic elements, respectively. $\mathrm{QINTA_s}$, $\mathrm{PINTA_s}$ and $\mathrm{QINT_{cs}}$ are expressed as the total amount of intermediate input, the total price and the quantity of intermediate input in the composite product, respectively. $\mathrm{QQ_c}$ and $\mathrm{PQ_c}$ are the quantity and price of imports, respectively. $\mathrm{QDC_c}$ is the quantity of products in the province; $\mathrm{QM_c}$ and $\mathrm{PM_c}$ are the quantity and price of imported products, respectively. pwm is the international price of imports. $\mathrm{tm_c}$ and EXR are import duty rates and exchange rates, respectively. $\mathrm{QKD_s}$ and $\mathrm{QTD_s}$ represent the respective requirements of capital and water in the capital–water synthesis elements, respectively. The parameters α, δ and ρ represent the scale parameter of capital–water (which is used to reflect the change of water conservancy technology), and share parameter and substitution elasticity, respectively. β is the departmental water-use efficiency.

3.2.2. Production output module. For the finished products of various industrial sectors, in addition to self-production and self-sale in the province, because the export share of Henan's economy accounts for a large proportion, it is necessary to further consider the export sales share. The size of the share is affected by the relative price at home and abroad, while the export price changes with the change of international market price and exchange rate. To maximize income, the distribution between provincial self-sale and export is represented by the boundary of production possibility. With reference to the theory of the constant conversion function, the conversion relationship between them is expressed by the constant elasticity of transformation (CET) function (Zhang, 2010).

$$\text{MAX. } \mathrm{PDA_s} \times \mathrm{QDA_s} + \mathrm{PE_s} \times \mathrm{QE_s} \tag{9}$$

$$\text{s.t. } \mathrm{QA_s} = \mathrm{CET}(\mathrm{PDA_s},\ \mathrm{PE_s}) \tag{10}$$

$$\mathrm{PE_s} = \mathrm{pwe_s}(1 - \mathrm{te_s})\mathrm{EXR},\ \ s \in S \tag{11}$$

Among them, $\mathrm{QDA_s}$ and $\mathrm{PDA_s}$ are the sale volume and price of product s in the province, respectively. $\mathrm{QE_s}$ and $\mathrm{PE_s}$ are the quantity and price of export products, respectively. $\mathrm{pwe_s}$ is the international price of export products. $\mathrm{te_s}$ is the export tax rate. These data can be calculated from the base period data in the SAM of Henan province.

3.2.3. Main body module. The main body module includes two parts: income and expenditure. From the perspective of residents, residents' income comes from labor remuneration, capital factor income and the corresponding transfer payment of the government, while residents' expenditure includes commodity consumption and tax payment. From the point of view of the enterprise, the income mainly comes from the capital income and the transfer payment from the government to the enterprise, and the expenditure is used for commodity consumption, factor consumption and tax payment. From the perspective of the government, government revenue comes from production tax and enterprise and individual income tax, and government expenditure includes commodity consumption and transfer payments to enterprises and individuals. The income of each main institution minus expenditure is its own savings.

3.2.4. System constraint module. According to the five basic assumptions set by the CGE model, it is necessary to ensure the balance of supply and demand in the commodity market, the clearing of the factor market and the balance of payments (Zhang, 2010). Therefore, the equilibrium conditions and their closure equations are as follows:

$$\mathrm{QQ_c} = \sum\nolimits_{s} \mathrm{QINT_{cs}} + \sum\nolimits_{h} \mathrm{QH_{ch}} + \overline{\mathrm{QINV}_c} + \overline{\mathrm{QG_c}},\ \ c \in C \tag{12}$$

$$\sum\nolimits_{s} \mathrm{QLD_s} = \mathrm{QLS} \tag{13}$$

$$\sum\nolimits_{s} \mathrm{QKTD_s} = \mathrm{QKTS} \tag{14}$$

$$\sum\nolimits_{s} \mathrm{pwm_c} \times \mathrm{QM_c} = \sum\nolimits_{s} \mathrm{pwe_c} \times \mathrm{QE_c} + \mathrm{FSAV} \tag{15}$$

$$\mathrm{EXR} = \overline{\mathrm{EXR}} \tag{16}$$

$$\mathrm{QLS} = \overline{\mathrm{QL}S} \tag{17}$$

$$\mathrm{QKTS} = \overline{\mathrm{QKTS}} \tag{18}$$

Among them, QH_{ch} is the demand of residents for composite products; $QINV_c$ is the final demand for investment in composite products. QG_c is the demand of the government for composite products. QLS and QKTS are the total supply of labor and capital–water synthesis, respectively. FSAV is the net savings of foreign countries. Among them, Equation (12) indicates the equilibrium of the commodity market, that is, the quantity of goods supplied in the province is equal to the quantity of goods needed in the province. Equations (13) and (14) mean that the clearing of the factor market requires that the total demand for labor and capital is equal to the total supply. Equation (15) indicates the balance of payments in the international market: that is, the balance of trade import and export. Equation (16) is expressed as the closure condition of the fixed exchange rate system. Equations (17) and (18) are expressed as the macro-closure conditions of neoclassicism. Underlined variables represent exogenous variables (Li *et al*., 2014).

4. Results and analysis

Based on the SAM table, the CGE model of water resource policy is simulated by The General Algebraic Modeling System (GAMS) software to analyze the influence of regional water supply change, water price change, water-use efficiency change and water conservancy technology change on the main economic indicators of Henan province.

4.1. Simulation of single scheme

It was estimated that the change range of water supply in Henan province from 2007 to 2017 was about 5%. To reflect the relationship more directly between water resources and the economic system of Henan province and further compare and analyze the four policy changes, considering the consistency of the range of changes in the simulation process, the four policy changes were all set at 5%. The impact of the four policies on the regional economic system was analyzed by comparing with the base period values (Table 1):

1. *Scenario analysis of the change of water supply*: In this part of the simulation, the water price is fixed as an endogenous variable. When the demand for water resources exceeds the supply, the negative impact on the regional economy is greater. Considering that the main characteristic industries in Henan province are heavily dependent on water resources, their supply bottlenecks will lead to the limitation of some industrial production activities, especially the reduction of agricultural and industrial outputs. The decrease in the output of the industrial sector will lead to two effects: first, if the product demand remains unchanged in the short term, the reduction of supply in the market will directly lead to the rise of product prices, the decline of residents' real income and the level of social welfare. Second, the demand for labor in the industrial sector is relatively reduced, the number of employees is reduced and the employment rate is declining.
2. *Scenario analysis of the change of water price*: When the water price changes, the amount of water supply is set as an endogenous variable. The price of purified tap water is split into residential water, nonresidential domestic water and water for special industries. Special water refers to nonordinary bath, sauna, golf course, car washing, beverage production (including pure water and beer), construction industry, ships and other water. At present, above water prices in Henan province are 4.10, 5.35

Table 1. Simulation results of four policies.

Regional economic indicators	The base period	The impact of policy changes/5%			
		Reduction in water supply by 5%	Increase in price of water by 5%	Increase in water-use efficiency by 5%	Increase in water technology by 5%
GDP/100 million RMB[a]	22,859.34	– 0.0263	– 0.0076	0.0109	0.0093
Labor demand/100 million RMB	10,351.49	– 0.0175	– 0.0046	0.0058	– 0.0039
Resident income/100 million RMB	17,595.40	– 0.0338	– 0.0070	0.0085	0.0071
Enterprise income/100 million RMB	1,257.20	– 0.0438	– 0.0040	0.0054	0.0053
Total investment/100 million RMB	5,791.46	– 0.0625	– 0.0019	– 0.0008	0.0039
Agricultural output/100 million RMB	7,658.03	– 0.0834	– 0.0051	0.0004	0.0015
Industrial output/100 million RMB	10,837.85	– 0.0171	– 0.0066	0.0058	0.0091
Construction industry output/100 million RMB	6,178.90	– 0.0035	– 0.0040	0.0066	0.0100
Service industry output/100 million RMB	1,5271.93	– 0.0121	– 0.0034	0.0009	0.0061
Water demand/100 million m^3	65.13	– 0.0163	– 0.0080	– 0.0415	– 0.0359

[a]Pay attention to the exchange rate conversion: 1 RMB ≈ 0.15 $ ≈ 0.11 €.

and 16.55 yuan per cubic meter, respectively. Judging from the current pilot experience of the water resource tax reform, the reform emphasizes increasing the tax burden on special industries, over-planned water use and other industries. Because the water resource tax is a specific tax, the reform will make the price of water rise relatively. As can be seen in Table 1, if the pilot project of the water resource tax reform is applied to Henan province, the relative increase of water price will directly lead to the reduction of water demand. As a factor of production, the price increase of water will increase the cost of enterprises, and the output will decline, resulting in a decline in the income of residents, enterprises and the government. But because companies can pass on some of the higher costs to consumers, their revenues have not fallen as much as household incomes. In the long run, the reasonable increase of water price will help to enhance the water-saving consciousness and the motivation of social subjects, such as enterprises, and the increase in enterprise costs will force enterprises to save energy and reduce consumption, urge enterprises to improve water-saving facilities and water-saving technologies, and optimize the internal structure of enterprises. It will eventually increase the overall social welfare level.

3. *Scenario analysis of water-use efficiency and water conservancy technology improvement*: In the simulation, the improvements of β and α are realized, respectively. As can be seen from Table 1, as a derivative effect of demand-side management, the improvement of water-use efficiency and technology will reduce the waste of water resources, and the demand for water resources will

decrease significantly. The relative decline in production costs will stimulate production activities, and the output of various industrial sectors will increase, which will reduce product prices and increase social welfare in the short term. Although the labor demand is relatively declining, it may only be the structural transformation within the labor market in the short term, or the adjustment of workers' skills training. The improvement of technology will eventually lead to the optimization and transformation of the labor market.

4.2. Sensitivity analysis of policy shock intensity

After simulating the impact of individual policy changes on the economy of Henan province, this paper makes a comparative analysis of the four policies, that is, the impact of the four policies on the regional macro- and micro-economy within the range of −20 to 20%. Thus, the inter-relationship between the four policies is simulated, and the water resource policy that plays a more positive role in the regional economy of Henan province is found:

1. *The impact on regional GDP*: Water price changes in reverse with GDP, and water-use efficiency, water conservancy technology and water supply have a positive effect on GDP growth (Figure 4). Water supply, water-use efficiency and water conservancy technology policy have the same change relationship with regional GDP, that is, with the increase of policy intensity, the level of GDP increases gradually. Among them, the improvement of water-use efficiency has the greatest positive impact on GDP in Henan province. Considering that the average water-use efficiency in Henan province is only 6.8%, the water-use methods of most enterprises are still relatively extensive, water-saving facilities and water-saving technologies are not in place, the production process is backward and there is still a great deal of room for improvement in water-use efficiency. The policy of water price is opposite to the change of GDP. Although the increase of water price will reduce the use of water resources, it does come at the cost of regional economic contraction.

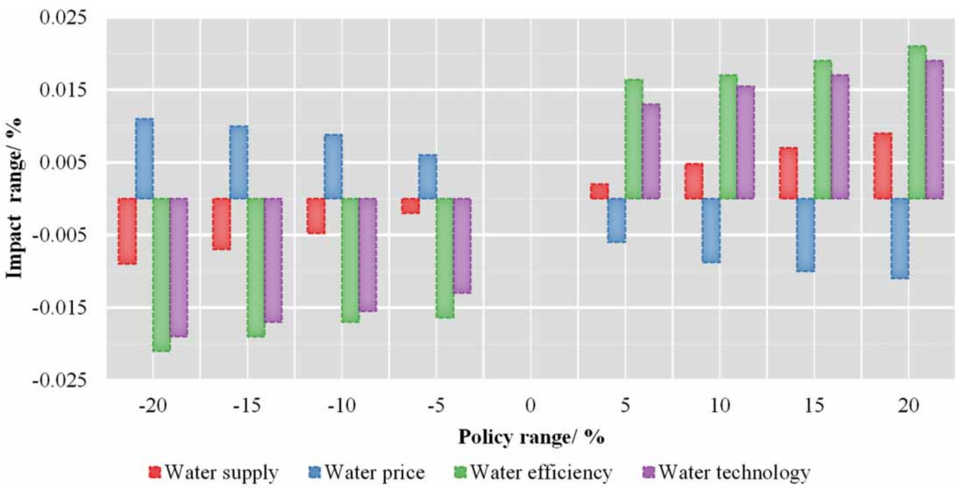

Fig. 4. The impact of four policies on regional GDP.

2. *The impact on regional employment*: Water price and regional employment change negatively, consistent with Touitou *et al*. (2020), while other policy and regional employment change positively (Figure 5). With the increase of the intensity of various policies, the change of residents' employment tends to be flat. As an important factor of production, the increase of water price will increase the production cost of most enterprises, reduce the production scale and reduce the labor demand. The impact of the increase of water price on regional labor employment is obvious. The improvement of water supply, water-use efficiency and water conservancy technology will lead to the relative reduction of enterprise production costs, and then expand production and increase labor input.
3. *The impact on the income of regional residents*: Water supply, water-use efficiency and water conservancy technology change in the same direction with residents' income, while the increase of water price reduces the relative income of residents (Figure 6). The first three policies will indirectly lead to a reduction in regional industrial costs. Among them, there is a strong positive correlation between water supply and regional residents' income, because more than 70% of Henan's water supply is used for agriculture, and an increase in water supply will at least ensure the normal output level of agriculture, while nearly half of Henan's population are rural residents. Agricultural production will have a greater positive impact on the income of regional residents, while agricultural output has a strong impact on the output of other sectors, and output in the commodity market will increase in the short term. Prices have declined relatively, while residents' income has increased relatively.
4. *The impact on the use of regional water resources*: In terms of water resource conservation, the four measures have shown the expected results. Water price, water-use efficiency, water conservancy technology and water consumption change in reverse, and water supply and water consumption change in the same direction (Figure 7). When the water price increases, the production cost of enterprises increases, forcing enterprises to adopt unconventional water sources such as sewage treatment and recycled water, and technological innovation to reduce the use of new water, which is the process of improving the water-use efficiency and water conservancy technology. Most urban residents are more sensitive to the price, so the rise of water price will reduce the demand for water to a certain extent. Price leverage can effectively regulate the use of water resources (Arbúes *et al*., 2004). The

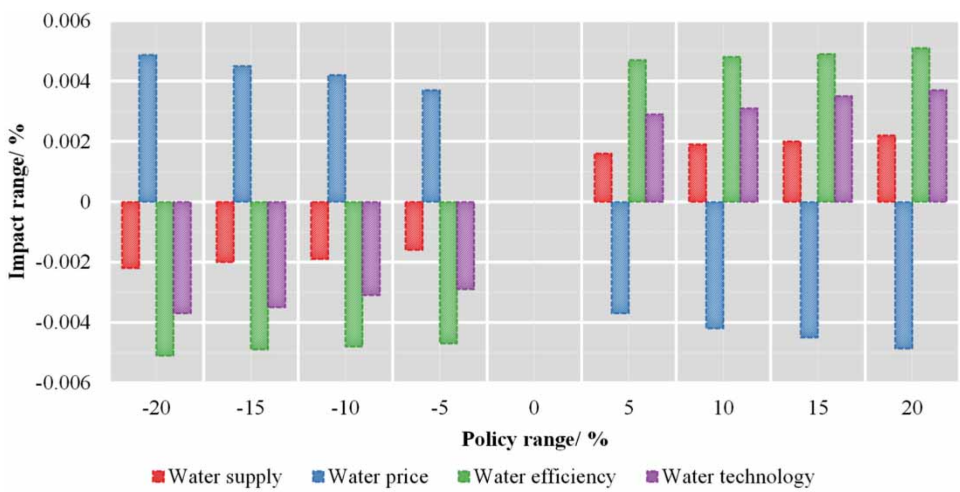

Fig. 5. The impact of four policies on regional employment.

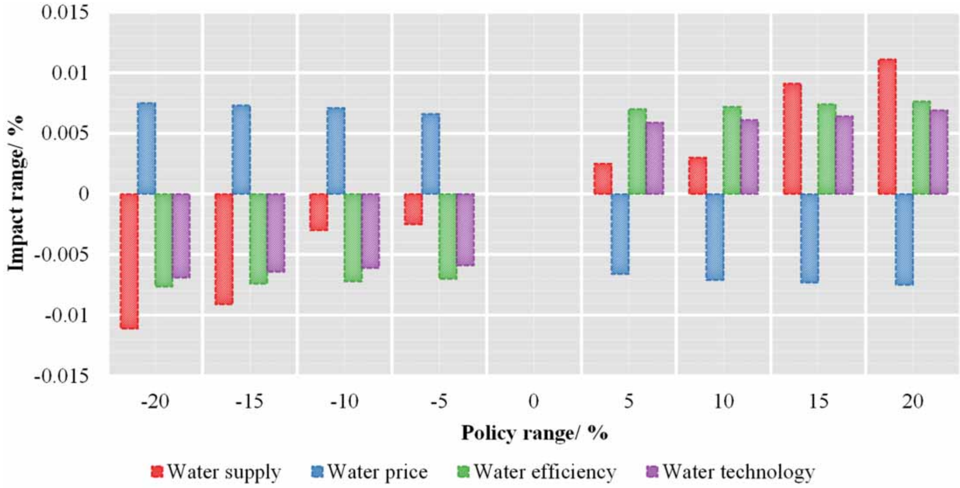

Fig. 6. The impact of four policies on the income of regional residents.

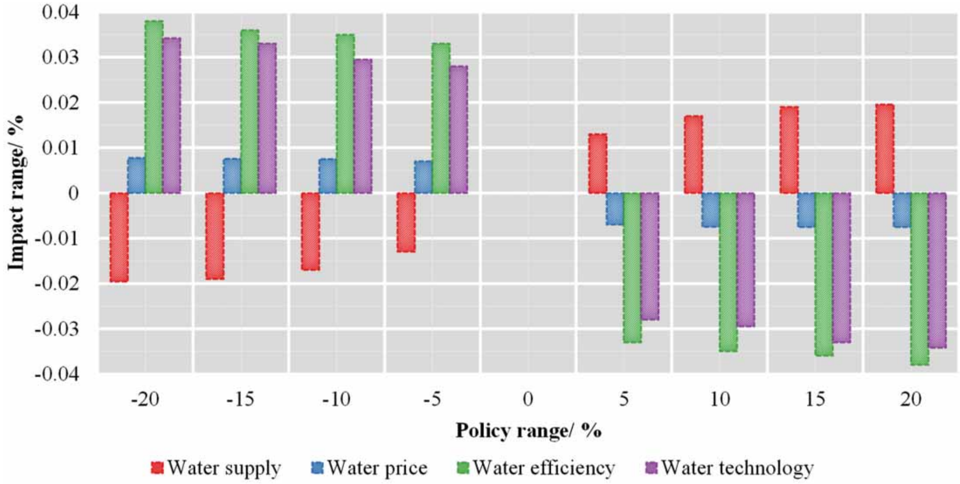

Fig. 7. The impact of four policies on regional water consumption.

improvement of water-use efficiency and water conservancy technology will increase the efficiency of per unit water resources and reduce the overall water demand of residential enterprises.

4.3. The influence of policies on departmental economic indicators

Taking into account the proportion of water demand in different industries and the different elasticity of demand for water resources, after simulating the impact of four policy changes on the main overall regional economic indicators, the changes of output level, labor demand and water consumption of the four sectors caused by policy changes are analyzed by comparing with the base period values (Figure 8).

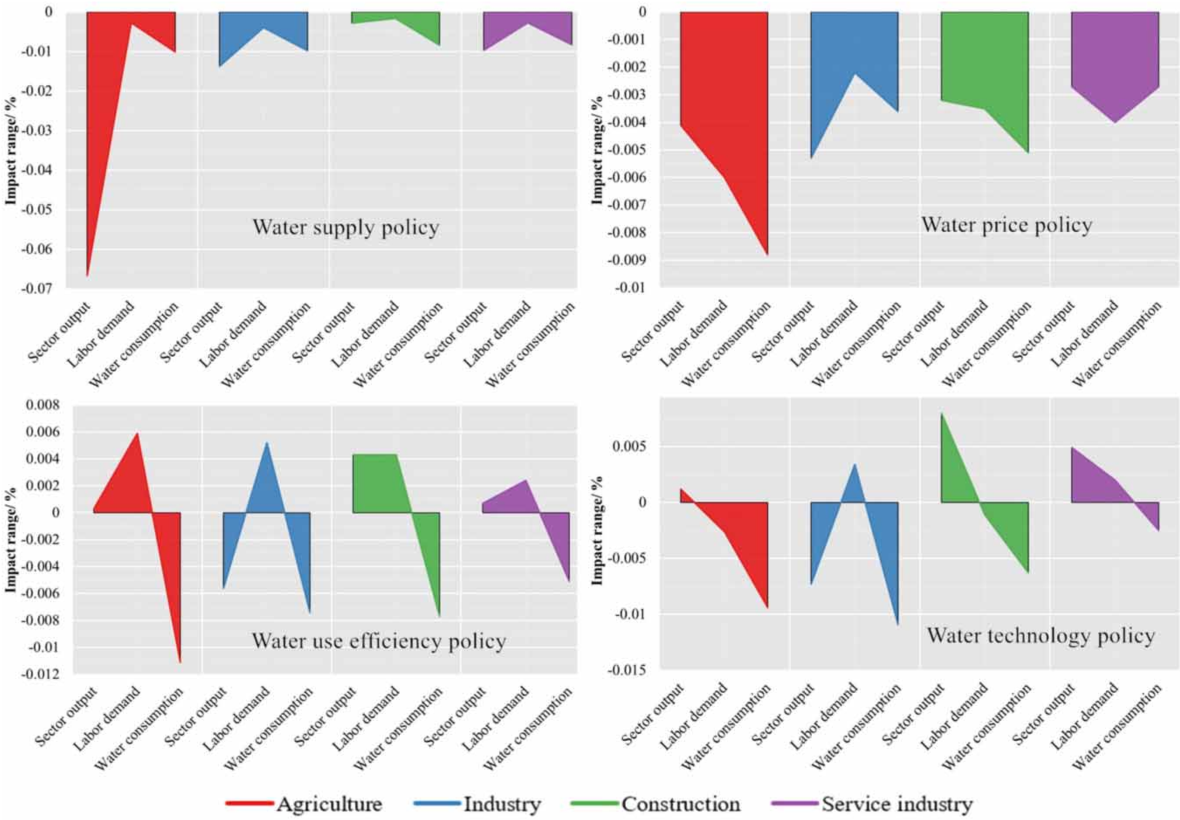

Fig. 8. The Impact of four policies on sectoral economic variables. Please refer to the online version of this paper to see this figure in color: http://dx.doi.org/10.2166/wp.2021.167.

Here, we keep the rest of the control variables unchanged and simulate the impact on the economic variables of each sector when the water supply quantity is reduced by 5%, the water price is increased by 5%, the water-use efficiency is increased by 5% and the water conservancy technology is improved by 5%. In Figure 8, the areas with different colors represent the overall size of each part affected by different water policies, and the height of the three endpoints of the area map represents the change percentage of the impact of specific economic variables. In Figure 8, the top left corner is the impact of water supply policy, the top right corner is the impact of water price policy, the lower left corner is the impact of water efficiency policy and the lower right corner is the impact of water technology policy.

In Henan province, the reduction of water supply generally occurs in the dry season. This scenario will have a direct impact on the water demand of various sectors in the region, especially in industry and agriculture, which are reduced by 0.0098 and 0.0100%, respectively. At the same time, the output of water-intensive industries also decreased to varying degrees. When the water supply was reduced by 5%, the output reduction of the agricultural sector was more than twice that of the other three sectors combined. (In the top left corner of Figure 8, the area in red is the largest.) Henan, as a major grain-producing province in China, will produce 56.954 billion kg of grain in 2019. In total, 1% of the grain production is 570 million kg. In the context of the global food security crisis, this is not a small number. Water supply security plays a key role in ensuring regional agricultural production, food security and the resulting economic and social stability. In addition, compared with the impact on the demand of agricultural labor, the reduction of water supply has a greater impact on the demand of industrial labor, and the loss is more serious. Our findings are intuitive and generally consistent with those of Li *et al*. (2015), which may lead to the transfer of nonagricultural labor to the agricultural sector. It shows that the impact of water supply on the economy of Henan province is relatively great.

When the water price increases, the output, labor demand and water consumption of the four sectors all show a downward trend. It can be predicted that the greater the increase in water prices, the more production costs, and the level of output of various sectors and the ability to absorb labor will also decline (shown in the top right corner of Figure 8). As a major water user, the elasticity of water demand in agriculture is different from that in the nonagricultural sector, which makes this sector particularly sensitive to change in water prices. Judging from the agricultural water price reform plan currently being explored, the price of agricultural water for the excess water use, groundwater and agricultural water for cash crops and facility agriculture will be relatively increased. With a 5% increase in water prices, the output level, labor demand and water consumption of the agricultural sector in Henan province will be reduced by 0.0041, 0.006 and 0.0088%, respectively, and the response of agriculture to the price of water resources is still relatively sensitive.

When the efficiency of water use is improved, the output and labor demand of all sectors increase, the waste of water resources decreases and the demand for water decreases (shown in the lower left corner of Figure 8). Among them, the increase in output in the industrial sector is the most prominent, and when the water-use efficiency increases by 5%, the output of the industrial sector will increase by 0.0056%. The improvement of water-use efficiency increases the marginal contribution rate of 1 m^3 water to the sector output, and the demand for labor force increases accordingly. When the water conservancy technology is upgraded, the output of all departments will increase, and water consumption will also decrease significantly, but the labor demand of the agricultural sector and the construction industry will be reduced by 0.0026 and 0.0011%, respectively (shown in the lower right corner of Figure 8). This may be due to the structural impact of technology on the labor market in the short term. The practice of economic and social development in the past shows that technology, as the source of growth, will bring more new jobs than it replaces. It can be seen that in the long run, the improvement of water conservancy technology still has a greater positive effect on the overall welfare level of the society. Considering other economic variables, the simulation results of this scheme are positive.

5. Conclusions

As far as the water supply is concerned, water resources are irreplaceable in production and life. When the water supply decreases, the output of the sectors closely related to water resource decreases in varying degrees, especially in the agricultural sector. The contradiction between supply and demand of water resources will have a great impact on the GDP and residents' income in Henan province, and the income of enterprises will decline, which will have a negative impact on the regional economy.

In addition, the water resource price lever can effectively regulate the use of water resources in Henan province and encourage the industrial departments of residents to pay attention to improving the utilization rate of water resources, to solve the chronic disease of the coexistence of scarcity and waste of water resources. The cost is that in the short term, the production cost of the enterprise increases, the output decreases, the labor demand decreases, the employment decreases, the real income of residents decreases, the social welfare decreases and the overall economy shrinks. It is only an expedient measure to reduce the contradiction between supply and demand of water resources by raising water prices in the short term. However, as the main means of demand-side management, water price is an effective catalyst to regulate the efficiency of regional water resource allocation and utilization and even technological innovation. Therefore, the sacrifice of acceptable GDP, caused by the increase of water price in a short period of time, is the requirement of social sustainable development.

Finally, when the water resource-use efficiency and the water conservancy technology are obviously improved, the economic level of Henan province increases obviously. As shown in the comprehensive review by Peng *et al*. (2020), various industrial sectors have contributed more added value to the regional economy, the unemployment rate in the industrial sector has dropped significantly, residents' income has increased and social welfare has increased. Therefore, to improve the water-use efficiency and the efficiency of residential industrial departments and reduce the water consumption per unit of products through technological innovation will be a long-term solution to alleviate the contradiction between supply and demand of water resources in Henan province.

Historically, the implementation of water policy in many areas depends on the application of the CGE model. According to Giesecke & Madden (2013), the water policy reform for the Murray–Darling basin, which contains Australia's major river system and traverses four states, was a successful case study of the CGE in water policy. Through the simulation of the CGE model, a voluntary buyback scheme would be conducive to the growth of regional GDP and the improvement of residents' income (Dixon *et al*., 2011). Based on the evidence of the CGE model, the local government finally adopted the voluntary repo scheme, which proved to be successful afterward. Therefore, according to the results of the CGE model, we also want to put forward some reasonable suggestions for China's water policy.

First, water security is the basis of the economic development of Henan province. We should strengthen and improve the construction of regional water conservancy infrastructure and speed up the construction progress of major water conservancy projects in the province. At the same time, the pollution control of major rivers, lakes and reservoirs should be strengthened, the pollution index of water functional areas should be strictly controlled within the prescribed range and the pressure of water supply in areas with dense population and cultivated land should be reduced.

Second, the increase of water price will make the economy of Henan province shrink relatively, so we should try our best to reduce the impact of the change of water price on the life of residents and the production of enterprises. Establish a reasonable water price formation mechanism, so that water prices truly reflect the degree of scarcity of water resources, regulate production and consumer behavior, reduce excessive demand for water resources and alleviate the shortage of water resources.

Third, the improvement of water-use efficiency and water conservancy technology will enhance the economic benefits of Henan province, and all departments should actively explore the experience of efficient water-saving and emission reduction. As Hassan & Thurlow (2011) suggested, the agricultural sector should reduce ineffective evaporation, promote water-saving irrigation technology and improve the utilization rate of water and fertilizer. The industrial department should strengthen the investment of water-saving funds and the water conservancy technology, install heat exchangers and circulating filters on water consumption equipment, realize the closed recycling of cooling water, strengthen the collection and utilization of precipitation and reclaimed water treatment and reuse, and strengthen the utilization of unconventional water. The management department should strengthen the responsibility assessment of water-saving objectives, tap the water-saving potential and improve the department's enthusiasm and initiative inefficient water use. The government should use the concept of sponge city, strengthen publicity and education on efficient water use, raise the social awareness of water conservation, regularly test regional water balance, implement management methods such as water-use audit and contract water-saving, promote the transformation of water resources utilization and economic development mode in Henan province and enhance economic benefits.

Acknowledgments

The work was financially supported by the fund for building world-class universities (disciplines) of the Renmin University of China (project no. KYGJC2020005).

Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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Received 11 August 2020; accepted in revised form 21 January 2021. Available online 12 February 2021