Residential Water Demand in China: Applications of Double-Log Model and EDM System

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Abstract: This study undertook the residential water demand analysis based on a panel data covered 31 provinces of China during the sample period from 2004 to 2013. Two models are employed in this study: Double-Log model and EDM model. The estimates of double-log model show that the different levels of income cannot impact the water price elasticities significantly but the fixed effects estimator gives a more appropriate estimate for the water demand system. In addition, both the water price and the income are inelastic. However, with the EDM model estimations, the results reveal that the water price is elastic for the residential water demand in the short run, and the partial price-supply elasticity is negative due to estimates of total elasticities. Both two models gave the result that the residential water is an inferior good in China.

Key words: Residential Water Demand; Total Elasticity; Partial Elasticity; EDM.

Introduction

During the past two decades, the water use in China increased approximately 11 percent, and the total water withdraw of China is 618.34 billion cubic meters in 2013 (Figure 1). The total water use mainly consists of agricultural water use, industrial water use and residential water use (Structure of water use see Figure 2), in which the residential water use accounts for the smallest portion (12%) but has the fastest growth. Since 1997, the residential water use has increased more than 40 percent with the annual speed of 2.7%. This situation may have a high correlation with the continuous growth of water consumers, because the number of water consumers grows 39.3% after the year of 2004.[1] Consequently, the residential water supply is suffering a burden from the rapid growth of water consumption. As a matter of fact, the increasing water demand is inconsistent with the capability of water supply in many areas of China. More than 400 cities are experiencing the water shortage, and 110 of them are seriously lacking of water (Chen and Yang, 2009). During the 1990s, drought annually happened on average 26.6 million hectares of Chinese land. Chinese residents had to confront 6 billion cubic meters[2] water scarcity in the cities (Hubacek and Sun, 2007). Therefore, the conflict between the increasing water demand and limitation of water resources is bound to affect both economic development and living quality in China. Based on this situation, analyzing the residential water demand system and knowing how the factors influence the residential water consumption appear to be increasingly important to Chinese water management policy.

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[1] All the growth rates are calculated according to the data from National Bureau of Statistics of China (NBSC). http://www.stats.gov.cn/english/Statisticaldata/AnnualData/

[2] One cubic meter (m^3, SI) = 10^3 liters (L) ≈ 264.2 gallons.

Figure 1 Total Water Consumption of China

Figure 2 Structure of Chinese Water Consumption in 2013

The main purpose of this research is to study Chinese residential water demand system and analyze how the residential water market is affected by water price, income and other non-economic factors. The process is scheduled as follows. The section two presents the literature review of world as well as Chinese residential water demand studies. The section three details the methodology of constructing the water demand system and model estimations. The data resources are discussed in the section four. Both double-log model and reduced-form equations are estimated for Chinese residential water consumption. The empirical results are interpreted in the section five, and the section six concludes.

Literature Review

Since the 1960s, researchers paid more attention to the water demand research because of its increasing importance to the national development as well as living standards. Many studies are concentrated on the analysis of residential water use and consumptions, including the impacts of price, income or some other environmental factors (Howe, 1967 & 1982; Nieswladomy, 1992; Dalhuisen at el, 2003; Gaudin, 2006; Ruijs at el, 2008). Some people considered the residential water as a normal commodity, so water pricing is recommended to be a good market tool for controlling the water consumption. But in other studies, water price was estimated to be inelastic as a matter of fact (Howe, 1982; Ruijs at el, 2008). And there are also some studies that found the price elasticity was related to regional characteristics. They argued the price elasticity of water demand was higher in water shortage areas than the other regions of the country. Because people in these regions perhaps have a greater awareness of the scarcity of water and thus have higher price elasticities (Nieswiadomy, 1992). Some researchers also attributed the low price elasticity to the absence of price information on the water bills. The study indicated that the water price elasticity could increase 30% or more with taking the effect of price-related information, such as income, household size or climate change, into account (Gaudin, 2006). However, there should be another reason for the diversity of their researching results. That is the difference in the selection of models.

Some studies choose the linear logarithmic model to estimate the water demand equations (Nieswiadomy, 1992; Gaudin, 2006; Olmstead at el, 2007), and some utilize semi-logarithmic form (Arbués and Barberán, 2004) or non-linear frame work (Dalhuisen at el, 2003) to deal with the corresponding problem. To estimate the water demand equation, the price variable is also seriously considered. Ruijs and Zimmermann (2008) selected marginal water price and average water price to estimate water demand models, and got the similar results for these two sets of models. Each model has two equations: one is a linear equation and another one is a linear form with only logarithmic income. All the results show that both price and income elasticities are inelastic. But there are also some studies indicate that consumers tend to respond to average prices for the water demand rather than marginal prices (Foster and Beattie, 1981; Shin 1985). Gaudin (2006) only chose the average water price in his model due to specificities of his dataset. In the study, a linear logarithmic model was built with average price, income, density, and some other climate factors. The results show that price-related information can raise the price elasticity of demand. Actually, this problem only exists with the block pricing policy. If no block pricing is implemented to the water market, the marginal water price equals average price.

Considering Chinese water demand, most of studies just focus on the industrial and agricultural water use, because water as an important production factor is concerned by many researchers (Wang and Lall, 2002; Yang, at el, 2003; Zhong and Mol, 2005). But for the residential water consumption, very few studies can be found. A survey was designed to collect information on the residential water use from Beijing and Tianjin cities (Zhang and Brown, 2005). The empirical work shows that households in Beijing and Tianjin consumed much more water per capita than previously imagined and the water price and income do not have the expected impact on household water consumption. As no block pricing policy is applied to the consumers in Chinese water market, some people believe block water price will be put into practice someday (Chen and Yang, 2009). They simulate the relationship between block water price and residential water demand of Beijing city by applying the extended linear expenditure system. In this research, we will concentrate on the analysis of residential water demand system and study how Chinese residential water market is affected by water price, income, water resource and other related environmental factors.

Methodology

Log-log Demand Model

In this study, two types of residential water demand models are considered. The first one is related to the double-log demand functional form, which has been employed by many previous studies (Gaudin et al., 2001; Olmstead at el, 2007), because they believe the log-log demand functional form instead of a linear form is easy to facilitate interpretation of the coefficient as elasticity. According to previous studies (Gaudin, 2006; Ruijs at el, 2008), the influence factors of the residential water demand can be divided into two parts: the sociological section and the environmental section. The sociological part is mainly determined by water price and income, while the environmental part is concerned with water resource, regional temperature and rainfalls.

As water is hardly substitutable, all the cross-price elasticities are assumed to be negligible in this study. Meanwhile, we suppose the price elasticities of residential water demand based on the different levels of income are diverse, due to the income effect of the uncompensated price elasticity. The annually per capita income can be divided into three levels with setting two dummy variables. In the middle level of income, we have D_1 equals 1, else equals 0. For another dummy variable, D_2 equals 1 with the high level of income, else equals 0. Then we can establish the double-log residential water demand function as follow:

$$lnQ_d = \alpha_0 + \alpha_2 lnP + \alpha_3 lnY + \alpha_4 lnRF + \alpha_5 lnTEMP + \alpha_6 lnRE + \alpha_7 D_1 * lnP + \alpha_8 D_2 * lnP \qquad (1)$$

where, Q_d is per capita residential water consumption, P is real residential water price, Y is per capita real income, RE is per capita water resource, RF is regional average rainfall, $TEMP$ is average temperature and D_is are dummy variables for each level of income. As a result, the price elasticity and the income elasticity can be calculated by the equations as follow:

$$\eta_p \approx \frac{dlnQ_d}{dlnP} = \alpha_2 \ and \ \varepsilon_Y \approx \frac{dlnQ_d}{dlnY} = \alpha_3$$

in which, η_p indicates the price elasticity and ε_Y reports the income elasticity. If $\alpha_2 < 0$ and $\alpha_3 > 0$ significantly, we can conclude that the residential water is a normal good and the water demand can be influenced by the water price and regional income.

Equilibrium Displacement Model

Except for the double-log demand model, another common method used to analyze the demand system is establishing an equilibrium displacement model (EDM), but it has not been employed in the study of Chinese residential water demand yet. An important assumption for the EDM is that the water price is not an exogenous variable as which in the double-log equation, and it allows the demand curve to shift due to the changes of income or some other factors. For example, if the residential water is a normal good, the water demand curve will shift up with the increased income (Figure 7). In the other words, when income goes up, people will have additional money to consume more residential water based on the same water price. Then a shortage will turn up between the water supply and water demand, which will prompt the equilibrium water price to increase. Thus, a new equilibrium point can be reached (Figure 7). In an equilibrium displacement model, the residential water price will adjust according to the changes of income or other exogenous variables.

Figure 7 Diagrams of Water Supply and Demand Equilibrium Assumption

To establish an equilibrium displacement model for Chinese residential water market, we firstly assume that the water market is closed, and no real water trade happens in the residential water market. Generally, the water trade is only occurred as an indirect form during the industrial or agricultural production process as “virtual water” (Hoekstra and Hung, 2002). Applying the factors analyzed in the log-log demand function, we can define Chinese residential demand system as

$$Q_d = D(P, Y, TEMP, RF) \quad \text{(Residential water demand);}$$

$Q_s = S(P, RE, TEMP, RF)$ (Residential water supply);

$Q_d = Q_s$ (Market equilibrium),

in which, Q_d is the quantity of residential water demand, Q_s represents the quantity of residential water supply, and RE indicates per capita water resource. Meanwhile, only Q_d, Q_s and P are endogenous variables, others are exogenous variables. Applying the first derivative, we can deduce the equilibrium displacement models as follows (Details see Appendix):

$$Q_d^* = \eta_p P^* + \eta_Y Y^* + \eta_T TEMP^* + \eta_{RF} RF^* \qquad (2)$$

$$Q_s^* = \varepsilon_p P^* + \varepsilon_R R^* + \varepsilon_T TEMP^* + \varepsilon_{RF} RF^* \qquad (3)$$

$$Q_d^* = Q_s^* = Q^* \qquad (4)$$

where, η_p implies the partial demand-price elasticity, ε_p is the partial supply-price elasticity, η_Y indicates the partial income elasticity and ε_R is the partial resource elasticity, etc. According to equation (4), we can get the reduced functional form for the residential water price as

$$P^* = \frac{\eta_Y}{\varepsilon_p - \eta_p} Y^* - \frac{\varepsilon_R}{\varepsilon_p - \eta_p} R^* + \frac{\eta_T - \varepsilon_T}{\varepsilon_p - \eta_p} TEMP^* + \frac{\eta_{RF} - \varepsilon_{RF}}{\varepsilon_p - \eta_p} RF^* \qquad (5)$$

Then put the equation (5) into the equation (2), and we can obtain the reduced functional form for the residential water consumption as

$$Q^* = \frac{\varepsilon_p \eta_Y}{\varepsilon_p - \eta_p} Y^* - \frac{\varepsilon_R \eta_p}{\varepsilon_p - \eta_p} R^* + \frac{\varepsilon_p \eta_T - \varepsilon_T \eta_p}{\varepsilon_p - \eta_p} TEMP^* + \frac{\varepsilon_p \eta_{RF} - \varepsilon_{RF} \eta_p}{\varepsilon_p - \eta_p} RF^* \qquad (6)$$

According to the equation (5) and the equation (6), the total elasticities are defined as

$$\eta_Y^p = \frac{P^*}{Y^*} = \frac{\eta_Y}{\varepsilon_p - \eta_p} \text{ and } \eta_Y^T = \frac{Q_d^*}{Y^*} = \frac{\varepsilon_p \eta_Y}{\varepsilon_p - \eta_p}$$

Similarly, if the residential water is a normal good, we can assume η_p is negative and ε_p and η_Y are positive, and then η_Y^p and η_Y^T should be also positive. But we cannot make sure whether the residential water is a normal good without the empirical work. The empirical results are discussed in the section 5.

Pooled and Fixed Effects Models

In this study, the dataset is built on 31 provinces of China during the period between 2004 and 2013, with eight variables. To deal with the longitudinal data, we choose pooled and fixed effects models to estimate the demand equations. The basic model is expressed as

$$Ey_{it} = \alpha + x'_{it}\beta + \epsilon_{it} \tag{7}$$

where, i indicates the ID of the province, and t means the time series. Both pooled and fixed effects models apply the assumptions that all the predictors are non-stochastic variables, and neither serial correlation nor contemporaneous correlation exists (Frees, 2004). The pooled model gives the same estimation with OLS model and follows the homoscedastic assumption. But the fixed effects model allows α in the equation (7) to vary by different provinces. For our longitudinal data, the number of provinces is much larger than the number of time periods. Then the one-way fixed effects model $Ey_{it} = \alpha_i + x'_{it}\beta + \epsilon_{it}$ can be employed to explicit parameterization of the province-specific heterogeneity.

To test the province-specific heterogeneity, we can set the null hypothesis of homogeneity as $H_0: \alpha_1 = \alpha_2 = \cdots = \alpha_n = \alpha$, and utilize the partial F-(Chow) test to give the results (Frees, 2004). The process mainly contains three steps: Firstly, estimate the one-way fixed effects model with $Ey_{it} = \alpha_i + x'_{it}\beta + \epsilon_{it}$ to get SSE_F and MSE_F, where $SSE_F = \sum e^2$ and $MSE_F = SSE_F/[N - (n + K)]$; Secondly, run the pooled model with $Ey_{it} = \alpha + x'_{it}\beta + \epsilon_{it}$ to get SSE_R; Thirdly, calculate the partial F-statistic, F-ratio $= (SSE_R - SSE_F)/(n - 1)\,MSE_F$. The test will reject the null hypothesis H_0, if F-ratio exceeds a percentile from an F-distribution with numerator degrees of freedom $n-1$ and denominator degrees of freedom $N-(n+K)$. Note: N is the number of observations, n indicates the number of provinces and K equals the number of predictors.

Data Description

The data used in this study covered 31 provinces of China during the period between 2004 and 2013, and the details are shown in Table 1. The data resources come from National Bureau of Statistics of China (NBSC) and contain the annual information on per capita residential water consumption, residential water price, per capita income, per capita water resource, and average rainfall and temperature.

Table 1 Data Description

Since 2003, the total water consumption of China increased 16.2% with the residential water use increasing 18.9%. But the per capita residential water use declines in most of regions during the sample period, as seen from Figure 4. The NBSC reports the annual number of residential water consumers from 2004 (303.4 millions), and the total number increased 39.3% up to the year of 2013 (422.6 millions), as shown in Figure 1. The NBSC does not report any changes of the statistical standard on population of water consumption. It seems that the decrease of per capita residential water use has a correlation with the shortage of water production. Meanwhile, regions including Beijing, Tianjin, Shanghai and Ningxia have to confront the serious water scarcity problem (Shown in Figure 3). The per capita water resource of Tianjin is only 72.8 cubic meters in 2010. To deal with the regional water shortage, Chinese government processes the transportation of water from the southern areas to the northern parts to relieve the press of water production (NBSC, 2014). The Xizang province has the largest per capita water resource, which is 142.5 thousand cubic meters and much higher than the average level of the whole country.

Figure 3 Per Capita Water Resource of China

Figure 4 Per Capita Residential Water Consumption of China

Furthermore, the residential water price is very low in many regions of China. The lowest nominal price is 1 RMB per m^3 in Xizang Province. And the region kept the same water price between 2004 and 2013. As we cannot study the impacts of unchanged water price, we will employ the real price and income to estimate the residential water demand system. The Tianjin city has the highest real water price 3.93 RMB per m^3, and the price totally increased 15.7% during the sample period. In contrast, the Xizang province has the lowest real water price in 2013, and it experienced 2.4% decrease since the year of 2004 (Details are shown in Figure 5).

Figure 5 Real Residential Water Price in China

During the sample period, the real per capita income kept increasing for each province (Figure 6), but the income inequality is quite evident among the different provinces. Beijing, Tianjin and Shanghai provinces have the highest level of income, which is over 80000 RMB per capita during the year of 2013. However, for Guizhou, Gansu, Yunnan and Xizang provinces, the per capita income is less than 25000 RMB. In 2004, the per capita income of these four provinces is even less than 10000 RMB. In terms of the dummy variables, they are defined by the different levels of the real per capita income. As the mean value of real per capita income is 25950.41, we set the low level income with $\mathrm{Y} \leq 15000$, the middle level income with $15000 < \mathrm{Y} \leq 30000$ and the high level income with $\mathrm{Y} > 30000$. Details are shown in Table 1.

Figure 6 Real per Capita Income in China

The temperature and rainfall are another two important factors considered in this study. Some people suggest that higher temperature and less rainfall make people consume more residential water (Gaudin, 2006; Ruijs at el, 2008). Because of the limitation of the data resource, we will use the information from the central city of each province to substitute the provincial temperature and rainfall.

Empirical Results and Discussion

Both the double-log model and the reduced functional form are estimated in this section. The double-log model gives the estimates of the partial elasticities, holding the water price constant, while the reduced-form estimation gives the total elasticities, allowing the water price to adjust. According to the data characteristics, pooled and fixed effect estimations are employed in the double-log model, and an iterated seemingly unrelated estimation is applied to the reduced functional form equations.

Log-log Model Estimation

Four models are estimated in this section, and the results are reported in Table 2. In the pooled estimations, the price elasticity of residential water demand from the non-dummy variable equation is -0.0937, and the coefficient is statistically significant. The value of the income elasticity equals -0.2337. The negative value implies the inferiority of residential water. Both the price and income are inelastic, as the absolute values of their elasticities are less than 1. The resource elasticity and the temperature elasticity are 0.2316 and 0.4299 respectively. They indicate the positive effects on the residential water consumption of China. The elasticity of average rainfall is also positive, but the estimated coefficient is not significant. Furthermore, we obtain the consistent results from the income dummy variable model by using the same estimator, and no large differences happen to the impact of the same factors except the price. With the income dummy variables, we can know the changes on the price elasticity due to the different levels of income. The price elasticities with income dummy variables are estimated by $(\alpha_2 + \alpha_7 D_1) * \ln\mathrm{P}$ and $(\alpha_2 + \alpha_8 D_2) * \ln\mathrm{P}$ according to the equation (1). The price elasticity for the low income level is -0.1238, and -0.1238 + 0.0472 = -0.0766 for the middle level of income. In terms of the high level of income, the estimate of price elasticity is -0.1238 + 0.0414 = -0.0824. Therefore, the water price becomes less elastic in the middle and high levels of income. But the coefficients of both two income dummy variables are not significant.

Table 2 Estimated Log-log Equations for Residential Water Consumption

In the fixed effects estimations, the results are somewhat different from those in the pooled estimations. Firstly, most of coefficients become less significant, and only income elasticities are statistically significant. Secondly, the impacts of average temperature and rainfall turn to be negative, which means that people tend to consume less residential water with the higher temperature and more rainfall. The price elasticities given by the fixed effects estimations are -0.0664 and -0.1104 for the no income dummy variable model and full model respectively. Compared with the results in the pooled model estimations, all the price elasticities become less elastic. For the middle level of income, the price elasticity is -0.1104 + 0.0681 = -0.0423, while for the high level of income, the estimated price elasticity is

-0.1104 + 0.0881 = -0.0223. Therefore, the water price becomes less elastic in the higher level of income. The income elasticity from the no income dummy variable model is -0.1998, which also implies that the residential water is an inferior good.

The partial F-(Chow) test is applied to determine the selection between the income dummy variable and non-dummy variable models, and also the choice between pooled and fixed effects estimators. Firstly, we found the income dummy variables cannot have significant effects on the residential water demand system. Specifically, the F-(Chow) test of pooled estimations reveals that the F-value of 0.19 cannot reject the null hypothesis of no income dummy variable model. When it comes to the fixed effects estimation, the null hypothesis cannot be rejected by the F-value of 0.84, either. In addition, the coefficients of two interaction terms with the income dummy variable are insignificant in both pooled and fixed effects models. And the residential water is proved to be inferior good by the empirical results. All the evidences imply that the impacts of different levels of income are irrelevant or not important.

Secondly, comparing the pooled model and the fixed effects model, we can find that the pooled model as the null hypothesis is rejected by the fixed effects model due to the F-(Chow) test value of 12.05. Meanwhile, the coefficients of most province dummy variables are significant in the fixed effects model, which indicates the heteroscedasticity problem exists among the different provinces. As a consequence, the no income dummy variable model gives the most appropriate results by applying the fixed effects estimation.

Reduced-Form Equation Estimation

Two reduced-form equations are derived from the equilibrium displacement model-- the price equation and the quantity equation. Each equation has four same exogenous variables, and can be just-identified at the same time. We apply the iterated seemingly unrelated estimator (SURE) to get the empirical results. The iterated SURE is popular for estimating the system equations that the equation errors are correlated across equations for a given individual but uncorrelated across individuals. The estimated results are reported in Table 3 (Function details see Appendix).

Table 3 Estimated Reduced-Form Equations for Water Price and Residential Water Consumption

According to the equation (5) and equation (6), we can get the total elasticities as follows:

$$\eta_Y^p = \frac{P^*}{Y^*} = \frac{\eta_Y}{\varepsilon_p - \eta_p} = 0.1276 \text{ and } \eta_Y^T = \frac{Q_d^*}{Y^*} = \frac{\varepsilon_p \eta_Y}{\varepsilon_p - \eta_p} = -0.2457$$

And

$$\varepsilon_R^p = \frac{P^*}{R^*} = -\frac{\varepsilon_R}{\varepsilon_p - \eta_p} = -0.0907 \text{ and } \varepsilon_R^T = \frac{Q_s^*}{R^*} = -\frac{\varepsilon_R \eta_p}{\varepsilon_p - \eta_p} = 0.2401$$

where, η_Y^p, η_Y^T, ε_R^p and ε_R^T are total elasticities, and η_Y, η_p, ε_p and ε_R are partial elasticities. Solving these equations, then we can obtain the results as η_p= -2.6472, ε_p= -1.9255, η_Y= 0.0920 and ε_R= 0.0655. As we have discussed in the double-log model, the empirical results show that the residential water is an inferior good and the income elasticity is significantly negative. We also get a negative value for the total income elasticity from the reduced functional form. However, with positive total income-price elasticity η_Y^p and negative total income-demand elasticity η_Y^T, we can only solve the negative partial supply elasticity ε_p. According to the estimated reduced-form results, we can draw the diagram for the water market equilibrium as Figure 8.

Figure 8 Estimated Water Supply and Demand Equilibrium

Because of the inequality $\left|\eta_p\right| > \left|\varepsilon_p\right|$, we can know that the water demand curve is more elastic than the supply curve, and then the supply curve will be steeper than the demand curve. The equation $\eta_Y^p = \frac{P^*}{Y^*} = 0.1276$ indicates that 1% increase in the income will take 0.128% increase in the residential water price. In the other words, the income growth will shift the demand curve up. At the new equilibrium point A, the water price increase to P_1, but the consumption decrease to Q_1. This situation is consistent with the result $\eta_Y^T = \frac{Q_d^*}{Y^*} = -0.2457$. When income increases 1 percent, the water consumption will decrease 0.246 percent. In contrast with the total income elasticity, the value of the partial income elasticity η_Y is positive. This situation implies the income growth will take a temporary increase in water consumption. But after a period of time, the water demand will go down with the increase of income.

For the water supply, an increase of water resource will shift the supply curve to the right as shown in Figure 8. Due to the equations $\varepsilon_R^p = \frac{P^*}{R^*} = -0.0907$ and $\varepsilon_R^T = \frac{Q_s^*}{R^*} = 0.2401$, one percentage increase in water resource will cause 0.09 percent decrease in water price and 0.24 percent increase in water consumption. After the shifting, the new equilibrium is reached at the point B. It is clear to see that the new equilibrium water price decrease to P_2 but the equilibrium water consumption arise to Q_2. The partial resource elasticity is ε_R= 0.0655, which is smaller than the total resource elasticity ε_R^T. It implies the water consumption will grow faster, if people see the water resource increasing during the long run.

Conclusion

This paper undertook the residential water demand analysis based on the panel data, covering 31 provinces during the sample period from 2004 to 2013 in China. Two models are employed in this study. For the double-log demand model, we found the different income levels cannot influence the water price elasticity significantly and the fixed effects estimator gives more appropriate estimates for the water demand system. The results show that both the water price elasticity and the income elasticity are negative. Although the water consumption would decline with an increase of water price, income growth cannot prompt the growth in the residential water demand. As a consequence, the residential water is proved to be an inferior good. In addition, both water price and income are inelastic for the residential water demand.

Furthermore, two reduced-form equations (price equation and quantity equation) are derived from the equilibrium displacement model to analyze the impacts of water price, per capita income, water resources and some other factors. The reduced-form equations give the total elasticities, allowing the water price to adjust. The partial elasticities can be solved according to the estimates of those total elasticities, as both the reduced-form equations are just-identified. The results reveal that income growth can raise the water price, and more water resource will prompt the price to go down. Both the partial price elasticities of water demand and water supply are negative and elastic in the short run. The negative estimate of the total income elasticity is consistent with the results of the double-log model estimation. But the partial income elasticity is positive. In the other words, income growth will prompt a temporary increase in residential water demand, but for the long run the residential water consumption will decline with continuous increasing in income. This may be caused by the inferiority of residential water. People with higher income are more likely to consume water with higher quality, such as the bottled water. That is true, because the pipe water needs to be boiled before drinking in China, while the bottled water can be drunk without any treatment healthily.

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Appendix

Establish the demand structure model as follow:

$$Q_d = D(P,\ Y,\ TEMP,\ RF) \ \text{(Water Demand)}$$

$$Q_s = S(P,\ R,\ TEMP,\ RF) \ \text{(Water Supply)}$$

$$Q_d = Q_s \ \text{(Market equilibrium)}$$

Apply the total derivative on each equation to get:

$$\frac{dQ_d}{Q_d} = \frac{\partial Q_d}{\partial P}\frac{P}{Q_d}\frac{dP}{P} + \frac{\partial Q_d}{\partial Y}\frac{Y}{Q_d}\frac{dY}{Y} + \frac{\partial Q_d}{\partial TEMP}\frac{TEMP}{Q_d}\frac{dTEMP}{TEMP} + \frac{\partial Q_d}{\partial RF}\frac{RF}{Q_d}\frac{dRF}{RF},$$

$$\frac{dQ_s}{Q_s} = \frac{\partial Q_s}{\partial P}\frac{P}{Q_s}\frac{dP}{P} + \frac{\partial Q_s}{\partial R}\frac{R}{Q_s}\frac{dR}{R} + \frac{\partial Q_s}{\partial TEMP}\frac{TEMP}{Q_s}\frac{dTEMP}{TEMP} + \frac{\partial Q_s}{\partial RF}\frac{RF}{Q_s}\frac{dRF}{RF},$$

$$\frac{dQ_d}{Q_d} = \frac{dQ_s}{Q_s}$$

where, $\frac{\partial Q_d}{\partial P}\frac{P}{Q_d}$ can indicate the price-demand elasticity, $\frac{\partial Q_s}{\partial P}\frac{P}{Q_s}$ represents the price-supply elasticity, $\frac{\partial Q_d}{\partial Y}\frac{Y}{Q_d}$ is the demand-income elasticity, and so on.

Then we can simplify the total differential equations as

$$Q_d^* = \eta_p P^* + \eta_Y Y^* + \eta_T TEMP^* + \eta_{RF} RF^*$$

$$Q_s^* = \varepsilon_p P^* + \varepsilon_R R^* + \varepsilon_T TEMP^* + \varepsilon_{RF} RF^*$$

$$Q_d^* = Q_s^* = Q^*$$

in which, $Q_d^* = \frac{dQ_d}{Q_d}$, $P^* = \frac{dP}{P}$, $Y^* = \frac{dY}{Y}$, etc. These parameters indicate the percentage change of each factor. Solve the above equations, and then we can get the reduced functional forms for both price and water consumption as

$$P^* = \frac{\eta_Y}{\varepsilon_p - \eta_p} Y^* - \frac{\varepsilon_R}{\varepsilon_p - \eta_p} R^* + \frac{\eta_T}{\varepsilon_p - \eta_p} TEMP^* + \frac{\eta_{RF}}{\varepsilon_p - \eta_p} RF^*$$

$$Q^* = \frac{\varepsilon_p \eta_Y}{\varepsilon_p - \eta_p} Y^* - \frac{\varepsilon_R \eta_p}{\varepsilon_p - \eta_p} R^* + \frac{\varepsilon_p \eta_T - \varepsilon_T \eta_p}{\varepsilon_p - \eta_p} TEMP^* + \frac{\varepsilon_p \eta_{RF} - \varepsilon_{RF} \eta_p}{\varepsilon_p - \eta_p} RF^*$$

Both two reduced-form equation can be estimated by the log-log model as

$$lnp = \alpha_1 lnY + \alpha_2 lnR + \alpha_3 lnTEMP + \alpha_4 lnRF + \alpha_0$$

$$lnQ = \beta_1 lnY + \beta_2 lnR + \beta_3 lnTEMP + \beta_4 lnRF + \beta_0$$

Each parameter is corresponding to the item of the same position in those two reduced-form equations. For example:

$$\frac{P^*}{Y^*} = \frac{\eta_Y}{\varepsilon_p - \eta_p} = \frac{\partial lnP}{\partial lnY} = \alpha_1 \text{ and } \frac{P^*}{R^*} = -\frac{\varepsilon_R}{\varepsilon_p - \eta_p} = \frac{\partial lnP}{\partial lnR} = \alpha_2$$

$$\frac{Q^*}{Y^*} = \frac{\varepsilon_p \eta_Y}{\varepsilon_p - \eta_p} = \frac{\partial lnQ}{\partial lnY} = \beta_1 \text{ and } \frac{Q^*}{R^*} = -\frac{\varepsilon_R \eta_p}{\varepsilon_p - \eta_p} = \frac{\partial lnQ}{\partial lnR} = \beta_2$$

where, α_1, α_2, β_1 and β_2 report the total elasticities for the water price and water consumption.

Figures

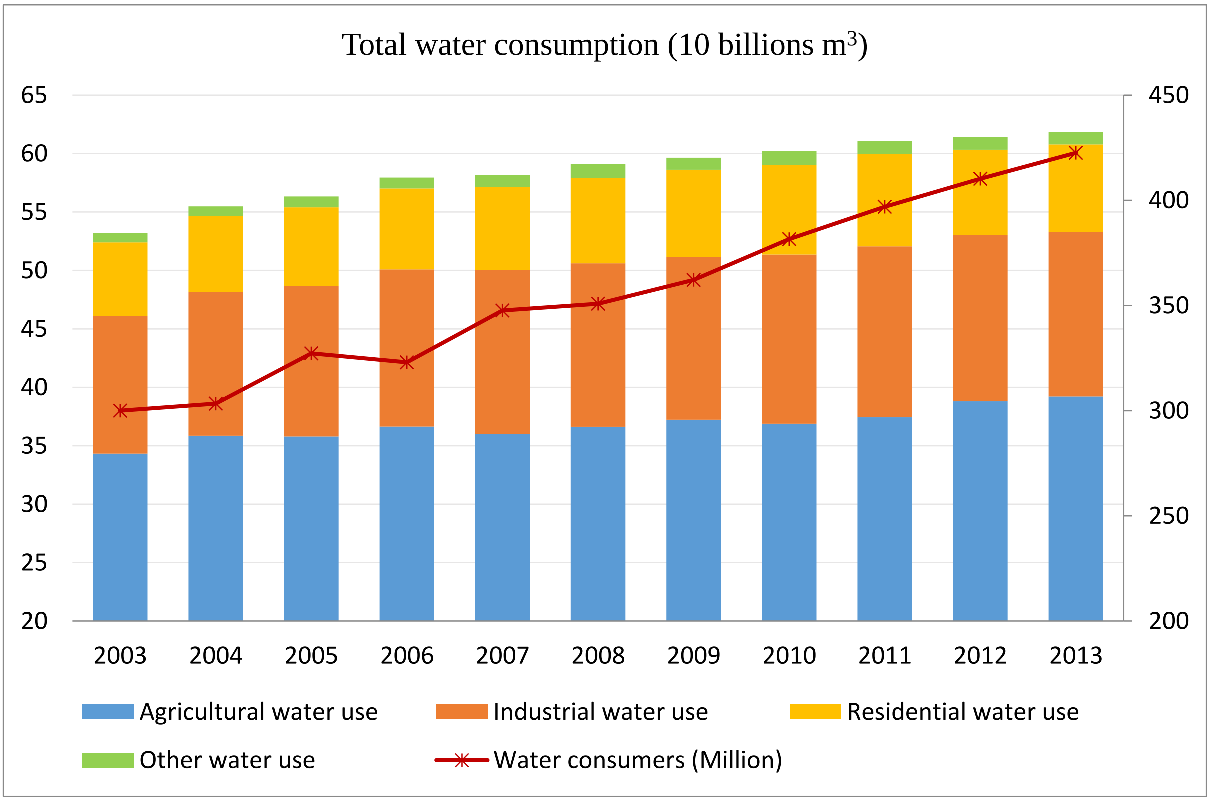

Figure 1 Total Water Consumption of China

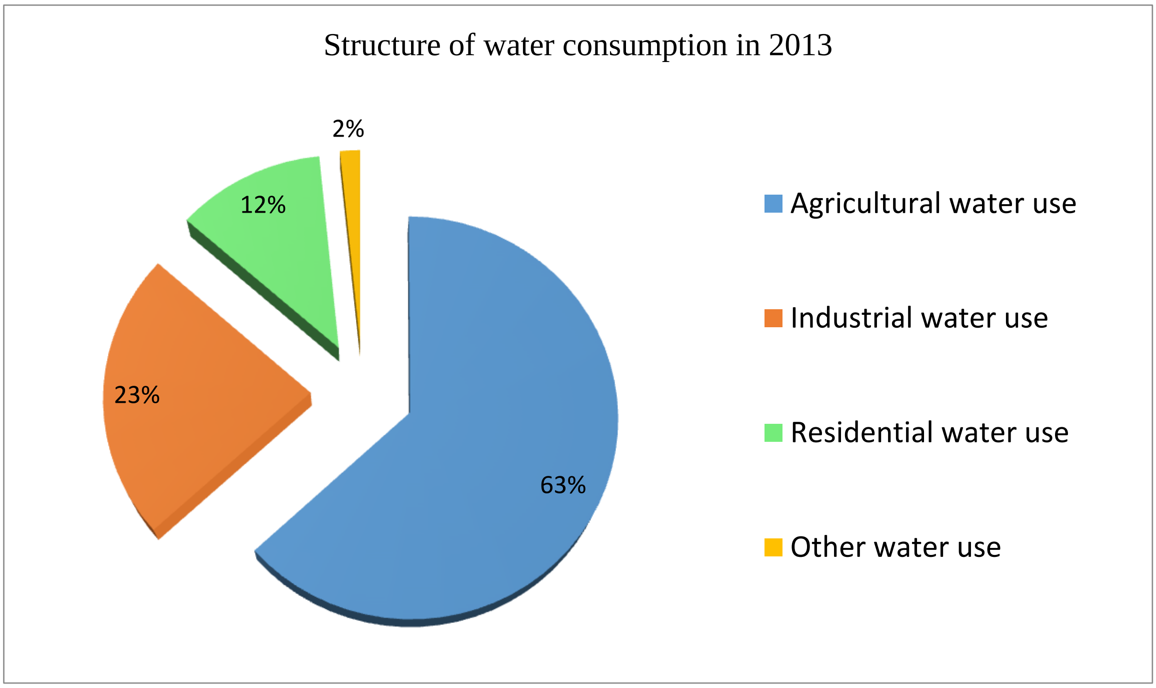

Figure 2 Structure of Chinese Water Consumption in 2013

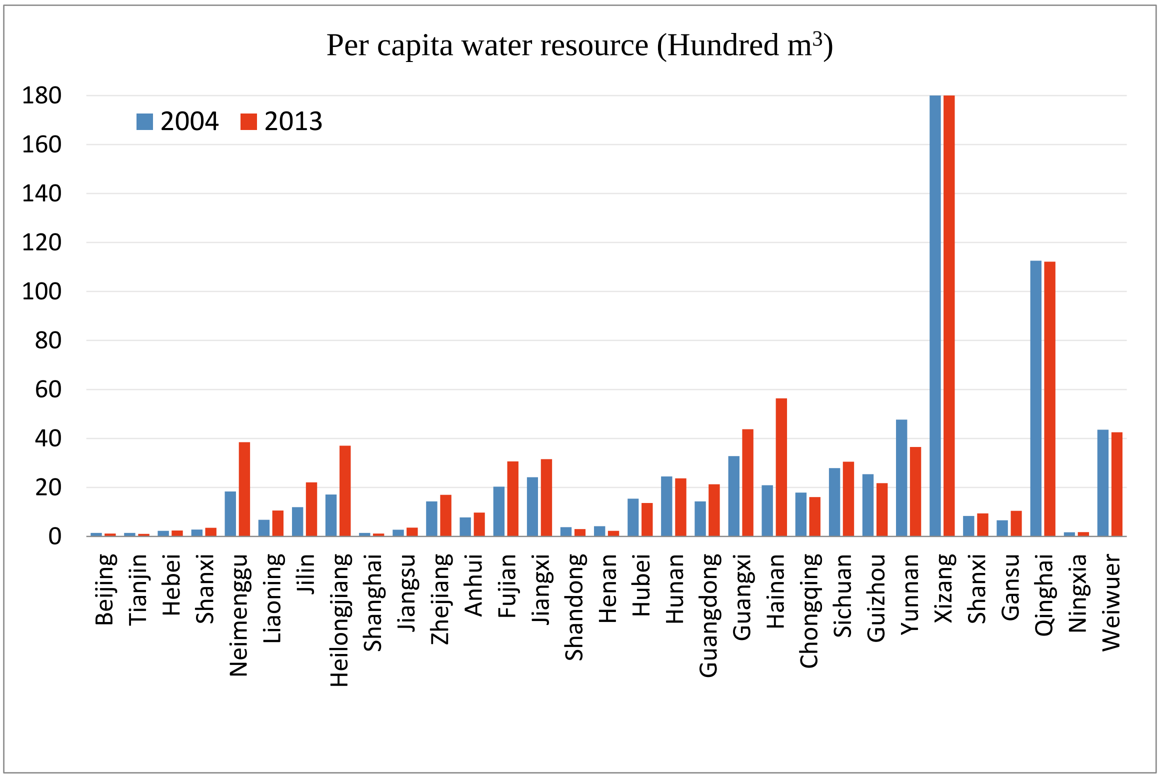

Figure 3 Per Capita Water Resource of China

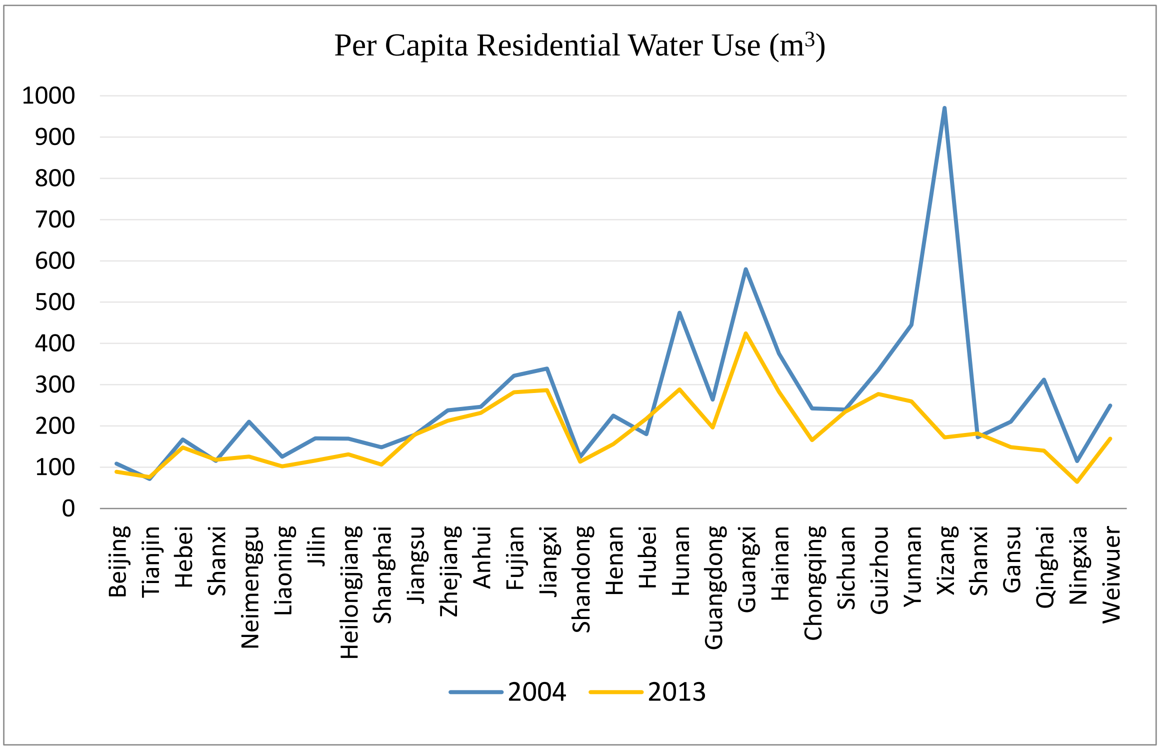

Figure 4 Per Capita Residential Water Consumption of China

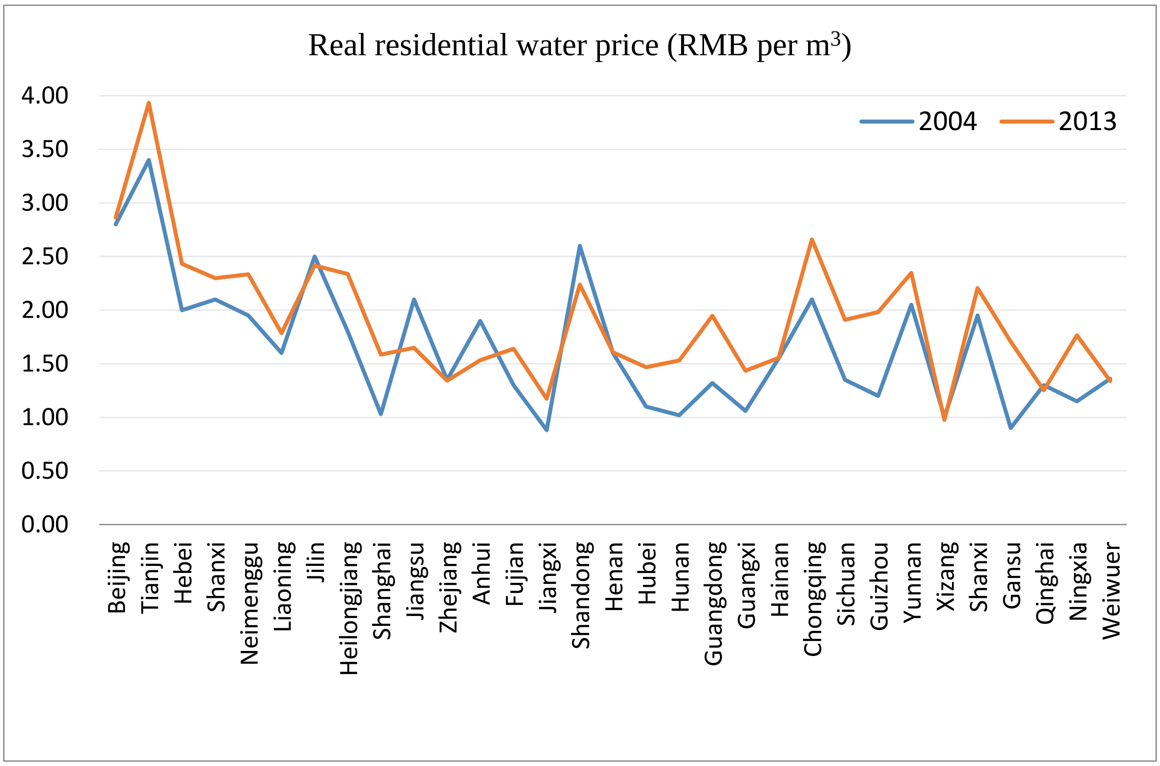

Figure 5 Real Residential Water Price in China

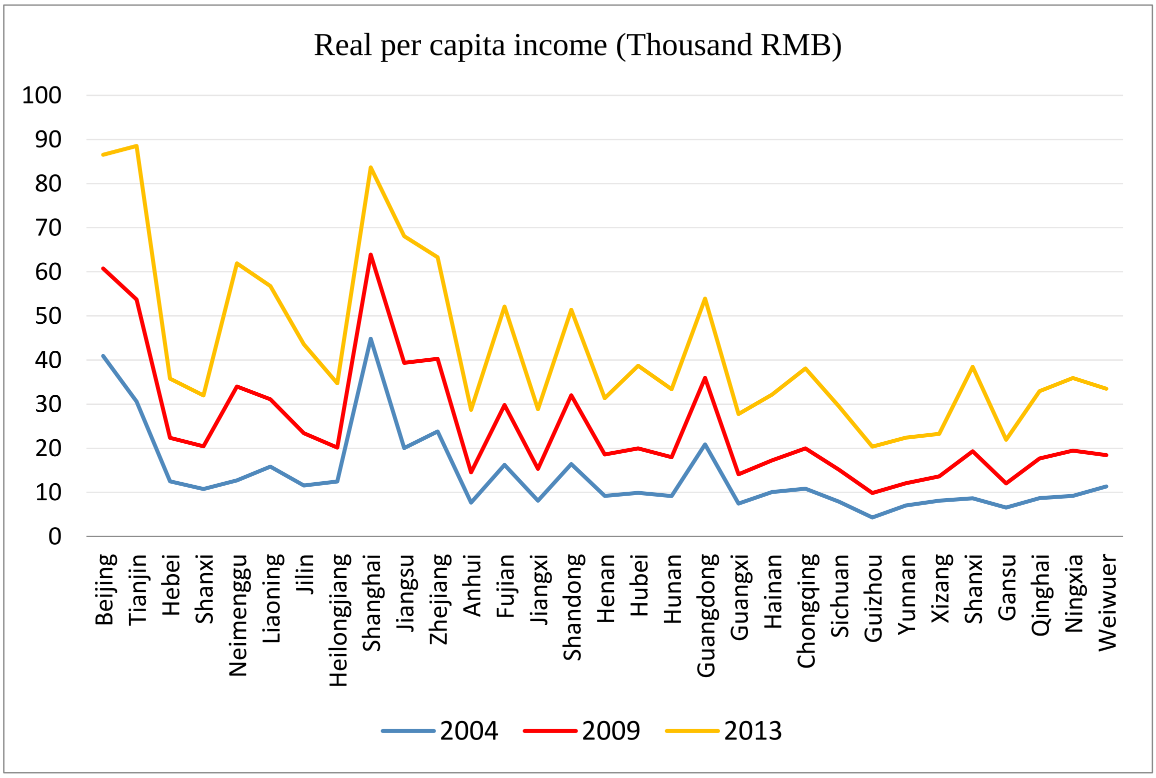

Figure 6 Real per Capita Income in China

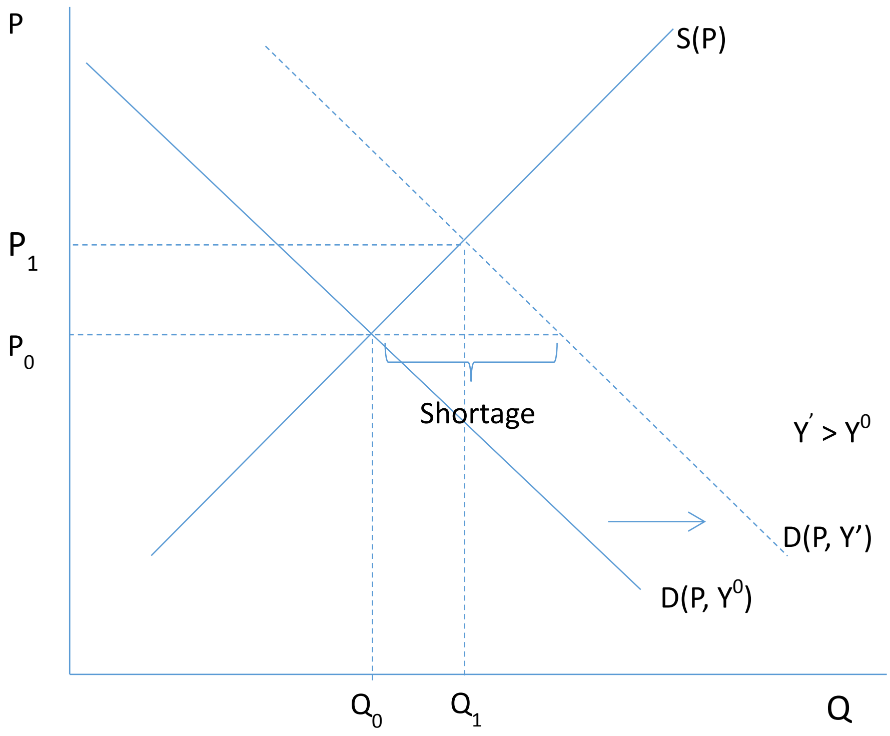

Figure 7 Diagrams of Water Supply and Demand Equilibrium Assumption

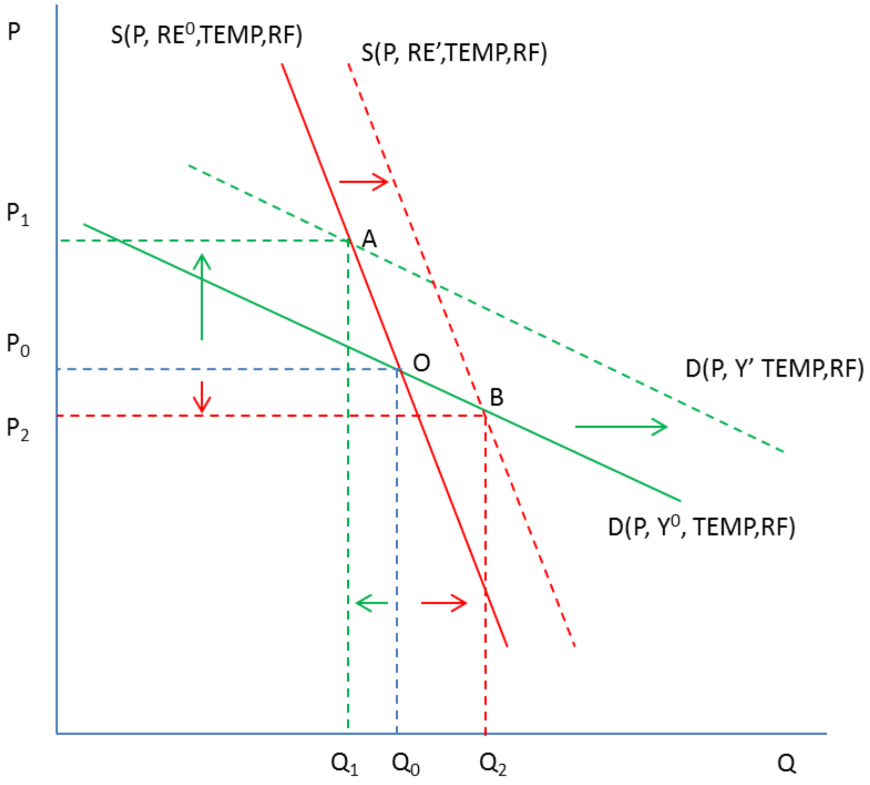

Figure 8 Estimated Water Supply and Demand Equilibrium

Tables

Table 1 Data Description

Variable	Description	Number	Mean	Min	Max
id	Province ID	310	16	1	31
t	Time (year)	310	5.50	1.00	10.00
Q_d	Per capita RW consumption (m^3)	310	234.64	64.38	1550.00
lnQ_d	Logarithm of Q_d	310	5.31	4.16	7.35
P	Real RW price (RMB per m^3)	310	1.69	0.80	3.93
lnP	Logarithm of P	310	0.46	-0.22	1.37
Y	Real per capita income (RMB)	310	25950.41	4317.00	88539.56
lnY	Logarithm of Y	310	9.97	8.37	11.39
RE	Per capita water resource (m^3)	310	6907.73	72.80	170261.31
lnRE	Logarithm of RE	310	7.18	4.29	12.05
RF	Annual rainfall (mm)	310	863.69	74.90	2628.20
lnRF	Logarithm of RF	310	6.59	4.32	7.87
TEMP	Average temperature (C^o)	310	14.32	4.30	25.40
lnTEMP	Logarithm of TEMP	310	2.59	1.46	3.23
D_1	D1=1 if 15000 < Y ≤ 30000	310	0.38	0	1
D_2	D2=1 if Y > 30000	310	0.30	0	1

Note: The data resources are published by National Bureau of Statistics of China.

Table 2 Estimated Log-log Equations for Residential Water Consumption

Variables	Pooled estimation (Standard Error)		Fix effect estimation (Standard Error)	
	Model without income dummy	Model with income dummy	Model without income dummy	Model with income dummy
Intercept	4.7977***	4.8891***	7.6100***	7.8559***
	(0.2722)	(0.3412)	(0.6592)	(0.6868)
lnP	-0.0937**	-0.1238*	-0.0664	-0.1104
	(0.0459)	(0.0684)	(0.0757)	(0.0831)
lnY	-0.2337***	-0.2435***	-0.1998***	-0.2253***
	(0.0239)	(0.0330)	(0.0259)	(0.0333)
lnRE	0.2316***	0.2312***	0.0234	0.0263
	(0.0113)	(0.0113)	(0.0510)	(0.0511)
lnTEMP	0.4299***	0.4304***	-0.0880	-0.0848
	(0.0471)	(0.0473)	(0.1705)	(0.1720)

lnRF	0.0172	0.0179	-0.0501	-0.0552
	(0.0316)	(0.0319)	(0.0490)	(0.0492)
D1*lnP		0.0472		0.0681
		(0.0721)		(0.0555)
D2*lnP		0.0414		0.0881
		(0.0851)		(0.0738)
CS1			-0.3773*	-0.3796*
CS2			-0.5784***	-0.5886***
CS3			-0.0626	-0.0573
CS4			-0.4707***	-0.4659***
CS5			0.0619	0.0630
CS6			-0.3839***	-0.3776***
CS7			-0.2968**	-0.2916**
CS8			-0.2342*	-0.2312*
CS9			-0.1766	-0.1365
CS10			0.2484	0.2652
CS11			0.3439*	0.3619**
CS12			0.2684	0.2814*
CS13			0.4853**	0.4938**
CS14			0.5133***	0.5114***
CS15			-0.2378	-0.2422
CS16			0.0717	0.0813
CS17			0.0474	0.0562
CS18			0.7478***	0.7497***
CS19			0.3718*	0.3860*
CS20			1.0780***	1.0750***
CS21			0.6557***	0.6616***
CS22			0.1794	0.1847
CS23			0.2795*	0.2795*
CS24			0.4115***	0.4072***
CS25			0.5584***	0.5699***
CS26			0.8153***	0.7985***
CS27			0.0182	0.0222
CS28			-0.1270	-0.1324
CS29			0.1775*	0.1771*
CS30			-0.8227***	-0.8209***
R-square	0.8131	0.8134	0.9195	0.9200
F-statistic	264.57***	188.06***	12.07***	12.08***
F-chow test [a]	0.19		0.84	
F-chow test [b]	12.05***			

Note: *, ** and *** indicate the rejection of null hypothesis at the level 0.1, 0.05 and 0.01; a: F-chow test for dummy or non-dummy model; b: F-chow test for pooled or fixed effects model. CS1-CS30 indicate the province dummy variables.

Table 3 Estimated Reduced-Form Equations for Water Price and Residential Water Consumption

Equation	lnY	lnRE	lnTEMP	lnRF	intercept	R-square
lnP	0.1276***	-0.0907***	-0.1867***	0.0104	0.2591	0.3138
	(0.0299)	(0.0110)	(0.0497)	(0.0400)	(0.3775)	
$\ln Q_d$	-0.2457***	0.2401***	0.4474***	0.0162***	4.7734***	0.8106
	(0.0259)	(0.0194)	(0.0454)	(0.0392)	(0.2798)	
Elasticity	Estimate		Elasticity	Estimate		
η_p	-2.6472		η_T	-0.0469		
ε_p	-1.9255		ε_T	0.0878		
η_Y	0.0920		η_{RF}	0.0437		
ε_R	0.0655		ε_{RF}	0.0362		

Note: *, ** and *** indicate the rejection of null hypothesis at the level 0.1, 0.05 and 0.01.