Economic analysis of domestic, industrial and agricultural water demands in China

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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 $-0.23$ for irrigated agriculture (per land area).

Keywords Demand management; elasticity; regional variation; water use

Introduction
Water is increasingly scarce in many regions and countries. 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. 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 urgent in China. 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.

Water is unevenly distributed in both spatial and temporal terms. The regional variation in availability of water resources in China is considerable, given its diverse climate and geographic conditions. 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 2,600 m$^3$ in water-abundant regions (CWRB, 2003).
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 for years 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.

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:

\[ W_{it} = \alpha + \beta X_{it} + \gamma Y_i + v_i + e_{it} \]  

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 \( e_{it} \) is the usual residual that includes non-explainable variations that are both spatial and temporal. \( \beta \) and \( \gamma \) 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 exist 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.

Results

Water use can be broadly classified into domestic, industrial, agricultural and sometimes ecological uses. 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. Figure 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.

Figure 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 higher agricultural share in economic activities and thus use more water. Agriculture-dominant regions remain economically worse off than industry, or services, dominant economy in China.

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 CWRB. 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 m³/capita in Shanxi province to 107 m³/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. We use the panel data to investigate the factors influencing domestic water use. The model is specified as follows:

\[ W_d = f(\text{income, prec, temp, wr, famsize, wp, coastal, western}) \]  

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. \( \text{Prec} \) refers to annual precipitation, \( \text{temp} \) is the mean annual temperature, \( \text{wr} \) stands for the average amount of water resources per
capita in a region, \( \text{famsize} \) refers to the average family size, and \( \text{wp} \) denotes the average domestic water prices in 2003. \( \text{Coastal} \) and \( \text{western} \) 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

![Map of China with water use per GDP](image)

**Figure 2** Water use per GDP (m²/1,000 yuan) (CWRB, 2003)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Log-log</th>
<th>Model 2</th>
<th>Log-log</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>18.88** (2.64)</td>
<td>1.86** (6.92)</td>
<td>2.20** (7.61)</td>
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<tr>
<td>Income</td>
<td>1.66** (5.95)</td>
<td>0.42** (8.79)</td>
<td>0.30** (6.21)</td>
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</tr>
<tr>
<td>Precipitation</td>
<td>0.003** (2.64)</td>
<td>-0.10* (-2.26)</td>
<td>-0.10* (-2.19)</td>
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</tr>
<tr>
<td>Temperature</td>
<td>0.63** (3.29)</td>
<td>0.23** (3.67)</td>
<td>0.19** (3.12)</td>
<td></td>
</tr>
<tr>
<td>Water resources</td>
<td>0.0002** (4.93)</td>
<td>0.13* (7.21)</td>
<td>0.15** (9.25)</td>
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</tr>
<tr>
<td>Family size</td>
<td>-0.18 (-0.12)</td>
<td>0.21 (1.37)</td>
<td>0.03 (0.20)</td>
<td></td>
</tr>
<tr>
<td>Water price</td>
<td>-0.73 (-0.45)</td>
<td>0.04 (0.80)</td>
<td>-0.01 (-0.27)</td>
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</tr>
<tr>
<td>Coastal</td>
<td>4.91 (1.84)</td>
<td>0.16** (3.54)</td>
<td>0.15** (3.91)</td>
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</tr>
<tr>
<td>Western</td>
<td>1.81 (0.99)</td>
<td>-0.01 (-0.32)</td>
<td>-0.04 (0.85)</td>
<td></td>
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<td>N</td>
<td>217</td>
<td>217</td>
<td>196</td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
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<td>160.55</td>
<td>159.64</td>
<td></td>
</tr>
<tr>
<td>Wald chi² (8)</td>
<td>129.15</td>
<td>303.11</td>
<td>276.18</td>
<td></td>
</tr>
<tr>
<td>Prob &gt; chi²</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

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

Table 1: Estimation results for domestic water use (t statistics are in parentheses)

Model 1 is estimated for all 31 provinces. Model 2 excludes Beijing, Shanghai and Tianjin.
significant group effect but there does not appear to be a significant period effect. Tests for both heteroskedasticity and first-order autocorrelation are rejected at 1% level, which implies that the data sets are heteroskedastic and serially correlated. This invalidates the use of OLS for estimation. Following our tests, we use the 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 in both linear and double log forms, which is presented as Model 1 in Table 1. In addition, the model with restricted provinces is performed excluding three exceptionally rich municipalities: Beijing, Tianjin and Shanghai. We intend to capture the difference in model results and to test the sensitivity of the model. This is presented as Model 2 in Table 1.

Most of the coefficients of the explanatory variables are statistically significant and have expected signs. Income, temperature and water resources are positively correlated to domestic water use, while precipitation contributes negatively to water consumption. Coastal shows a positive sign, which implies that the coastal regions consume more water than inland regions. 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. Also, lacking monthly data, the seasonal differences cannot be captured by this analysis.

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. (2004) 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 3,700–17,000 US$ (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 criterion; 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:

\[ W_i = f(\text{outp}, \text{prec}, \text{temp}, \text{wr}, \text{wp}, \text{coastal}, \text{western}) \]  

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

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 2. Most other variables except precipitation are statistically significant and have the expected signs. The output 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 while temperature and water resources have positive signs. 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.

**Agricultural water use**

Agricultural use comprises 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. The regional variation of agricultural products, practices and water use in China is rather wide. For example, South coast

### Table 2 Estimation results for industrial water use (t statistics are in parentheses)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1 Linear</th>
<th>Model 1 Log-log</th>
<th>Model 2 Log-log</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.82** (9.86)</td>
<td>1.02** (3.15)</td>
<td>1.31** (3.97)</td>
</tr>
<tr>
<td>Output</td>
<td>(-0.25E-03)</td>
<td>(-0.32)</td>
<td>(-0.38)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>0.08E-04 (1.07)</td>
<td>(-0.02)</td>
<td>(-0.06)</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.05** (4.88)</td>
<td>0.63** (6.2)</td>
<td>0.74** (7.13)</td>
</tr>
<tr>
<td>Water resources</td>
<td>0.001* (1.96)</td>
<td>0.10** (3.26)</td>
<td>0.11** (3.01)</td>
</tr>
<tr>
<td>Water prices</td>
<td>(-0.26)</td>
<td>(-0.35)</td>
<td>(-0.22)</td>
</tr>
<tr>
<td>Coastal</td>
<td>(-0.78)</td>
<td>(-0.66)</td>
<td>(-0.83)</td>
</tr>
<tr>
<td>Western</td>
<td>0.001 (0.01)</td>
<td>(-0.22)</td>
<td>(-0.28)</td>
</tr>
<tr>
<td>N</td>
<td>217</td>
<td>217</td>
<td>196</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>(-7.35)</td>
<td>77.78</td>
<td>88.51</td>
</tr>
<tr>
<td>Wald chi2 (8)</td>
<td>515.79</td>
<td>462.16</td>
<td>364.44</td>
</tr>
<tr>
<td>Prob &gt; chi2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*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.
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 a 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 (Kaneko et al., 2004). If we consider the total agricultural use, it is hard to compare between regions because of the variation in the cultivated area.

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/m³.

The common inputs for agricultural production in empirical analyses are land, labor, chemical fertilizer and agricultural machinery. 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. In this case, water use per irrigated land area is more appropriate to be the dependable variable. The model for agricultural water use is specified as follows:

\[ W_a = f(\text{agrp, prec, prect}^{-1}, \text{temp, income, famsize, coastal, western}) \]  

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 \( \text{income} \) stands for per capita net income of rural households in a region. \( \text{prect}^{-1} \) 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 PGLS and the results are shown in Table 3.

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 increases 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.

Summary and conclusions
This study presents econometric analyses of water uses in China and provides insights into the responses of consumers to exogenous changes. 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. 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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References


