Water Use in China's Domestic, Industrial and Agricultural Sectors: An Empirical Analysis

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Abstract

Demand management plays an increasingly important role in dealing with water scarcity in China. It is important to understand the level and pattern of water use in various sectors across the regions for any measures being put into effect. The aim of this study is to enhance the understanding of the factors that influence water demand by examining closely the water use in domestic, industrial and agricultural sectors. Using province level panel data from 1997 to 2003, the examination shows that the regional disparity in the level and pattern of water uses is considerable. The estimation of water demand shows that both economic and climatic variables have significant effects on water demand. The results suggest an income elasticity of 0.42 for the domestic sector, an output elasticity of -0.32 for industrial water use (per unit of output), and an output elasticity of –0.24 for irrigated agriculture (per land area).

Keywords: water use, regional variation, elasticity, demand management

1. Introduction

Water is increasingly scarce in many regions and countries. Conflicts over water have involved competition among alternative uses or among geographical regions. In water scarce areas of China, residential and industrial sectors have seized a great amount of water from agriculture and left the land unirrigated. Also, there are often disputes and tensions between upstream and downstream users. As water supply fails to meet the demand in many areas, careful analysis of decisions on the allocation of water is of great significance. The past policy responses to water scarcity are mainly supply-oriented and aim at fostering the development and exploitation of new sources and expansion of the network infrastructure to guarantee the water supply. In recent years water policies have increasingly addressed demand management, which means development of water conservation and management programs to influence water demand. Demand driven measures include adoption of water saving technologies and appliances, awareness raising and economic instruments such as price and tax. The character of water as a scarce good and the need to efficiently price its consumption has gained increasing recognition (Arbues et al., 2003).

The regional variation in availability of water resources in China is considerable, given its diverse climate and geographic conditions. Water is unevenly distributed in both spatial and temporal terms. In South and West China the water endowment is abundant while in the North China Plain water scarcity prevails strikingly. The overall water use in China has grown significantly over the last decades but has leveled off since 1997 (Liu and Chen, 2001). Among the major users, urban and industrial demands for freshwater have grown considerably in recent years. Population growth, rapid urbanization and overall expansion in economic activities are the major factors underlying the increase in water consumption. Irrigation has been the largest water-using sector although with a decreasing proportion. In addition to water resources, the pattern of water use also differs greatly across regions. For instance, the overall water use per capita ranges from 170 m^3 in water-scarce areas to 2600 m^3 in water-abundant regions (China Water Resources Bulletin 2003).

While the total population in China is projected to stabilize in 2050 and the corresponding water use to level off (Liu and Chen, 2001), the urban population is still expected to increase and the economy likely to continue growing. Irrigation continues to remain dominant in water use but perhaps with high water use efficiencies and a lower quota. Aggregated demand for water is expected to continue its growth. However, developing additional water resources and infrastructure in the future would be limited, as new projects tend to be less profitable and technically harder. Although desalination strikes as an alternative as its cost has decreased significantly in recent years (Zhou and Tol, 2005), it would not be feasible in a few years in China because it is still more expensive than traditional sources and it would take time for desalination to develop and reach the desired capacity which could produce a vast amount of water.

Concerned with the increasing costs of developing new water supply and dealing with the existing inefficiency in the system, an initiative to adopt conservation and water use efficiency measures and a move towards demand management seems urgently needed. In some extremely water-scarce places like Tianjin, water saving technologies and appliances, as well as recycling of water have been widely implemented. At a larger scale, however, demand management measures are still rarely adopted in China. An overview of water uses in various sectors and a better understanding of the determinants help bring forward any effective measure in this direction.

This paper proceeds as follows. Section 2 provides a brief introduction to issues related to water demand estimation and a review on previous studies. Section 3 describes the data and methodology employed. Section 4 elaborates on the regional disparity in the level and pattern of water use, examines domestic, industrial and agricultural uses of water respectively and estimates the corresponding demand by panel data analysis. Section 5 provides the policy implications of the analysis, followed by summary and conclusions.

2. Water demand estimation issues

Many studies on residential water demand have been done, using various functional forms and data and a range of econometric methods (Espey et al., 1997; and Dalhuisen et al., 2003). The most common explanatory variables include water price, income, climate variables, household characteristics, and the frequency of billing and rate design. Datasets used vary from cross-section, to time-series and pooled panel data. A wide variety of econometric models, ranging from linear, Cobb-Douglas, semi-log to double log, from a single equation to a set of simultaneous equations, have been employed in these studies. The estimation methods used vary as well. The most common one is ordinary least squares (OLS), followed by maximum likelihood (ML). Under simultaneity that occurs often with multiple block rates, instrumental variables techniques, such as two-stage least square (2SLS) or three-stage least square (3SLS) are preferred to OLS estimation (Arbues et al., 2003).

In a meta-analysis of US estimates published between 1967 and 1993, Espey et al. (1997) found an average price elasticity of residential water demand of –0.51. Renwick and Archibald (1998) found that low-income families are more responsive to price (-0.53), whereas the middle and high income households were less responsive (-0.22). Dalhuisen et al. (2003) also found that the absolute magnitude of price and income elasticities is significantly greater for areas with higher income. Literature survey reveals that little has been published on estimates of price and income elasticities of water for developing countries. Those existing estimates are usually higher than that of developed countries. In the US and Western Europe, the consumption level and service level have reached the threshold of income-inelastic level. Consumers have fulfilled their minimum needs so that an increase in income results in no significant change in water consumption. However, in most developing countries where water infrastructures are obsolete or in dismal situations and the service level is unsatisfactory, income increases are likely to induce the growth in water demand. For instance, people would prefer to improve the sanitary facilities and use water intensive appliances, such as flush toilets, washing machines and dishwashers. The price elasticity of water is also expected to be high because water is under-priced in most regions and a considerable increase in prices is very likely to bring down the current consumption level once consumers start to save water consciously.

Little research has been done on water demand estimation in China. The main reason is the lack of the time-series and cross-sectional data that are typically derived from surveys. There are several urban household water use surveys conducted in municipalities Beijing and Tianjin. The surveys are normally conducted over a short period of one to two years and for a relatively small sample. The survey results are largely presented in qualitative terms regarding the current household characteristics, housing, water using appliances and amenities, water consumption levels, as well as water use behavior and perception (Zhang and Brown, 2005). The price or income elasticity of water consumption is rarely reported. Cai and Rosegrant (2002) use a price elasticity of domestic water demand of –0.35 to –0.55 that is drawn from previous empirical studies and an income elasticity of 0.75 for China in their global water demand and supply model. Wang and Lall (2002) apply a marginal productivity approach to two thousand

Chinese industrial firms to estimate the value of water for industries and suggest an average price elasticity of industrial water demand of –1.0. By analyzing the effects of increased water prices on industrial water use in Beijing, Jia and Zhang (2003) suggest a price elasticity of –0.49 for industrial water demand. They conclude, based on an industry survey, that rapid price increases have induced the reduction of industrial water use significantly, especially to those price-elastic industrial firms. In terms of agricultural use, water demand in irrigation has often not been estimated economically due to data constraints and the fact that irrigation charges did not vary significantly until very recently. Nevertheless, under current setting of irrigation institutions, the price elasticity of irrigation water demand is bound to be low and is expected to remain low in the near future (Yang et al., 2003).

3. Data and methodology

This study uses aggregated province-level data for 31 provinces or municipalities covering the period 1997-2003. The data on annual precipitation, availability of water resources, overall water use, sectoral breakdown into domestic, industrial and agricultural uses are obtained from China Water Resources Bulletin (CWRB, 1997-2003). The data on population, GDP, urban disposable income, net income of rural households, gross industrial output value, value-added of industry, irrigated land area, value of agricultural production, family size, as well as temperature are derived from the Statistical Yearbook of China (1998-2004). Current water prices for domestic and industrial use are obtained from http://www.waterchina.com. Among these, mean annual temperature and water prices are available only for the capital cities of each province. Therefore the data for each capital city is taken as being representative of the corresponding province. There has been little empirical analysis on water uses of three major sectors in China. This study attempts to bridge the gap by providing a comprehensive analysis on water uses and also for the first time using panel data in examination.

Table 1 Summary of the main variables used in the estimations

Variable	Unit	Mean	Standard deviation	Minimum	Maximum
Per capita domestic water use	m^3/person	49.5	20.9	23.9	134
Per capita GDP	yuan*/person	8449	5946	2300	38730
Mean annual temperature	°C	14.4	5.0	4.6	25.4
Annual precipitation	mm	922.4	559.6	116	2231
Total volume of water resources	billion m^3	91.9	101	0.3	494.6
Water resources per capita	m^3/person	7814	30689	28	196258
Average family size	person	3.6	0.5	2.7	6.8
Domestic water price	yuan/m^3	1.6	0.7	0.7	3.7
Industrial water use	billion m^3	1.8	1.2	0.1	5.8
Value-added of industry	billion yuan	87.3	93.2	0.7	571.8
Industrial water price	yuan/m^3	2.0	1.0	0.9	4.6
Agricultural water use	m^3/hectare	13.1	7.8	3.9	42.4
GDP of primary industry	billion yuan	50.3	36.5	2.9	142.5

Annual net income of rural households	yuan/person	2478	1046	1185	6276

* yuan (Chinese currency, = 0.12 USD)

The data used have a panel structure. The number of period is the same across provinces or municipalities, hence the panel is balanced. The equation for the estimation of water demand is specified as follows:

$$W_{it} = \alpha + \beta X_{it} + \gamma Y_i + v_i + \varepsilon_{it} \qquad (1)$$

where W_{it} is the dependent variable, X_{it} is the explanatory variables that vary over both time and region, Y_i is the time-invariant variables; v_i is region-specific residual that differs between regions but for any particular region, its value is constant; and ε_{it} is the usual residual that includes non explainable variations that is both spatial and temporal. β and γ are the slope coefficients associated with the time varying and static variables respectively.

Referring to Wooldridge (2000, 2002) and Green (2003), there are several types of models for panel data and various estimation methods. Equation (1) could be estimated using pooled OLS if the errors are independent, homoskedastic and serially uncorrelated. When there exists unobserved effects and they are not correlated with any element of explanatory variables, we could still apply pooled OLS. However, if they are correlated to any of explanatory variables, then pooled OLS is biased and inconsistent (Wooldridge, 2002). In this case, it is often estimated using the generalized least squares (GLS) in fixed effects and random effects estimations. If the errors are generally heteroskedastic and serially correlated across the time, a feasible generalized least squares (FGLS) analysis can be used. In this study, due to the issues of heteroskedasticity and serial correlation, FGLS was selected to estimate the models.

4. Water use and its regional disparity in China

Water use is by definition the amount of water distributed to each sector including the leakage and transfer loss. It is not the final consumption of the users. Water use can be broadly classified into domestic, industrial, agricultural and sometimes ecological uses. The level and purpose of water use differs intrinsically across the sectors. For example, industrial and agricultural sectors uses water mainly as production input as opposed to the residential sector that use water as a direct consumption good. Of the overall water use in 2003, domestic use accounted for 12%, industrial use 22% and agricultural use about 65% (CWRB, 2003). However, the regional disparity in water use is considerable, given the differences in economic activities, social factors, such as culture and customs, as well as the level and pace of economic development. Therefore, it is logical to analyze demand for water in various sectors separately.

Fig. 1 illustrates the proportional water use of domestic, industrial and agricultural sectors in each province. They do not add to 100% because the rest accounts for ecological use. It shows that agriculture in northwestern provinces, such as Xinjiang, Qinghai, Tibet

(Xizang) and Inner Mongolia, has the highest share of water use, which is over 85%. The agricultural use prevails in the South coast regions e.g. Guangxi and Hainan, as well as in the two agriculture-dominated provinces of Hebei and Shandong in the North China Plain. The four municipalities demonstrate the lowest proportion in this case and subsequently higher industrial and domestic uses. In general, moving from east to west across the country, the agricultural use becomes increasingly dominant, while the proportion of domestic and industrial uses fall.

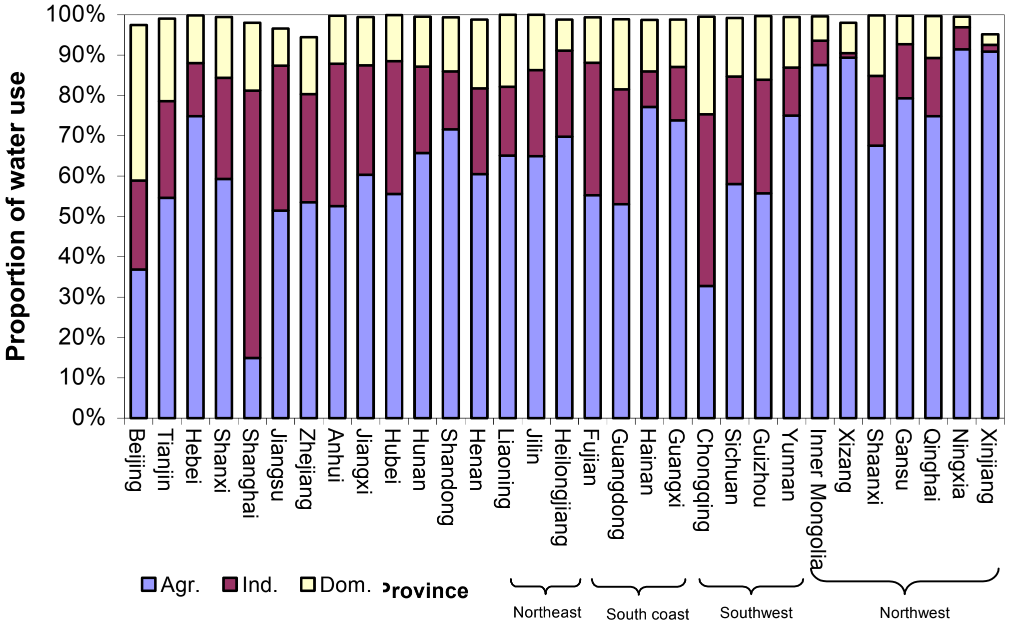

Fig.1. Provincial share of water use by domestic, industrial and agricultural sectors

Examining the per capita water use and GDP across the regions, we find that high economic development occurs in the coastal regions of China, while high water consumption appears mostly in the northwest and the South coast regions. It shows little evidence that overall water use depends solely on economic development. Indeed, the economic indicator is only one of the many important determining factors in the level of water use. Fig. 2 shows the water use per unit value of GDP across the country, which reflects the water use efficiencies in production. It suggests that the under-developed regions use more water for a unit of GDP than developed regions. It is hardly surprising since the poor regions usually have a higher agricultural share in economic activities thus use more water. Agriculture-dominant regions remain economically worse off than industry- or services- dominant economy in China.

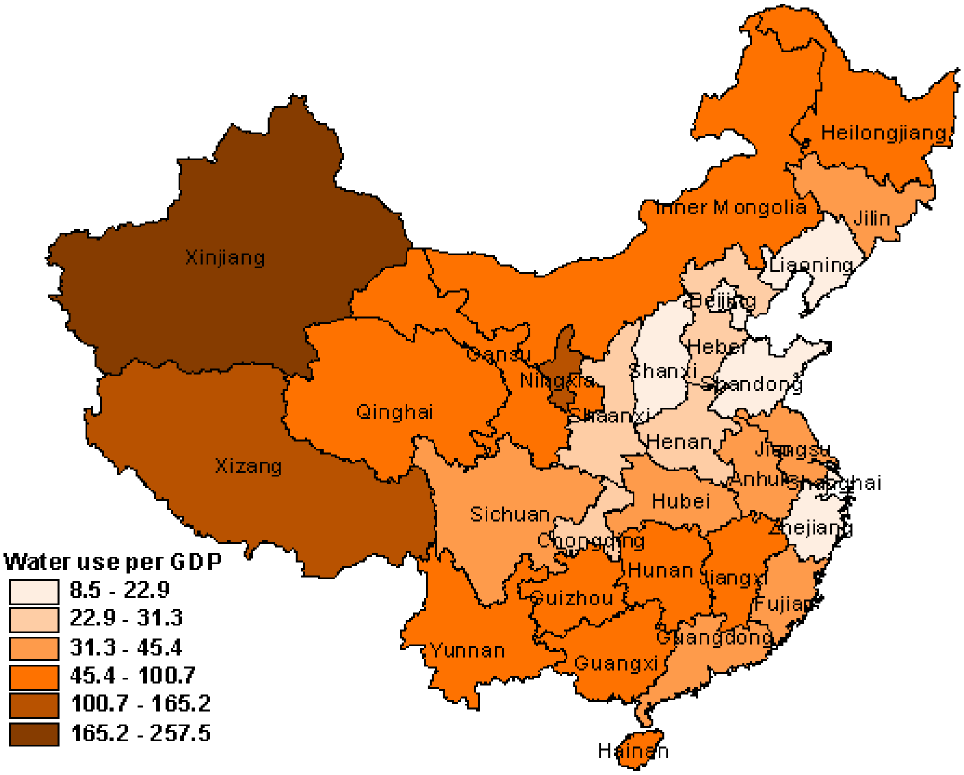

Fig. 2. Water use per GDP (m^3/1000 yuan) (CWRB, 2003)

4.1 Domestic water use

Domestic use here refers to the water used for urban households, urban public sector, rural households and livestock; this follows the definition of the China Water Resources Bulletin. The water consumption for urban households has increased substantially since 1980 with improvements in the standard of living. The migration from rural to urban areas contributes partly to the increase. The rural domestic consumption has also increased but not considerably. The regional disparity in domestic water use is apparent. The average annual domestic water use varies from about 26 m^3/capita in Shanxi province to 107 m^3/capita in Shanghai. Domestic use tends to be higher in wealthy regions such as municipalities Beijing and Shanghai, or water-abundant provinces in West and South China, such as Guangdong, Guangxi and Tibet. Income elasticity of residential water demand measures the rate of response of quantity demand due to a rise (or lowering) in a consumer's income. Price elasticity of water demand is used to measure how consumers change their water consumption in response to changes in prices. We use the panel data to investigate the factors influencing domestic water use. The model is specified as follows:

$$W_d = f(income, prec, temp, wr, famsize, wp, coastal, western)$$

where W_d refers to annual water use of households in a region. GDP per capita is taken as a proxy of domestic income. As domestic use comprises both urban and rural households, a general economic indicator would be more appropriate. GDP value is deflated to its 1997 level using the Consumer Price Index. *Prec* refers to annual precipitation, *temp* is the mean annual temperature, *wr* stands for the average amount of water resources per capita in a region, *famsize* refers to the average family size, and *wp* denotes the average domestic water prices in 2003. Among these, precipitation, temperature, water resources, and household size are panel data, while water prices are cross-sectional data. *Coastal* and *western* are regional dummies, which are included in order to take into account any potential difference between coastal and inland provinces and between western and non western regions. Coastal regions include Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. Western regions consist of Xinjiang, Tibet, Qinghai, Ningxia, Gansu, Shaanxi, Yunnan, Guizhou, Sichuan, Chongqing, and Guangxi.

Due to the panel form of the data set, several tests have to be performed in order to choose the correct specification for the model. To avoid multicollinearity, population density is excluded to be an explanatory variable as it is highly correlated with GDP. The test of the significance of the unobserved effects suggests that the data have a statistically significant group effect but there does not appear to be a significant period effect. Tests for both heteroskedasticity and first-order auto correlation are rejected at 1% level, which implies that the data sets are serially correlated and not homoskedastic. This invalidates the use of OLS for estimation. Following our tests, we use the feasible generalized least square (FGLS) method as an alternative, which allows for the estimation in the presence of AR (1) autocorrelation within panels and heteroskedasticity across panels. The model with data on all the provinces is estimated with assumptions of heteroskedasticity and autoregression in both linear and double log forms. This is presented as Model 1 in Table 2. In addition, the model with restricted provinces is performed excluding three exceptionally rich municipalities: Beijing, Tianjin and Shanghai. This is presented as Model 2 in Table 2. We will focus on analyzing the results of double log function. The linear model is shown for comparison only.

Table 2. Estimation results for domestic water use

	Model 1		Model 2
Variable	Linear	Log-log	Log-log
Constant	18.88** (2.64)	1.86** (6.92)	2.20** (7.61)
Income	1.66** (5.95)	0.42** (8.79)	0.30** (6.21)
Precipitation	0.003** (2.64)	-0.10* (-2.26)	-0.10* (-2.19)
Temperature	0.63** (3.29)	0.23** (3.67)	0.19** (3.12)
Water resources	0.0002** (4.93)	0.13** (7.21)	0.15** (9.25)
Family size	-0.18 (-0.12)	0.21 (1.37)	0.03 (0.20)
Water price	-0.73 (-0.45)	0.04 (0.80)	-0.01 (-0.27)
Coastal	4.91 (1.84)	0.16** (3.54)	0.15** (3.31)
Western	1.81 (0.99)	-0.01 (-0.32)	-0.04 (0.85)
N	217	217	196
Log likelihood	-641.52	160.55	159.64
Wald chi2 (8)	129.15	303.11	276.18
Prob> chi2	0.00	0.00	0.00

The t statistics are in parentheses.
*Significance at the 0.05 level ** Significance at the 0.01 level
Model 1 is estimated for all 31 provinces. Model 2 excludes Beijing, Shanghai and Tianjin.

Most of the coefficients of the explanatory variables are statistically significant and have expected signs. The positive coefficient of income implies that consumers who have a high income tend to consume more water. The positive value of temperature suggests domestic consumers use more water when the weather is relatively warm. Similarly, in water abundant areas more water will be used. Precipitation contributes negatively to water consumption, meaning that households tend to use less water when there is enough rainfall. *Coastal* shows a positive sign, which implies that the coastal regions consume more water than inland regions, which further confirms that richer households tend to consume more water. Family size and water price are not significant at any level, which may be due to the fact that both variables vary little with time.

The double log estimation suggests an income elasticity of 0.42 in model 1, that is, for every 1% increase of domestic income, the domestic water use increases by 0.42%. Model 2 suggests a somewhat lower income elasticity of 0.30. The difference in the two values suggests a high sensitivity of the income elasticity to the data used. Both values are comparatively lower than the presumed value of 0.75 in Cai and Rosegrant (2002). As China continues to develop at a rapid pace and domestic income consequently increases, the water demand is thus expected to grow. The estimation also suggests a precipitation elasticity of –0.10 and a temperature elasticity of about 0.23. Due to the lack of time-series water prices, this study fails to provide a valid estimation of price elasticity of water. The estimate in Table 2 is not significantly different from zero. Also, lacking monthly data, the seasonal differences cannot be captured by this analysis.

Table 3. Double log estimation results for split samples

	Sample 1		Sample 2	
Variable	Rich	Poor	Water rich	Water scarce
Constant	0.51(1.32)	2.33** (7.68)	1.59** (4.94)	3.49** (5.41)
Income	0.60**(9.43)	0.21** (3.63)	0.37** (8.69)	0.40** (5.13)
Precipitation	0.05 (0.78)	-0.19** (-4.21)	0.04 (0.77)	-0.12 (-1.70)
Temperature	0.08 (1.03)	0.42** (4.55)	0.10 (1.20)	0.10 (0.79)
Water resources	0.02 (0.72)	0.17** (11.62)	0.07** (2.75)	0.03 (0.96)
Family size	1.17**(4.29)	-0.10 (-0.72)	0.44* (2.49)	-0.36 (-0.97)
Water prices	-0.05 (-0.68)	-0.03 (-0.52)	-0.15** (-2.56)	0.15 (1.63)
N	112	105	119	98
Wald chi2 (6)	176.71	205.49	111.57	104.29
Prob> chi2	0.00	0.00	0.00	0.00

The t statistics are in parentheses.
*Significance at the 0.05 level ** Significance at the 0.01 level

In addition, the data were further split in two ways: rich provinces versus poor provinces, and water abundant provinces versus water scarce provinces. The rich versus poor provinces is split based on the median of the per capita GDP. The water abundant versus scarce provinces is split according to the median of the available water resources per capita. They are shown respectively as Sample 1 and 2 in Table 3. The results in Sample 1 suggest a large difference between rich provinces and poor ones. The estimation with rich provinces indicates an income elasticity of 0.60, which is higher than the average in Table 1. Family size is significant in rich provinces, but not in poor ones nor in the whole sample. However, the estimation of poor provinces suggests a much lower income elasticity of 0.21 but a negative significance of precipitation and positive significance of temperature and water resources. The difference between income elasticity implies that rich households are more responsive to income changes than poor ones in terms of water demand. It may be explained by that households in poor provinces prefer to use the increase of income to meet other needs such as food or shelter than water. Alternatively, the reason may be that, in richer provinces, there are water-intensive household appliances (flush toilets, washing machines) while in poorer provinces these are largely absent. Table 3 also shows that poor provinces are more responsive to natural and climatic conditions than richer ones. Surprisingly, the results in Sample 2 indicate that water abundant regions are more responsive to availability of water resources and water prices while water scarce regions only respond to income.

4.2 Industrial water use

Industrial use refers to the amount of water withdrawn for industrial purposes, excluding recycling water in firms. The major water consumers are metallurgy, timber processing, paper and pulp, petroleum and chemical industries. Industrial water use presently accounts for 22% of the overall water use in contrast to 10% in 1980. Yet the total volume of industrial water use has stopped growing in recent years. Jia et al. (2003) use the Environmental Kuznets Curve to analyze the relationship between industrial water use and economic development, drawing on the experiences of developed countries. They conclude that industrial water use increases up to a capita GDP threshold in the range of US$3700-$17000 (Purchasing power parity, base year of 1985) and decreases thereafter. The corresponding secondary industry share in the total GDP is 30%-50%. According to this, about half of the regions in China have reached this criteria therefore a drop in industrial water use is expected. Improvement in water use efficiencies is the primary factor for reducing industrial water use, coupled by economic structure adjustment that includes moving from conventional heavy industries towards high-tech and knowledge-based industries. The main driving incentives are the pressing need for upgrading of the industrial structure, more stringent environmental laws and regulations, as well as cutting down the costs for potential resources or environmental crisis. The actual water use per production value has declined rapidly, thanks to the economic structure shift and an improvement in water use efficiencies.

It is straightforward that industrial water use depends highly on the magnitude of industrial firms, particularly of those water intensive industries. If the industrial structure of a region consists of a high proportion of water intensive industries, it is most likely that it has a high water use. However, our concern is not the total amount of water used by industry, but the water use per industrial production value, which reflects the water use efficiency of the industrial sector. Therefore, the model is specified as follows:

$$W_i = f(outp, prec, temp, wr, wp, coastal, western)$$

where W_i stands for water use per gross industrial output value, which reflects the sectoral water use efficiency in a region. *outp* refers to the value-added of the industry, and its value is deflated to the 1997 level. *wr* is the total amount of water availability in a region, and *wp* denotes the average industrial water prices in 2003. All the other variables are defined as before.

Table 4. Estimation results for industrial water use

	Model 1		Model 2
Variable	Linear	Log-log	Log-log
Constant	1.82** (9.86)	1.02** (3.15)	1.31** (3.97)
Output	-0.25E-03** (-8.52)	-0.32** (-10.35)	-0.38** (-11.0)
Precipitation	0.68E-04 (1.07)	-0.02 (-0.27)	-0.06 (-0.88)
Temperature	0.05** (4.88)	0.63** (6.2)	0.74** (7.13)
Water resources	0.001* (1.96)	0.10** (3.26)	0.11** (3.01)
Water prices	-0.26** (-9.22)	-0.35** (-4.51)	-0.22** (-2.74)
Coastal	-0.78** (-7.18)	-0.66** (-9.00)	-0.63** (-7.87)
Western	0.001 (0.01)	-0.22** (-2.81)	-0.28** (-3.36)
N	217	217	196
Log likelihood	-7.35	77.78	88.51
Wald chi2 (8)	515.79	462.16	364.44
Prob> chi2	0.00	0.00	0.00

The t statistics are in parentheses.
*Significance at the 0.05 level ** Significance at the 0.01 level
Model 1 is estimated for all 31 provinces. Model 2 excludes Beijing, Shanghai and Tianjin.

The model is estimated using FGLS, with assumptions of heteroskedasticity and autoregression. The model estimates with all data and a subsample are shown in Table 4. The regression suggests that there is no correlation between precipitation and industrial water use. Most other variables are statistically significant and have the expected signs. The output of industry has negative signs, implying that when the value of industrial production grows in a region the water use per production value declines. This makes sense because through learning by doing and technological change industries tend to improve water use efficiencies. Additionally, industrial structural change helps to phase out water intensive industries. Water price also has negative sign, which means that an increase in industrial water price will result in a decrease in water use. Temperature and the amount of water availability contribute positively to industrial water use. In addition, coastal regions have a lower water use per production value than inland regions.

The regression results suggest an output elasticity of water use of –0.32, i.e. for every 1% increase of the output of industry the industrial water use (per unit of output) decreases by 0.32%. The estimation also suggests a water price elasticity of – 0.35 with all data and –0.22 with a subsample, which are a bit lower than previous estimates of -1.0 (Wang and Lall, 2002) and –0.49 (Jia and Zhang, 2003). Again, the value of price elasticity should be taken with caution due to the problematic data.

We did not do a split sample analysis, because one would want to split the sample according to industrial classification. Unfortunately, we lack the data for this.

4.3 Agricultural water use

Agricultural use comprises of water used for farmland irrigation, forestry, animal husbandry and fishery. Although the total amount of water used in agriculture has not increased in recent years, it remains the largest water user. The proportion of agricultural water use has decreased from 83% in 1980 to 65% in 2003 as a result of giving priority to growing population and expanded industry, as well as increasing scarcity of water. The regional variation of agricultural products, practices and water use in China is rather wide. For example, South coast (e.g. Hainan, Guangdong, Fujian) and Northwest (e.g. Xinjiang, Ningxia and Qinghai) have the highest water use per irrigated land area. The South coast also demonstrates higher grain productivity to water input. In contrast, the Northwest consumes vast amount of water but shows the lowest productivity to water input, which is less than one sixth of the national average. The Southwest (e.g. Sichuan, Guizhou, Yunnan) demonstrates the highest productivity, for example, the grain productivity of Sichuan province is about 2.4 times higher than the national average (Kaneto et al., 2004).

Water leakage in irrigation systems and networks is one of the major sources of inefficiency. Bringing water to the field also involves substantial waste of water. In general, the average water use efficiency is between 0.4-0.6 in irrigation ditch, 0.6-0.7 in the field and about 0.5 for irrigated water (Liu and He, 2001). Flood irrigation is predominant and more advanced technologies, such as sprinkle and drip irrigation are not widely practiced. A survey in northern China reveals that other more efficient and yet less capital and energy intensive water saving methods, such as canal lining, border irrigation, hose water conveyance and water quantity and timing control are also not widely used in the region (Yang et al., 2003). The production benefit of farm water (crop yield per unit water quantity) is less than 1 kg/m^3.

The common inputs for agricultural production in empirical analyses are land, labor, chemical fertilizer and agricultural machine. Kaneto et al. (2004) also take water into account as an input to analyze the water efficiency in agricultural production in China. In this study rather than taking a production function approach we focus on examining the direct relationship between agricultural water use and influential factors. If we consider the total agricultural use, it is hard to compare between regions because of the variation in the cultivated area. Therefore, water use per irrigated land area is more appropriate to be the dependable variable. The model for agricultural water use is specified as follows:

$$W_a = f(agrp, prec, prec_{t-1}, temp, income, famsize, coastal, western)$$

where W_a refers to the agricultural water use per hectare, the GDP value of primary industry (mainly agriculture) is taken to be a proxy for agricultural production, and *income* stands for per capita net income of rural households in a region. $prec_{t-1}$ refers to precipitation in the previous year. All other variables are as defined before. All the monetary variables are deflated to the 1997 level. Irrigation water price is believed to be considerably low in China. However, under current data constraints we do not have access to the price on a province basis thus it is not included. The model is estimated using FGLS and the results are shown in Table 5.

Table 5. Estimation results for agricultural water use

	Model 1		Model 2
Variable	Linear	Log-log	Log-log
Constant	-1.84 (-0.84)	-0.41 (-0.49)	0.51 (0.71)
Agricultural production	-0.007** (-9.71)	-0.24** (-5.89)	-0.22** (-4.77)
Precipitation	-0.98E-03 (-0.34)	0.007 (0.27)	-0.02 (-0.84)
Precipitation (t-1)	0.9E-02** (4.17)	0.06** (2.84)	0.03* (1.95)
Temperature	0.29** (4.27)	0.20* (2.41)	0.17* (2.19)
Rural income	0.003** (6.23)	0.35** (3.69)	0.26** (3.13)
Family size	1.32** (2.70)	0.40* (2.26)	0.41*8 (2.62)
Coastal	1.86* (2.35)	0.27** (3.18)	0.39** (4.41)
Western	2.98** (5.16)	0.23** (3.38)	0.23** (3.26)
N	216	216	195
Log likelihood	-337.34	194.68	218.60
Wald chi2 (7)	255.49	120.64	94.56
Prob> chi2	0.00	0.00	0.00

The t statistics are in parentheses.

*Significance at the 0.05 level ** Significance at the 0.01 level

Model 1 is estimated for all 31 provinces. Model 2 excludes Beijing, Shanghai and Tianjin.

All the explanatory variables except precipitation are statistically significant. Agricultural production has a negative sign, which implies that water use per land area decreases where agriculture is widely practiced or is highly productive. This may reflect that through learning by doing water use efficiency increases; it may also be because of increasing returns to scale. However, as the agricultural products pertain to both rainfed and irrigated land, the correlation between water use and agricultural products from irrigated land is hard to observe. Mean annual temperature has a positive sign, which means higher amount of water is irrigated per land area in warmer areas. This is consistent with the agronomic information that the elevated temperatures generally facilitate crop growth, which in turn increase the amount of water uptake by crops. Precipitation (t-1) is positively correlated with water use, which implies that sufficient rainfall in the previous year provide more water for the coming year. The positive values of rural net income and family size imply that more water is used for irrigation when farmers are financially better off or have a bigger family. In general, farmers with higher income can afford their own irrigation facilities, such as drilling wells and pumping water in farmland or conveying water from rivers into their farmland if otherwise unavailable. *Western* shows positive sign, implying that western regions irrigate more water per land area compared to other regions. It is somewhat surprising that *coastal* also has positive sign and a greater coefficient in double log estimation.

The regression suggests a production elasticity of water use of –0.24, i.e. for every 1% increase of the value of agricultural products, water use per hectare decreases by 0.24%. In contrast, a 1% increase of rural net income will result in a 0.35% increase in water use per hectare. These two factors pull agricultural water use in opposite directions. It also suggests that water use increases by 0.2% for every 1% increase in temperature. Overall, our results show that water use per irrigated land area is significantly influenced by the economic as well as climatic variables.

Table 6. Double log estimation results for split samples

	Sample 1		Sample 2	
Variable	Urban	Rural	Water rich	Water scarce
Constant	-4.87** (-3.0)	1.73 (1.80)	-2.91** (-3.84)	-3.50* (-2.17)
Agricultural production	-0.19** (-3.46)	-0.25** (-4.78)	-0.18** (-3.58)	-0.42** (-9.66)
Precipitation	0.07 (1.13)	-0.02 (-0.51)	-0.02 (-0.52)	0.008 (0.18)
Precipitation (t-1)	0.12** (2.58)	0.03 (1.33)	0.06** (3.26)	0.12** (3.06)
Temperature	0.20 (1.54)	0.03 (0.23)	0.09 (0.94)	-0.09 (-0.73)
Rural income	0.64** (3.55)	0.20 (1.67)	0.71** (8.13)	0.84** (6.20)
Family size	1.40** (3.18)	0.37 (1.76)	0.50** (2.73)	0.82 (1.63)
N	104	111	111	104
Log likelihood	49.97	117.59	123.55	59.57
Wald chi2 (6)	104.2	58.2	94.11	147.5
Prob> chi2	0.00	0.00	0.00	0.00

The t statistics are in parentheses.
*Significance at the 0.05 level ** Significance at the 0.01 level

The data were again split into urban versus rural provinces in Sample 1 and water rich versus scarce provinces in Sample 2. The urban versus rural provinces are split based on the proportion of urban and rural population as well as the ratio of primary industry to GDP. The water rich versus scarce provinces are split according to the absolute value of water resources. Sample 1 shows different results between urban and rural provinces. Water use in rural provinces is more responsive to increase in agricultural production than that in urban provinces although the difference is not significant. In urban provinces, water use shows a positive correlation to precipitation in the previous year, rural income and family size. Comparing the results in Sample 2, it is noticeable that agricultural water use in water scarce provinces shows a higher output elasticity and it is also more responsive to changes in precipitation in the previous year and rural net income, although these differences are not significant. Nonetheless, the found differences are all intuitive. The lack of significance is probably due to the limited amount of data.

5. Policy implications

Water scarcity and its impact on both human welfare and economic activities have significant implications in China. Yet how to deal with the problem remains controversial. Supply-oriented solutions are still the main interest of the government although demand management including water conservation and a rational pricing system becomes increasingly recognized. Generally, demand-oriented measures are not widely adopted. Great efforts need to be made to improve the level of water management in this regard. To optimize the economic efficiency, water will need to be allocated on market principles rather than on administrative planning principles. Resources and service charges for all sectors are not currently set at appropriate levels to reflect the cost of service delivery or the degree of scarcity. Industry and domestic consumers who already have priority to the use of water need to be charged more since the marginal value of water use is high in these sectors. Agricultural use of water needs to be charged on a volume basis where applicable rather than on a per hectare basis. However, water pricing reform involves relevant institutional and legal supports that are likely to be difficult. Institutional changes include further development in water resources allocation between and within river basins and the various sectors, regulations and enforcement, demand management, financing and incentives, and service delivery organizations.

Water conservation can be achieved in the domestic sector by introducing water saving appliances such as taps, toilets, and showering devices, using water pricing instruments e.g. increasing block tariff and awareness raising. In the industrial sector, this can be achieved by increasing recycling of water, using desalinated water, and most importantly, by putting the right price on it.

There is plenty of room for improvement of water use efficiency in the agricultural sector. Measures to improve irrigation system efficiency for on-farm and main canal systems include water-saving measures and low-yield land improvement. This involves investing in water infrastructure, irrigation system and irrigation equipment as well as providing relevant knowledge and technical support. Under the current setup of water pricing, farmers have little incentive to invest in irrigation. Also, farmers who live on the marginal financial gain are reluctant to increase any of their expenses in terms of irrigation. Under current irrigation management system, further increasing the irrigation price may not serve the purpose of water conservation (Yang et al., 2003). In this context, significant reform in the agricultural sector will be required. A top down approach will be appropriate to begin with. The government needs to take initiatives in investing in water and irrigation system to improve the water transfer and conveyance efficiencies, and by promoting more advanced irrigation technologies. Following this, a water pricing reform should be carried out aiming at raising the water price to its supply costs. Ideally the collected revenues could again be used to maintain and improve the water system. Water Use Associates are often proposed to replace the irrigation district units in taking charge of maintaining irrigation system and collecting fees for improving efficiencies.

6. Summary and conclusions

This study presents econometric analyses of domestic, industrial and agricultural use of water in China using province level panel data. It provides insights into the responses of consumers to exogenous changes. By examining the water use patterns, the study concludes that water use varies substantially across various sectors and across regions. Economically developed or more industrialized areas at the coast consume less water than the agriculture dominated economy in provinces of the west and far south of China.

In general, the results of the study indicate that water uses are significantly related to both economic and climatic variables. For the domestic sector, income is the dominant factor influencing the magnitude of water use and shows an income elasticity of 0.42. We find that richer provinces have a *higher* income elasticity than do poorer provinces. Availability of water resources and climatic variables also contributes to domestic water use. The coastal area shows a relatively higher consumption than the inland area. For the industrial sector, water use per industrial output is negatively related to industrial development, which implies that less water is needed when the industry grows and expands. Industrial demand is also responsive to price changes and shows a price elasticity of –0.35. As for the agricultural sector, the water use per irrigated land area decreases when agricultural production increases. Rural net income, family size and temperature contribute to agricultural use positively.

The results of this study are of direct relevance to water resources planning and policy making. The estimates of elasticities can be used in water demand forecast or in cost benefit analysis of future water supply projects. The estimation can be improved by using panel data covering a longer time period or more disaggregated sub-regional level analyses. It would also be useful to extend the study with more adequate data especially regarding time series water prices for the various sectors. Well-designed household surveys would provide richer information and greater insights into the factors influencing domestic water demand.

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