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# Calculation of optimal tax rate of water resources and analysis of social welfare based on CGE model: a case study in Hebei Province, China

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## Abstract

The determination of the optimal tax rate of water resources is one of the core as well as the key economic and technological issue in the ‘fee to tax’ work of water resources in China. Therefore, based on the introduction of the computable general equilibrium (CGE) model of water resources tax, using production parameters and consumption parameters of Hebei province in 2008–2017, the optimal tax rate of water resources is simulated and calculated, and the impact of the optimal tax rate on social welfare is analyzed. The results show that the reference of the best water resources tax rate in Hebei Province is 18%, and taxation on water resources effectively promotes the water use structure and water resources utilization efficiency in Hebei, which is beneficial to its water resources protection. The effective calculation of the optimal tax rate of water resources tax in Hebei Province proves the effectiveness of the CGE model in the formulation of water resources tax rate, which provides an important reference for the nationwide popularization of water resources ‘fee to tax reform’ in China and the formulation of water resources tax rate in other regions.

*Keywords:* CGE model; Consumer utility; Optimal tax rate; Social welfare; Water resources fee to tax

## Highlights

- The shortage of water resources and the malpractice of water resources fee policy promoted the water resources ‘fee to tax reform’.
- The calculation of optimal tax rate of water resources is the key step of tax reform.
- The collection of water resources tax can improve the level of social welfare.
- The results show that CGE model is an effective method to calculate the optimal tax rate of water resources.



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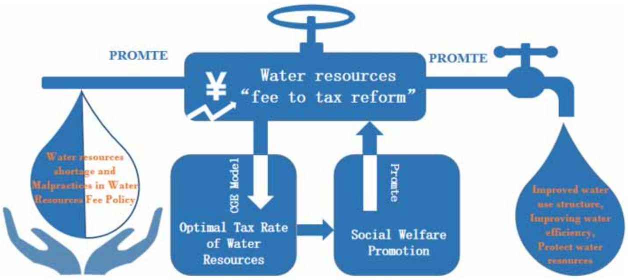
**Graphical Abstract**




## 1. Introduction

The Chinese government uses a variety of policy measures to manage the country's limited water resources, including the system of paid use of water resources. The collection of water resources fee is an important way to promote the system of paid use of water resources in China. Its purpose is to use economic means to promote water conservation, especially to control the exploitation of urban groundwater. At present, the water shortage in China is becoming increasingly severe, with the coexistence of resource water shortage and water quality shortage, and the per capita water resources holding is far lower than the world average level. Therefore, the scarcity and uneven spatial distribution of water resources has become one of the major obstacles to China's green and sustainable economic development. Controlling the water intake, balancing the distribution of water resources and using water resources efficiently are important ways to alleviate the problem of water shortage. Water conservation requires both the government and the market, and the price mechanism is a key tool and means for market regulation. Accordingly, after the promulgation of the Water law of the People's Republic of China in 1988, the water resources fee began to be collected comprehensively. Due to the ambiguous responsibilities of relevant departments, low overall water prices, significant differences in regional water prices, and non-standard use of water resources fee, the policy of collecting and paying water resources fee is no longer applicable to the current national development needs. China is now reforming the 32-year-old water resources fee policy, and plans to replace the weak binding water resources fee policy with more stringent water resources tax, thus the work of 'fee to tax' water resources is launched.

In July 2016, Hebei Province actively responded to the national pilot policy and took the lead in transforming the water resources fee to tax. Since the implementation of water resources tax reform, the unreasonable water demand in Hebei Province has been effectively restrained, and the growth of finance and taxation in the province has been promoted. This also shows that water resources tax reform work has the basis and conditions to expand the pilot reform. In November 2017, the tax reform based on success in Hebei Province, and to expand the scope of water resources tax reform pilot, the '$1+9$' pilot pattern was formed in China, and the feasibility of the nationwide promotion of water resources tax reform was further explored through the pilot projects in different regions. The determination of water resources tax is an indispensable part of water resources tax reform process; the determination of reasonable water resources tax rate is an effective way to improve the water shortage problem and an important factor to give full play to the role of water resources tax. It is of far-reaching significance to improve the existing situation of water resources. But from the point of pilot areas, to achieve the smooth transition of the 'fee to tax reform', the water resources tax rate is mostly fine-tuned on the basis of the original water resources rate, which can reduce the difficulty of implementing this reform. Because the amount of water resources tax collected after the reform is similar to the previous water resources fee, the resistance tendency of water users will be reduced. However, if the water resources tax rate standard simply follows the previous water resources fee rate, the determination of water resources tax will lack the scientific argument of tax rate validity, consumer effect, and social welfare, which may affect the overall effect of water resources fee tax reform. Therefore, it is necessary to study the calculation of optimal tax rate of water resources from the perspective of social economic accounting and social welfare maximization, and then demonstrate the feasibility of the current tax rate in the pilot area.

## 2. Literature review

From the perspective of tax classification, water resources tax belongs to resource tax, which is also known as green tax. Early scholars, such as Pigou, advocated taxing natural resources according to the degree of destruction, which laid the theoretical foundation of resource tax collection. Later, some, such as Conrad & Hool (1984) focused on the impact of taxation on resource extraction and how to design a tax system to optimize resource allocation. After that, research on the theory of resource tax and its scope were studied in depth. Deroubaix & Leveque (2006) believed that from the perspective of protecting the ecological environment, not only energy products should be taxed but also natural resources such as water resources. Some scholars have also studied the impact of resource tax on economic development. Groth & Schou (2007) used endogenous growth model to compare the growth effect of a traditional resource tax, and found that the collection of resource tax plays an important role in economic growth. China's green tax revenue appears relatively late, but in 1984, China began to collect resource tax, and gradually reformed and improved the institutions and regimes of resource tax. Guang-Cheng (2002) found that mineral resource tax had gone through two stages of free mining, tax and fee concurrent, and put forward reasonable suggestions according to the existing practice of mineral resources tax in China. Xie & Zhang (2003) used econometric models to construct a method system to determine the tax rate of coal resources. Hua-Guo *et al*. (2011) conducted a preliminary quantitative analysis of coal resource tax rate based on the regulatory function of mineral resource tax in China in terms of benefit distribution and mineral protection. Lingyun *et al*. (2016) analyzed the effectiveness of relevant policies in the leverage process by studying the impact of resource tax leverage on carbon emissions. Chen & Wang (2018) found that the collection of carbon tax is more effective than government subsidies in promoting the development of low-carbon manufacturing industry. Xiong & Li (2019) believe that the tax system plays a positive role in the ecological environment. Zhou & Fan (2019) proposed that resource tax should take social and economic value into account, and the setting of tax rate should be closely combined with the scarcity of resources and the externality of mining.

With the occurrence of a series of problems such as serious over-extraction of groundwater and excessive waste of water resources, relevant departments of the country must pay close attention to and focus on the treatment of water resources, and the collection of water resources fee and tax has gradually developed into a hot research topic. For example, Tiwari & Dinar (2002) found that water price policy reform reduced water consumption in Israel by 50%. Bontemps & Couture (2002) argued that only when water price keeps rising to a 'threshold' price can the price elasticity of water demand play out, that is, the increase of water price can restrain the demand of water users. Li & Ma (2014) analyzed the economic effect of all-natural resource tax reforms, including water resources, and also concluded that the low proportion of current resource tax revenue hindered the function of resource tax regulation. Chen & Wang (2018) believed that water resources tax can only accomplish its task of regulating water resources utilization behavior if it has a certain absorption capacity.

Another aspect of research on the effect of water resources fee and tax policy focuses on the impact on the industry. Internationally, Llop & Ponce (2012) quantitatively simulated the impact of water resources tax policy on the economic system of Catalonia, Spain by using the single-region computable general equilibrium (CGE) model. Of course, their research also included the impact of water resources tax policy on water consumption. Chinese scholars have carried out a series of research on the theoretical basis of water resources fee collection and the establishment of standards. Shen (2006) established the calculation method of water resources fee from the aspects of costs and market supply and demand. Ji *et al*. (2011), based on a fuzzy mathematical model to establish a water resources fee standard, considered various factors. However, scholars have found that there are many problems regarding the water resources fee, and related research on the water resources 'fee to tax reform' has been carried out. Shen *et al*. (2002) compares the difference between water resources and other taxable resources, obtained the three principles of water resources tax collection, and puts forward relevant suggestions of 'fee to tax reform'. Ping & Chang-Fan (2016) comprehensively analyzed the level of water resources fee burden based on three perspectives: the proportion of water resources fee to unit price of tap water, the proportion of enterprise load bearing, and the proportion of urban water fee to per capita disposable income. Li (2017) analyzed the actual situation of Hebei Province's water resources 'fee-to-tax reform' and put forward some theoretical suggestions on the object, scope, and tax standard of taxation. Chen & Wang (2018) believed that establishing a perfect water resources tax burden system and the guarantee of special funds for water resources taxation are conducive to the protection of water resources. Li *et al*. (2019), based on the problems in the overall operation of water resources tax pilot in Shanxi Province, put forward some suggestions for improvement.

Looking back at the relevant literature, we can find that although the paid use of water resources fee can promote the rational allocation of water resources and its utilization efficiency, and play a role in ensuring the steady development of economy and society, there are still problems such as not collected, not collected in place, not collected according to standards. In order to practice the concept of 'water-saving priority' and 'two-hand (Market and Government) effort', water resources 'fee to tax reform' needs to be popularized all over the country, and the establishment of accurate water resources tax standards is particularly important. Prior to this, the study of water resources tax is still in the stage of theoretical analysis, only the necessity and feasibility of water resources 'fee to tax reform' are analyzed, and few scholars have carried out targeted research on the determination of water resources tax rate. Water resources tax is not only a price policy tool in the field of water resources management, in addition to influencing people's behavior of using water, it will profoundly affect the entire economic system. Water resources tax is an important price lever to encourage water conservation. China's water resources shortage and uneven distribution in time and space means it is necessary to promote water saving through water resources tax rate optimization. At the same time, the increase of water resources tax will increase the economic burden of water users and affect the production of the whole economic system. We must scientifically evaluate the optimal tax rate of water resources from the perspectives of production, consumption, and social equilibrium. As a normative economic model, the CGE model can well integrate production, consumption, and market, and be generally applied to the scientific evaluation of resource policy. Keqiang *et al*. (2015) analyzed the impact of water resources policy on the agricultural water efficiency in China by constructing a CGE model and found that the collection of water resources tax on the agricultural sector can save water for production and increase the central and local government income. Zhong *et al*. (2016) further analyzed the impact of the cost change of water resources as a factor of production in the CGE model on the economic system. The results showed that the rising cost of water use did more harm than good. Li *et al*. (2018) analyzed the impact of resource tax reform on the economy through a CGE model, and found that tax policies could promote the transformation of resource economy. In calculation of the optimal tax rate, the CGE model also has its application value. Zhihui (2009), based on the CGE model with producers, consumers, and government as the main body, introduced a tax system including fuel tax and based on the level of social welfare, the best tax rate was found by the enumeration method. Xiaoliang & Xuefen (2013) used the CGE model to analyze the resource tax rate, and believed the level of economic development affects the collection of resource tax. Shi *et al*. (2019) used the dynamic CGE model to discuss the carbon tax level with the least impact on the macro-economy under the energy conservation and emission reduction targets.

China's practice of 'fee to tax reform' on water resources provides a good case for the scientific evaluation of the economic problem of water resources optimal tax rate. This study chooses the first province to be China's water resources tax reform pilot – Hebei Province – as the research object. Based on the existing CGE model, the water resources tax module is added, and the water resources tax rate is calculated by enumeration method, and the optimal tax rate of water resources tax is simulated and analyzed on the principle of maximizing social utility, thus proving the effectiveness of the CGE model in the calculation of the optimal tax rate of water resources.

## 3. Methods

The CGE model is based on the general equilibrium theory proposed by Johansen (1960), which is used to describe the equilibrium relationship between supply, demand, and market, and plays a crucial role in macroeconomic quantitative analysis. In recent years, the CGE model has been used more in solving the optimal tax rate, and the deep understanding of the local economic development level and the current tax system is an important factor affecting the design of the applicable CGE model. The collection of water resources tax has a great influence on the cost of the goods, with water as the factor of production and then affects the price of the related goods, and finally, affects the demand and supply of the related goods. Due to the relatively closed nature of water resources tax, this paper does not consider the foreign sector for the time being. For convenience of research, the CGE model established in this paper includes four modules: production module, consumption module, water resources tax module, and equilibrium module.

### *3.1. Production module*

In this paper, the whole macroeconomic system is regarded as a production unit in the production module. According to the characteristics of water resources tax, the new factor of production, water resources quantity $R$, is introduced on the basis of capital quantity $K$ and labor force $L$. Its production decision-making process is shown in Figure 1.

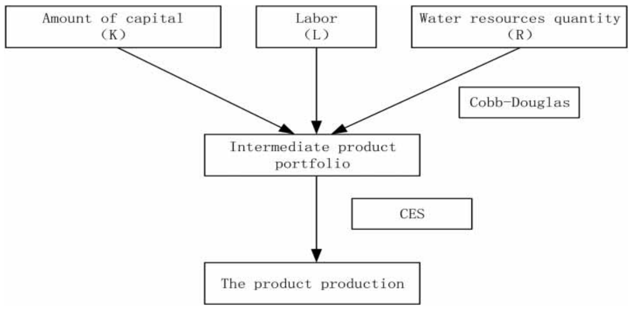



Fig. 1. Production module of water resources tax CGE model.

$A$ indicates that productivity through technological progress is independent of input from other factors. These three elements are combined using the Cobb–Douglas (C-D) production function:

$$Q(K, L, R) = AK^{\alpha}L^{\gamma}R^{\beta} \quad (\alpha + \beta + \gamma = 1) \tag{1}$$

where, $Q$ denotes the total output and $\alpha, \beta, \gamma$ denotes the proportion of $K, L, R$, respectively. $Q, K, L, R$ is humanized for simple calculation. Equation (1) can be converted to:

$$q(k, r) = Ak^{\alpha}r^{\beta} \quad (\alpha + \beta < 1) \tag{2}$$

where, $q$ is per capita output, $k$ is per capita capital, and $r$ is per capita water resources.

When the cost is minimized, the per capita cost function of the producer is as follows:

$$\text{Min}C(k, r) = (1 + T_k)zk + (1 + T_r)\theta r + (1 + T_l)w \tag{3}$$

where, $T_k$ means the capital tax rate, $T_l$ means labor tax rate, $T_r$ means water resources tax rate, and $z, w, \theta$ means the price of capital, labor, and water resources, respectively.

### 3.2. Consumption module

For convenience of research, this paper divides consumption into two parts: government consumption $C_g$ and household consumption $C_p$.

*3.2.1. Household consumption.* For the investigation of family behavior, economists usually analyze it through multi-stage utility function. Families need funds to buy consumer goods, and the source of funds is a variety of income. In order to facilitate research, this paper attributes the source of funds to labor income. Thus, the utility function at the first level knows the total utility of households for goods ($C_p$); the utility function at the second level shows how the quantity of each commodity ($Y_i$) can be selected to maximize the utility. The family utility selection structure is shown in Figure 2.

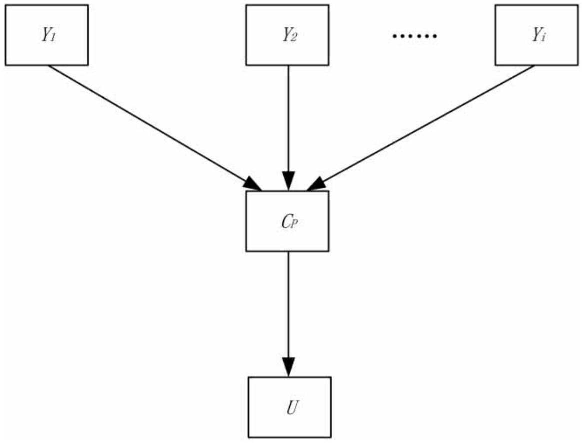



Fig. 2. Water resources tax CGE model household consumption module.

In order to facilitate the study, this paper takes the income of labor as the total income of the household, and the water resources tax as the income tax to be paid, set as:

$$C_p = (1 - T_l)w - T_r\theta_r \tag{4}$$

*3.2.2. Government consumption.* The fiscal revenue of the government mainly comes from various taxes. In this paper, the main tax revenue includes capital tax, labor tax, and water tax. Government expenditure is mainly public expenditure. In this paper, the proportion of government public consumption in government fiscal revenue is $\mu$, set as:

$$C_g = \mu(T_l w + T_k zk + T_r\theta r) \tag{5}$$

*3.2.3. Consumer utility.* This paper uses C-D consumer utility function to find out consumer utility $U$:

$$U = C_p^m C_g^n \quad (m + n = 1) \tag{6}$$

## *3.3. Water resources tax module*

Water resources tax is a new tax item, and what kind of collection method should be adopted is also an important part in the process of collecting water resources tax. For the time being, this paper holds that the water resources tax, as a kind of resource tax, is more suitable to be collected by using the method of metering. The primary purpose of collecting water resources tax is to promote the rational development and economical utilization of water resources, and quantity-based collection cannot only reflect this purpose well but also achieve tax efficiency and fairness.

The water resources tax is levied according to the number of water resources used in practice. This method cannot only ensure that the tax rate is not affected by the exploitation cost of water resources and the market price, but also effectively reduce the exploitation cost of water resources and improve its utilization efficiency. For example, Equations (7) and (8):

$$T_w = R \cdot P \cdot t_i \tag{7}$$

$$t_w = P \cdot t_i \tag{8}$$

where, $T_w$ means water resources tax revenue, $P$ means unit water price, $t_i$ means water resources tax rate, and $t_w$ means unit water resources tax revenue. The optimal tax rate of water resources obtained in this paper can be regarded as proportional tax. The difference of water price caused by the method of water intake and water use unit will also lead to the difference of water resources tax. We use different tax rates to distinguish the difference of paid use of water resources.

### *3.4. Equilibrium condition*

When total output is equal to total consumption, the macroeconomic system can be considered to be in equilibrium, namely:

$$Q = C_p + C_g \tag{9}$$

When the market reaches equilibrium, that is, when the marginal cost equals the marginal benefit, the capital price can be derived:

$$z = \frac{\alpha q}{(1 + T_k)k} \tag{10}$$

and the equilibrium conditional capital price:

$$z^* = \left|\frac{\alpha q^*}{(1 + T_k)}\right|^{\frac{\alpha+\beta}{\alpha}} \left|\frac{A}{q^*}\right|^{\frac{1}{\alpha}} \left|\frac{\beta(1 + T_k)}{\alpha(1 + T_r)\theta}\right|^{\frac{\beta}{\alpha}} \tag{11}$$

## 4. Case analysis

Hebei Province is located in the North China Plain. The per capita water resources ownership is only 1/7 of the per capita water resources ownership in the country, which is characteristic of a typical resource shortage province. Moreover, Hebei Province is the province with the most serious over-extraction of groundwater, so it is urgent to reduce the amount of groundwater extraction through a price lever. Since May 2016 it became the only pilot province in China for water resources tax reform. The water resources 'fee to tax reform' in Hebei Province has achieved remarkable results, and the ability of water resources supervision improved significantly. Water-saving awareness of water users has generally increased. Some high water-consuming enterprises have changed their previously uneconomical ways of using water, begun to explore new ways of industrial transformation and technological innovation, actively adjusted the structure of tax sources, optimized utilization of unconventional water sources such as reclaimed water, and the role of economic levers in regulating social water use behavior has gradually emerged.

However, the standard of water resources tax collection in Hebei Province is based on the simple translation of the standard of water resources fee collection before the tax reform. However, this only carries a small increase of the tax standard to some special objects, and the tax standard lacks the corresponding theoretical basis and scientific nature. Thus, a set of accurate and scientific calculation methods of water resources tax is an important guarantee for the orderly implementation of water resources tax reform.

### *4.1. Model determination and parameter estimation*

Before using the CGE model to carry out the case simulation of Hebei Province, we must first determine several more important parameters, so as to reduce the errors in the process of case simulation.

*4.1.1. Parameter estimation for production modules.* According to Formula (2), the equation of production function is a nonlinear equation. In order to determine the parameters: per capita capital elasticity coefficient $\alpha$, per capita resource elasticity coefficient $\beta$ and a given variable to measure technological progress $A$, a new logarithmic linear estimation equation is obtained by logarithmic processing, such as Formula (12):

$$\mathrm{Ln}(q) = \mathrm{Ln}(A) + \alpha\mathrm{Ln}(k) + \beta\mathrm{Ln}(r) \tag{12}$$

In the production function, the parameters involved are shown in Table 1.

The number of employees in Hebei Province at the end of each year from 2008 to 2017 was selected as the labor factor value and substituted into the model. In order to more accurately reflect the change of per capita output, the impact of price changes must be deducted when the data are used. This paper takes 2008 as the base period, and converts the GDP of Hebei Province from 2008 to 2017 into the GDP at the constant price of 2008. Using the method of Zhang & Wu (2004), the capital stock is accounted by the

Table 1. Production module indicator setting.

| Level 1 indicators | Level 2 indicators | Level 3 indicators |
|---|---|---|
| Production module | Indicator of economic development | GDP (100 million yuan) |
| | | Working population (10,000) |
| | | Per capita output (yuan) |
| | | Capital stock (100 million yuan) |
| | | Per capita capital stock (yuan) |
| | Indicator of water access | Water consumption (100 million cubic meters) |
| | | Per capita water consumption (cubic meters) |

sustainable inventory method, which is converted into the capital stock which eliminates the influence of price change factors in the base period of 2008.

The calculations are as follows:

$$K(2008)_{2008} = K(2008)_{1952} * \frac{P(2017)_{1952}}{P(2017)_{2008}} \tag{13}$$

$$P(2017)_{2008} = \prod_{2008}^{2017} P_t \tag{14}$$

where, $K(2008)_{2008}$ indicates the capital stock data for 2008 excluding price changes of Hebei Province in the base period, $K(2008)_{1952}$ indicates the capital stock of Hebei Province for 2008 calculated in the base period of 1952, $P(2017)_{1952}$ indicates the fixed assets investment price index for 1952–2017 in the base period of 1952, and $P_t$ indicates the fixed assets investment price index for 10 billion yuan a year in Hebei Province.

After determining the capital stock of the base period, the capital stock of Hebei Province for 2008–2017 is calculated according to the perpetual inventory method. The formula is as follows:

$$K_t = \frac{I_t}{P_t} + (1 - \delta)K_{t-1} \quad (\delta = 9.6\%) \tag{15}$$

where, $K_{t-1}$ represents the capital stock of the previous year, $K_t$ represents the capital stock of the year, $I_t$ indicates the investment of the nominal fixed assets of the year, $P_t$ indicates the price index of the fixed assets of the year, $\delta$ indicates the depreciation rate, and $t$ indicates the time.

According to the per capita data estimated from the above data, the relevant parameters in the production function are shown in Table 2.

Table 2. Related parameters in production function of Hebei Province.

| Time | GDP (100 million yuan) | Working population (10,000) | Per capita output (yuan) | Capital stock (100 million yuan) | Per capita capital stock (yuan) | Water consumption (100 million cubic meters) | Per capita water consumption (cubic meters) |
|---|---|---|---|---|---|---|---|
| 2008 | 16,011.97 | 3,725.66 | 42,977.54 | 35,955.10 | 96,506.65 | 195.02 | 523.4509 |
| 2009 | 17,613.17 | 3,792.49 | 46,442.22 | 42,239.23 | 111,375.98 | 193.72 | 510.7990 |
| 2010 | 19,761.97 | 3,865.14 | 51,128.74 | 48,973.85 | 126,706.54 | 193.68 | 501.0944 |
| 2011 | 21,995.08 | 3,962.42 | 55,509.20 | 57,245.06 | 144,469.94 | 195.97 | 494.5715 |
| 2012 | 24,106.60 | 4,085.74 | 59,001.81 | 66,008.27 | 161,557.68 | 195.33 | 478.0774 |
| 2013 | 26,083.35 | 4,183.93 | 62,341.73 | 74,960.83 | 179,163.69 | 191.29 | 457.2017 |
| 2014 | 27,778.76 | 4,202.66 | 66,098.05 | 83,870.55 | 199,565.40 | 192.82 | 458.8047 |
| 2015 | 29,667.72 | 4,212.50 | 70,427.82 | 92,484.24 | 219,547.16 | 187.2 | 444.3917 |
| 2016 | 31,685.12 | 4,223.95 | 75,013.02 | 101,628.53 | 240,600.70 | 182.6 | 432.2968 |
| 2017 | 33,776.34 | 4,206.66 | 80,292.54 | 109,162.68 | 259,499.64 | 181.6 | 431.6964 |

To better simulate its parameters, this paper logarithms the three parameters of per capita output, per capita capital, and capita water consumption in Table 2, as shown in Table 3.

Using SPSS software to process the above table data for linear regression, we get $A = 2.2255$, $\alpha = 0.682$, $\beta = 0.324$, then the production function is $q(k, r) = 2.2255k^{0.682}r^{0.324}$. From the processing results, we can see that the value of $F$-statistics and $R^2$ is greater than the reference value, and the model fits the data to a good degree. The parameter estimates of $\alpha$ and $\beta$ are also at the significant 0.05 level, which also achieves the expected results.

*4.1.2. Parameter estimation in the consumption module.* For convenience of research, this paper divides the total consumption into two parts: government consumption and resident consumption, and adopts the government consumption and resident consumption data of Hebei Province in the ten years of 2008–2017 as the basic data to determine the elasticity coefficient of government consumption and resident consumption. The relevant parameters of the consumption function of Hebei Province for 2008–2017 are shown in Table 4.

Table 3. Related parameters after legitimatization.

| Time | lnq | lnk | lnr |
|---|---|---|---|
| 2008 | 10.6684 | 11.4774 | 6.2604 |
| 2009 | 10.7460 | 11.6207 | 6.2360 |
| 2010 | 10.8421 | 11.7496 | 6.2168 |
| 2011 | 10.9243 | 11.8808 | 6.2037 |
| 2012 | 10.9853 | 11.9926 | 6.1698 |
| 2013 | 11.0404 | 12.0961 | 6.1251 |
| 2014 | 11.0989 | 12.2039 | 6.1286 |
| 2015 | 11.1623 | 12.2993 | 6.0967 |
| 2016 | 11.2254 | 12.3909 | 6.0691 |
| 2017 | 11.2934 | 12.4665 | 6.0677 |

Table 4. Related parameters of consumption function.

| Time | Government consumption (100 million) | Residents consumption (100 million) | Specific value (Resident/ Government) | Government revenue (100 million) | Government consumption ratio |
|---|---|---|---|---|---|
| 2008 | 2,168.35 | 4,526.79 | 2.0877 | 1,824 | 1.1888 |
| 2009 | 2,177.48 | 5,043.35 | 2.3161 | 2,020.77 | 1.0775 |
| 2010 | 2,594.58 | 5,731.44 | 2.2090 | 2,409 | 1.0770 |
| 2011 | 2,741.16 | 6,892.66 | 2.5145 | 3,017.59 | 0.9084 |
| 2012 | 3,272.71 | 7,808.39 | 2.3859 | 3,479.26 | 0.9406 |
| 2013 | 3,438.53 | 8,448.06 | 2.4569 | 3,652.4 | 0.9414 |
| 2014 | 3,583.11 | 8,955.86 | 2.4995 | 3,764.56 | 0.9518 |
| 2015 | 3,698.67 | 9,499.11 | 2.5683 | 4,065.11 | 0.9099 |
| 2016 | 3,865.36 | 1,0670.77 | 2.7606 | 4,390.65 | 0.8804 |
| 2017 | 4,144.36 | 1,1911.34 | 2.8741 | 5,085.98 | 0.8149 |
| Average | | | 2.4673 | | 0.9691 |

The average ratio of consumer consumption to government consumption is taken as a basic ratio of 2.47; the average of government consumption ratio is regarded as government public consumption $\mu$, namely, $\mu = 0.97$. In the consumer utility function, $m + n = 1$, we can find that the residents' consumption elasticity coefficient $m$ of Hebei province is 0.712 and the government consumption elasticity coefficient $n$ of Hebei province government is 0.288.

As there is no direct definition of labor tax rate $T_l$ and capital tax rate $T_k$ in the current tax rate of China, and part of the capital tax is included in the personal income tax, it is impossible to replace the labor tax rate with the personal income tax rate. This paper draws on the research results of Bei & Zhiwen (2012) on the effective labor tax rate and the effective capital income tax rate and adopts the capital tax rate $T_k = 26.8\%$, and the labor tax rate $T_l = 11.2\%$.

By calculating the average salary of on-the-job workers in Hebei Province in 2013–2017 as 51,181.2 yuan, this paper sets the labor price at 51,181.2 yuan. The average water price in Hebei Province is 2.76 yuan per cubic meter. The equation of consumption of the government and residents of Hebei Province is as follows:

$$C_g = 0.97(0.112 * 51181.2 + 0.268zk + 2.76T_r r) \tag{16}$$

$$C_p = (1 - 0.112) * 51181.2 - 2.76T_r r \tag{17}$$

### 4.2. Simulation of water resources tax rate

Based on the equation of the model and the determination of key parameters, the influence of different water resources tax rates on consumer utility is simulated by comparative static analysis, and the optimal water resources tax rate in Hebei Province is found based on the principle of consumer utility maximization.

*4.2.1. Production module.* According to the formula, in the case of known labor tax rate $T_l$ and capital tax rate $T_k$, the water resources tax rate $T_r$ becomes one of the main factors affecting the equilibrium output $q*$ per capita. It can be seen from the formula that $q*$ is a reduction function with the increase of $T_r$, that is to say, the water resources tax rate is not the higher the better, and it limits the economic development to some extent. Through the experience of the existing research, the loss range of macroeconomic output is controlled within 1%. Therefore, this paper calculates an acceptable water resources tax rate through the CGE model to achieve consumer utility to Pareto optimality.

*4.2.2. Consumption module.* To compare the effect of water resources tax rate change on consumer utility more intuitively, this paper sets the water resources tax rate between 0 and 20%. Using 1% tax rate increase as the minimum tax rate change unit, the effect of water resources tax rate change on consumer utility is analyzed by enumeration.

*4.2.3. Analog result.* By bringing specific values into the model, we can get the effect of the change of water resources tax rate on the per capita equilibrium output and the amount of water resources consumption and the magnitude of consumer utility under the change of tax rate, as shown in Table 5.

Table 5. Balanced output, water consumption, and consumer utility at different tax rates.

| Water resources tax rate (%) | Equilibrium output change ratio (%) | Water consumption reduction ratio (%) | Consumer utility |
|---|---|---|---|
| 1% | −0.012% | −1.007% | 32,320.858 |
| 2% | −0.023% | −1.995% | 32,344.181 |
| 3% | −0.034% | −2.963% | 32,365.263 |
| 4% | −0.045% | −3.912% | 32,384.248 |
| 5% | −0.055% | −4.842% | 32,401.269 |
| 6% | −0.066% | −5.755% | 32,416.452 |
| 7% | −0.076% | −6.651% | 32,429.911 |
| 8% | −0.086% | −7.530% | 32,441.753 |
| 9% | −0.096% | −8.392% | 32,452.080 |
| 10% | −0.106% | −9.239% | 32,460.984 |
| 11% | −0.115% | −10.070% | 32,468.553 |
| 12% | −0.124% | −10.886% | 32,474.867 |
| 13% | −0.134% | −11.687% | 32,480.003 |
| 14% | −0.143% | −12.475% | 32,484.033 |
| 15% | −0.151% | −13.248% | 32,487.021 |
| 16% | −0.160% | −14.008% | 32,489.031 |
| 17% | −0.169% | −14.754% | 32,490.122 |
| 18% | −0.177% | −15.488% | 32,490.347 |
| 19% | −0.185% | −16.210% | 32,489.759 |
| 20% | −0.193% | −16.919% | 32,488.406 |

According to the results of the calculations in Table 5, the per capita output is also reduced to a certain extent when the water resources tax rate is increasing, while the water resources consumption is also decreasing, and the proportion of water resources consumption reduction is much larger than that of equilibrium output when the tax rate is increased from 1% to 20%, the impact of equilibrium output is only increased from 0.012% to 0.193%, but the impact on the per capita water resources consumption has increased from 1.007% to 16.91%. This indicates that although the water resources tax has a certain negative effect on the economic development of Hebei Province, it has greatly reduced the water consumption and has a water-saving effect.

The calculated Hebei Province consumer utility chart (Figure 3) shows that when the water resources tax rate changes within 0% to 20%, the consumer utility increases first and then decreases, showing an

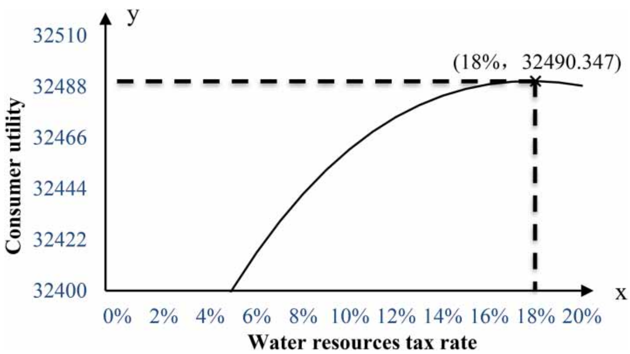



Fig. 3. Consumer utility under different water resources tax rates.

'inverted ∩' shape. This shows that the collection of water resources tax will improve consumer utility, and there is an optimal rate of water resources tax to maximize consumer utility. From the calculation results, when the tax rate reaches 18%, the consumer utility is the highest, and the maximum value is 32,490.347. At this point, the average price of water in Hebei Province is 2.76 yuan per cubic meter, and the corresponding average amount of water resources tax is 0.497 yuan per cubic meter. Compared with the current standard of water resources tax in Hebei Province, the amount of water resources tax is about 0.5 yuan per cubic meter, and the two are relatively close, which accords with the basic standard of 'fee to tax translation'. After the water resources tax of Hebei Province was levied for a period of time the tax revenue increased obviously, and the enthusiasm of enterprises to save water increased. The response was good, so the tax rate also has certain reference significance to other regions.

### *4.3. Analysis on the social welfare impact of water resources tax*

In the Measures for Pilot Implementation of the Reform of Water Resources Tax, it is pointed out that the first principle of 'fee to tax reform' in water resources is 'fee to tax translation'. That is to say, when collecting water resources tax, the basic elements such as the payer, the object, and the basis of collecting water resources fee previously should be maintained, to realize the steady transformation of the Fee-to-Tax Policy. After the tax reform, it is necessary to ensure the 'three unchanged': the burden of public water supply in cities and towns remains the same, the burden of water for the normal daily life of the residents remains the same, and the burden of water for the normal production of industry and agriculture remains the same. This is to ensure the water resources tax reform work from the pilot undergoes a smooth transition to national popularization.

To carry out the primary principle of water resources tax reform, the influence of the increase of water resources tax rate on the social welfare of Hebei Province is preliminarily analyzed. Through the consumer utility obtained above, the scientific rationality of the optimal water resources tax rate is again verified by using the Hicks variable method (including the Hicks equivalent variable (EV) and the Hicks compensation variable (CV)) to obtain the social welfare level under the change of the tax rate between 1 and 20%. The social welfare level equations are shown in Equations (18) and (19):

$$EV = \frac{U_i - U_0}{U_0} q_0 \tag{18}$$

$$CV = \frac{U_i - U_0}{U_i} q_i \tag{19}$$

where, $U_0$ means consumer utility when water resources tax rate is 0%; $U_i$ means consumer utility when water resources tax rate changes between 1 and 20%; $q_0$ means equilibrium output when water resources tax rate is 0%; $q_i$ means equilibrium output when water tax rate changes between 1 and 20%. By substituting the above data into Equations (18) and (19), the change value of the social welfare level after the increase of the water resources tax rate from 0% to 20% can be obtained, as shown in Table 6.

As can be seen from Table 6, in the process of increasing the water resources tax rate from 1% to 18%, the EV and CV values are also increasing with the increase of tax rate, which shows that the social welfare level of Hebei Province is increasing continuously; while the water resources tax rate increases from 18% to 20%, the EV and CV gradually decrease, which indicates that the social welfare

Table 6. Changes in social welfare following the change in water tax rates from 0% to 20%.

| | | | | Welfare change as a percentage of GDP per capita | |
|---|---|---|---|---|---|
| Tax rate | Consumer utility | EV | CV | EV | CV |
| 1% | 32,320.858 | 224.97 | 223.72 | 0.496% | 0.493% |
| 2% | 32,344.181 | 267.93 | 266.26 | 0.590% | 0.587% |
| 3% | 32,365.263 | 306.77 | 304.65 | 0.676% | 0.671% |
| 4% | 32,384.248 | 341.74 | 339.18 | 0.753% | 0.747% |
| 5% | 32,401.269 | 373.10 | 370.11 | 0.822% | 0.815% |
| 6% | 32,416.452 | 401.06 | 397.67 | 0.884% | 0.876% |
| 7% | 32,429.911 | 425.86 | 422.07 | 0.938% | 0.930% |
| 8% | 32,441.753 | 447.67 | 443.53 | 0.986% | 0.977% |
| 9% | 32,452.080 | 466.69 | 462.23 | 1.028% | 1.018% |
| 10% | 32,460.984 | 483.10 | 478.34 | 1.064% | 1.054% |
| 11% | 32,468.553 | 497.04 | 492.04 | 1.095% | 1.084% |
| 12% | 32,474.867 | 508.67 | 503.45 | 1.121% | 1.109% |
| 13% | 32,480.003 | 518.13 | 512.73 | 1.142% | 1.130% |
| 14% | 32,484.033 | 525.55 | 520.02 | 1.158% | 1.146% |
| 15% | 32,487.021 | 531.06 | 525.41 | 1.170% | 1.158% |
| 16% | 32,489.031 | 534.76 | 529.04 | 1.178% | 1.166% |
| 17% | 32,490.122 | 536.77 | 531.02 | 1.183% | 1.170% |
| 18% | 32,490.347 | 537.19 | 531.42 | 1.184% | 1.171% |
| 19% | 32,489.759 | 536.10 | 530.36 | 1.181% | 1.169% |
| 20% | 32,488.406 | 533.61 | 527.92 | 1.176% | 1.163% |

level of Hebei Province is gradually decreasing. This shows that when the water resources tax rate reaches 18%, the social welfare level in Hebei Province is the highest, reaching Pareto optimality. This is because residents' affordability of the water resources tax rate is within 18%, and that a tax rate of more than 18% may affect the residents' daily life. When the water resources tax rate rises from 0% to 18%, the amount of water resources tax collected will increase substantially, and the total amount of government tax revenue will increase so that the government will increase its investment in social public investment, public infrastructure construction, sewage disposal, and environmental protection. At the same time, because of the increase in revenue, the government will also increase its investment in education, culture, and other basic social undertakings, thus improving the level of social welfare in all aspects. In terms of social welfare changes as a percentage of GDP per capita, the percentage is small, that is, water resources tax will increase the government's revenue, but it has little impact on the improvement of social welfare.

## 5. Conclusions

Based on China's latest water resources planning and management program, this paper analyzes the relationship between water resources tax, water resources fee, and resource tax. In this paper, a CGE model of water resources tax is proposed and applied to the calculation of the optimal tax rate of water resources tax in Hebei Province. On this basis, the social welfare of Hebei Province is analyzed, and the following conclusions are reached:

1. Considering that the amount of tax on water resources levied by different regions, sources, and use ways should vary, the water resources tax rate calculated is a ratio tax rate, and the amount of tax on water resources calculated by different water prices according to this tax rate is also different, so as to reflect the difference in the collection of water resource tax. The reference value of the optimal water resources tax rate in Hebei Province is 18%. Based on the average price of water resources in the province of 2.76 yuan per cubic meter, the average water resources tax amount should be 0.497 yuan per cubic meter. Compared with the current standard of water resources tax in Hebei Province, the amount of water resources tax is about 0.5 yuan per cubic meter. The two are relatively close, which accords with the basic standard of tax reform 'fee to tax translation', not too much influence on residents' life and social-economic operation. The CGE model for China's optimal water resources tax rate calculation has certain reference significance, so that other provinces when determining optimal conforms to this province water resources tax rate can use this method for measurement.
2. After water resources tax is levied according to the optimal tax rate calculated by the CGE model, the fee and tax collection department has changed from the original water resources department to the tax department, and the collection process has become more mandatory. The tax revenue of Hebei provincial government has increased to some extent, so that the government can increase expenditure on ecological protection, science and technology education, and other aspects, to draw from and benefit the people, and thus improve the social welfare level of Hebei Province to a great extent.
3. The increase of water resources tax rate in Hebei Province has effectively improved the unreasonable water use structure and promoted the utilization efficiency of water resources in Hebei Province. Hebei Province, as a water-scarce region in China, has promoted the protection of its water resources to some extent by collecting water resources tax.

The good operation of the pilot reform of water resources tax indicates that the comprehensive promotion of water resources tax is about to be carried out, and the establishment of water resources tax rate is the important link as to whether this work can be carried out in an orderly manner. This paper takes the first pilot Hebei Province of water resources tax reform as an example. Through the analysis of model establishment and simulation, it is found that the CGE model is relatively simple in modeling, and the data involved is also relatively easy to obtain. The result is similar to the 'fee to tax translation', but more scientific, and the level of social welfare will improve in the process of water resources tax collection. Therefore, other provinces and municipalities in the next water resources tax reform work can learn from this method, according to local conditions, to formulate the actual situation of the province's water resources tax rate.

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## Data availability statement

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

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