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Have Chinese Water Pricing Reforms Reduced Urban Residential Water Demand?

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Key Points:

- We investigated the effectiveness of Chinese urban water pricing reforms.
- We compared household water consumption with and without increasing block rate prices.
- The price reforms reduced annual residential water demand by 3-4% in the short-run and 5% in the longer-term.

Abstract

China continues to deal with severe levels of water scarcity and water pollution. To help address this situation, in 2002 the Chinese central government initiated urban water pricing reforms that emphasized the adoption of increasing block rate (IBR) price structures in place of existing uniform rate structures. By combining urban water use records with micro-level data from the Chinese Urban Household Survey, this research investigates the effectiveness of this national policy reform. Specifically, we compare the household water consumption in 28 cities that adopted IBR tariffs during 2002-2009, with that of 110 cities that had not yet done so. Based on difference-in-differences models, our results show that the policy reform reduced annual residential water demand by 3-4% in the short-run and 5% in the longer-term. These relatively modest reductions are consistent with the typically generous nature of the IBR tariffs that Chinese cities have chosen to implement, and imply that more efforts are needed to address China's persistent urban water scarcity challenges.

Keywords： water pricing, increasing block rates, urban water demand, residential water consumption, China

1. Introduction

China has been experiencing serious water scarcity problems in the presence of rapid socioeconomic development, urbanization and industrialization [*Liu and Yang*, 2012; *Piao et al.*, 2010]. Available water per capita is only approximately one quarter of the world average [*Liu and Yang*, 2012; *UN-Water,* 2003]. According to the China Water Resources Security Report, , 82 Chinese cities are facing water shortage problems, 32 of which are seriously lacking water [*Jia et al.*, 2004]. In the latest version of the Asian Water Development Outlook, China's water security index is still far from a satisfactory level [*Asian Development Bank (ADB).* 2016]. Meanwhile, potential sources of water supply suffer from significant pollution problems: more than 40% of China's rivers are severely polluted, and 80% of the lakes in Chinese urban areas are suffering from eutrophication [*Jiang*, 2009].

To help address growing water scarcity problems, the Chinese central government initiated water pricing reforms in 2002 that were designed to reduce residential demand in urban areas [*Zhong and Mol*, 2010]. Consistent with the large body of literature that demonstrates the responsiveness of water demand to higher prices [*Dalhuisen et al.*, 2003; *Sağlam*, 2015], these reforms specifically encouraged Chinese cities to adopt increasing block rate (IBR) price structures in place of commonly used uniform rate structures. The Chinese government suggested that IBR tariffs should be adopted across cities gradually through time, and selected 14 cities to be the initial pilot cities for the policy reform. The government required that the first price block should meet the basic living need of residents. But otherwise, cities were largely able to design their own price policy details and to determine a schedule for policy adoption.

Although this national policy reform in China is now more than 15 years old, researchers have not yet investigated the extent to which it has accomplished its conservation goals. *Zhong and Mol* [2008] focused on the decentralization of decision-making authority associated with a broad set of urban water management reforms, and the role of participatory public hearings in the context of historically centralized bureaucratic decision-making in China. The same authors also examined institutional and governance challenges associated with the same reforms, finding that these were significant barriers to achieving the benefits of decentralized approaches to resource management, including pricing [*Zhong and Mol*, 2010]. Fu et al. (2008) provide a thorough book-length review of Chinese urban water reforms, including seventeen case studies, but mainly focus on institutional challenges, measures of progress, and issues related to change management. None of these authors, and to our knowledge, no authors to-date, have investigated the extent and nature of the effects of the policy reforms of 2002 on residential water demand in Chinese cities. Given the current and anticipated water scarcity situation in China, and the broader interest in using increasing block rate pricing for water conservation in other countries, China's recent experience holds potentially important lessons for both its own domestic water policy and that of other governments and agencies.

2. Increasing Block Rate Tariffs

Increasing block (also called tiered or multi-step) rate structures are thought to have important advantages over standard uniform rate structures, including the ability to charge a high marginal price (thus sending a clear scarcity signal to consumers who presumably will respond by keeping consumption low) while also providing a reasonable amount of low-cost water for essential uses (i.e., drinking, cooking, cleaning, bathing). Many investigations have explored the crucial question of how consumers react to block pricing in an effort to help guide the decisions of managers and policymakers. According to economic theory, rational consumers should exhibit both substitution and income effects in response to changes in the marginal price but only income effects in response to changes in the average price [*Howe and Linaweaver*, 1967]. Under uniform rates, marginal and average prices are the same; however, they differ under block rates. Under increasing block rates, marginal price is higher than average price for any household consuming outside of the first block. Earlier work sought to correctly identify demand parameters and price responsiveness under block rates [*Agthe and Billings*, 1980; *Billings and Agthe*, 1980; *Hewitt and Hanemann*, 1995; *Terza and Welch*, 1982]. Some researchers have found that water consumers are more responsive to marginal prices than average prices under block rates, [*Billings*, 1982; *Gibbs*, 1978; *Howe and Linaweaver*, 1967; *Nataraj and Hanemann*, 2011]. Other researchers argue that consumers should be more sensitive to the average price because the complexity of block prices makes them relatively difficult and costly to understand [*Foster and Beattie*, 1981]. *Shin* [1985] tested this hypothesis for electricity consumers, as well, and found evidence to support it. Similarly, *Ito* [2014] found that the average price, rather than the marginal price, has economically and statistically significant effects on electricity consumption in a more recent investigation. Water demand research by *Wichman* [2014] in North Carolina also supports this viewpoint. Of particular relevance for this study, research conducted prior to water pricing reform in China in the late 1990s suggested that most citizens would likely treat IBR pricing as uniform pricing and respond to the average price [*Ma et al.*, 2014].

Researchers also have shown that the price responsiveness of demand varies under different rate structures [*Dalhuisen et al.*, 2003; *Espey et al.*, 1997; *Reynaud et al.*, 2005] and that IBR tends to produce a higher price elasticity than a uniform rate pricing structure [*Nieswiadomy and Molina*, 1989; *Olmstead et al.*, 2007]. *Baerenklau et al.* [2014] estimated that demand under IBR "water budgets" (i.e., when the block sizes vary with household and climatic conditions) was as much as 17% below where it would have been under a comparable uniform rate price structure in southern California; however, *Wlodarz and Griffin* [2014] obtained opposite conclusions in their community-level research in Texas. Furthermore, although price increases generally tend to reduce welfare, some empirical analyses support the notion that IBR price structures can help protect consumer welfare and ensure sufficient operator revenue while reducing total demand [*Baerenklau*, 2015; *Gong et al.,* 2016]. However, *Sibly* [2006] noted that high consumption is not necessarily wasteful; thus, the high marginal cost of consuming large quantities under IBR pricing may be perceived as inequitable by some. And to the extent that family size and per capita income are negatively related, IBR is likely to make poor families pay higher prices [*Borenstein*, 2008].

3. Empirical Setting

While all of these studies help to establish intuition for the anticipated effects of the Chinese pricing reform, it is important to bear in mind that IBR pricing entails multiple degrees of freedom that ultimately determine the actual effects. These include the number of blocks, the size of each block, and the price level associated with each block. The Chinese central government required cities to adopt a three-block pricing structure for residential water consumption. The first block had to cover at least 80% of local monthly average household water consumption to guarantee access to water for basic needs. The sum of the first two blocks had to cover 95% of local average monthly use to help avoid adverse welfare effects and to promote greater quality of life for residents. Furthermore, the ratio of prices between these three blocks also had to be no less than 1.0:1.5:3.0. However, regions facing more serious water shortage problems could increase the price ratios to promote greater conservation.

Aside from these requirements, the actual executors and decision makers were the local municipal governments. This means that each city could individually decide how, when, and in what manner to implement IBR tariffs depending on the municipal government's own considerations. For example, Shenzhen, the earliest Chinese city to adopt a block rate water pricing structure (in 1990, prior to the policy reform presently under consideration), has revised its residential water pricing structure at least four times to meet new water demands [*Liu*, 2008]. Nanjing initiated IBR tariffs in 2006 and established different pricing policies for different family sizes. Other cities have delayed the process simply because they believe that they are not ready for water price reform, whether for technical, political or other reasons.

In general, water pricing reform efforts proceeded slowly during the first decade of the 21st century due to out-of-date infrastructure (e.g. insufficient metering) and time-consuming negotiations in most cities. However, we identified 28 cities across 16 provinces that adopted pricing reforms between 2002 and 2009 and that we can match to supplementary data in the Chinese Urban Household Survey (CUHS). Figure 1 shows the locations of these cities and table 1 provides some summary statistics on relevant characteristics. This group of cities provides a convenient test sample for investigating the effect of the water pricing reform on residential water demand across Chinese urban areas.

3. Data and Methods

Data for this study are derived primarily from the Chinese Urban Household Survey (CUHS). The CUHS has been administered by China's National

Bureau of Statistics (NBS) since the 1980s. Each year, different households are selected based on stratified random sampling to compose a representative sample for each area [*Zhou*, 2013]. Numbers of selected households from each city are related to population, and by using the administrative region codes we can determine in which city each household is located. The survey asks selected household to provide information about property ownership, family characteristics, and income, as well as a detailed diary of daily expenditures. Government officials collect and verify the data regularly, eventually summarizing and aggregating records from individual households into monthly, quarterly and annual data on demographics, income and expenditures. Notably, CUHS includes annual figures for water consumption and expenditures based on each household's water bills.

The CUHS dataset provides us with annual household-level records from 160 cities across 16 provinces. We omit data from 20 cities because the CUHS did not survey those cities in all eight years of our observation period (2002-2009), and we remove obviously problematic records (e.g. negative income). We calculate the annual average water cost per cubic meter for each household by using annual water expenditure divided by total water consumption and we drop 1% of households from both the top and bottom of the cost distribution to prevent outliers from affecting our results. Our final sample includes 184,466 individual household records from 2002 to 2009, for 138 cities across 16 provinces in China, including 20,132 records for which households are facing an IBR water tariffs. .

Finally, we augment the CUHS data with annual temperature data from the U.S. National Oceanic and Atmospheric Administration (NOAA), with precipitation data from city-level yearbooks, and with water price information from the official records of the local water supply agencies. The water price data allows us to determine which cities initiated the IBR structure in each year, the time of year when the tariffs changed, and details such as the number of tiers and prices for each tier. By combining all of this information, we create an independently pooled cross-sectional dataset at the household level. Relevant summary statistics are reviewed later in this section.

One issue we face with our data is that each city can initiate its IBR policy at any time during the year, yet the CUHS data is annual. Because the hot summers from June to August lead to higher water consumption during those months, we implement the following principle to match the IBR policy start date with the annual CUHS data: for cities that adopt IBR before June, we consider the first IBR year to be the same year when the policy change is implemented; otherwise, we consider the first IBR year to be the second year after the adoption of IBR. Following this convention, Fig. 2 shows that in 2002, only 1 city (Kunming) had implemented an IBR policy; however, this number grew rapidly from 2005 to 2007 and eventually increased to 28 among all sample cities in 2009.

Figure 3 presents the annual water consumption for both the 28 IBR cities (red lines) and for our full sample (blue lines). Solid and dashed lines represent average water consumption per household and per capita, respectively. For the full sample, both household and per capita water consumption generally increase over time, but especially after 2006. In 2009, the average household water consumption was approximately 110 cubic meters, whereas the average water consumption per capita was about 40 cubic meters. The average water consumption for the 28 cities that have adopted IBR during our research period has continuously been lower than the full sample: the gap decreased in 2004 and then increased until 2008, when 26 cities had completed their water pricing reforms.

Table 1 shows consumption statistics for the cities, before and after the rate changes. Overall there was a 22.8% and 25.6% average increase in annual household and per capita water consumption, respectively, among these cities after the adoption of IBR. However, whether city-level water consumption increased or decreased depends on the specific city; our calculations show that only about half of the IBR cities experienced an increase in average household water consumption after new IBR water pricing was implemented, whereas the remaining cities experienced a decrease.

Determining whether observed trends and changes in consumption can be attributed to the pricing reform requires additional data for regression analysis. Crucial elements in any econometric demand study are price and income. Under IBR there are multiple price levels that may influence consumer behavior. Because the pricing reform of interest emphasized moving from uniform rates to IBR, our main concern is controlling for differences in price levels so that we may focus on the effect of the policy. *Baerenklau et al.* [2014] accomplished this by considering uniform and IBR tariffs with the same average prices. The authors state, "From the perspective of a water utility, this is a useful baseline from which to judge the demand effect of water budgets, since such a uniform rate structure would produce revenues equal to those of the water budget structure under the null hypothesis that there is no demand effect." (p.693) This approach suits our investigation, as well, because it enables us to use a single demand specification that can accommodate both uniform and IBR tariffs, which in turn facilitates hypothesis testing about the demand effects of IBR tariff features. This approach also is feasible given the available data, which includes information on the average price paid by each household but not on the marginal price paid. Furthermore, *Ma et al.* [2014] found that Chinese citizens may be more responsive to the average price of water than to the marginal price. For all of these reasons, the price variable we use here is the annual average price paid for water by each household (Chinese Yuan (CNY) per cubic meter). To control for inflation, we use 2002 as the base year and use the consumer price index to convert nominal prices (and incomes) to real values.

An important problem that must be addressed by researchers using data with block rates is simultaneity, as the price of water both determines and is determined by consumption [*Nieswiadomy and Molina*, 1989]. To address this simultaneity bias, we use a jackknife grouping approach to generate a valid instrument for the average price [*Angrist*, 1999] More specifically, for each household we use the average price faced by other households in the same city and in the same year as an instrument. For example, if $\overline{p}$ is the average price in a given city and year, and p_i is the price for household i, then the jackknife price instrument for household i is $(N\bar{p} - p_i)/(N-1)$ where N is the total number of households. By construction, the price instrument is uncorrelated with any choices made by household i.

In addition to water price and household income, many other factors are known to have substantial effects on residential water consumption. The ownership of water-consuming appliances is believed to play an important role in residential water consumption [*Gibbs*, 1978; *Hansen*, 1996], as the presence of these appliances may change residents' water-consuming behaviors. For example, the ownership of a hot water heater likely will increase frequency of bathing, which may cause higher water consumption. Furthermore, a larger family and a larger residence have been shown to have strong positive effects on residential water use in many cases [*Borenstein*, 2008; *Gaudin*, 2006; *Schleich and Hillenbrand*, 2009]. Because outdoor water use might be a large part of residential water consumption, we separate the detached house structure from other building styles because it typically requires more water for outdoor irrigation. *Schleich and Hillenbrand* [2009] used the same strategy in their research on water demand in Germany. Finally, *Piper* [2013] discusses the potential effects of the unemployment rate and numbers of tiers in a block rate schedule on residential water demand, suggesting that both variables may have significant negative effects, as unemployed family members may spend more time at home compared to employed ones. Temperature and precipitation also should have effects on water consumption, as cool, rainy days reduce the need for outdoor irrigation. We obtain our temperature data from NOAA and use the variable referring to "number of days hotter than 30 degrees Celsius" to replace the annual average temperature variable in this research, as a hotter summer is believed to lead to higher residential water use. Annual total precipitation is included as well.

Table 2 provides descriptions of the key variables used in the analysis, and Table 3 presents the statistical details. The average annual household water consumption is 99.5 cubic meters, and the average annual per capita water consumption is 36.0 cubic meters. The percentage of detached houses in Chinese cities is relatively low, as most Chinese citizens live in apartments or dormitories. A family of three is the mode in China, and the relatively low employment rate is reasonable because we do not count retired people as employed since employed people likely spend more time out of the home, at work, which leads to lower residential water use. For all IBR cities, the largest price ratio between the highest and lowest blocks is a factor of 4. The consumption allowed in the basic block varies significantly across cities because municipal governments were allowed to make these decisions; however, the basic block is intended to cover most of the daily residential water use in each city.

We use several related models to manipulate this data and investigate the effect of the pricing reform. In each case, we adopt the commonly-used log-log form (e.g. Baerenklau et al. 2014; Pint 1999; Hewitt and Hanemann 1995; Olmstead, Hanemann, and Stavins 2007; Olmstead 2009) which allows us to readily interpret coefficients as elasticities and facilitates comparisons with other studies:

$$ln\_Q_{ijt} = \beta_0 + \beta_1 IBR_{it} + \beta_2 ln\_Ap_{it} + \beta_3 ln\_Income_{it} + \alpha X_{it} + \theta X_{jt} + \sum \delta_j city_j + \sum \gamma_t year_t + \varepsilon_{it} \quad (1)$$

where i indexes households, j indexes cities, and t indexes years. ln_Q_{ijt} is the logarithm of annual water consumption for household i in city j in year t. IBR_{it} equals 1 if a household is under an IBR tariff in year t, otherwise it equals 0. Therefore the coefficient β_1 captures the average differential change in annual water consumption at households under IBR relative to households under uniform tariffs. ln_Ap_{it} is the logarithm of a household's annual average water price, and ln_Income_{it} is the logarithm of household's annual income. X_{it} encompasses household-level socio-economic characteristics, including the number of family members, the size of the residence, ownership of appliances, building style, and family employment rate. X_{jt} refers to weather variables (high temperature days and total precipitation). The inclusion of *city* and *year* fixed effects means that we control for general macroeconomic factors that affect all households over time as well as city-specific characteristics which are time invariant. ε_{it} is the usual idiosyncratic error term.

4. Results and Discussion

4.1 Main results

Our main results for the basic model are reported in Table 4. The table shows that our policy dummy (IBR) has a significant negative impact on household water demand and that price always attenuates consumption. After including all of our control variables (Column 5), we estimate that the adoption of IBR water pricing decreased annual water consumption by 3.3%, on average. Coefficients on average price and household income are statistically significant; the magnitude implies that a 10% increase in average water price will reduce the demand by 5.45%, whereas a 10% increase in household income will increase consumption by 3.01%. Compared to other water demand studies conducted in Europe and America, both price and income elasticities fall within reasonable ranges [*Dalhuisen et al.*, 2003; *Espey et al.*, 1997].

Most control variables are highly statistically significant, although some of them are quite small in absolute value. In Column (2), we add residence size, which has been shown to have a strong positive effect on household water consumption, and in Column (3) we consider ownership of two water consuming appliances. Building style and employment rate are included in Column (4). Finally, in Column (5) we add our weather variables. Our results support the intuition that a larger house and a larger family each increase annual water consumption. In particular, every additional family member translates to a 7.4% increase in water use. Moreover, the ownership of two types of water-consuming household appliances, washing machines and water heaters, significantly increases residential water use; and water heater ownership contributes even more to higher water consumption.

Additionally, higher ambient temperatures cause increased residential water use, whereas precipitation decreases water consumption. Outdoor irrigating may not be as common in China as it is in countries like the U.S., as our results do not support the idea that a detached house has higher water consumption.

4.2 Robustness checks

To validate these results, we make several changes to our basic model and estimate additional regressions. First, as noted above, recall that we set the initial IBR year for the test cities by comparing their adoption date against a June 1st cut-off. This design assumption may have influenced our estimate of the effect of the policy change on household water consumption. Therefore, we change our design by setting the initial IBR year as the calendar year of adoption for each IBR city. For instance, the city of Taiyuan adopted IBR in September 2008; we had previously allocated this change to 2009, but now we use 2008 instead. As before, we control for both city and year fixed effects in these regressions. Table 5 reports the results. Compared to our previous design, the estimated coefficient on IBR in Column (5) is only slightly larger in absolute value at -3.6%.

Second, previous research has shown that using different price variables may lead to different results [*Gibbs*, 1978; *Nieswiadomy and Cobb*, 1993]. In our basic model, we use the household annual average unit water cost as the water price. As an alternative we consider the average regional (local) price paid by all sample households. In addition to a robustness check, this specification also may help to mitigate the influence of errors in individual price data records. Because regional price has limited correlation with individual household water consumption, we no longer use 2SLS but rather a simple OLS regression. As shown in column (1) of Table 6, this approach again produces a similar but slightly larger policy effect of -3.8%.

Third, we implement a different specification for comparing uniform and IBR pricing structures. Rather than using a policy dummy, we consider the uniform price structure to be a "block rate structure with only one block." We remove the policy dummy and replace it with a new explanatory variable, $Tiers_{jt}$, which represents the number of tiers. The price variable, Pb_{jt}, is no longer the average price faced by each household but instead the basic (lowest) block price for each city. This approach allows us to determine the effect of the number of tiers on consumption after controlling for the base price. With the other variables remaining same with equation (1), the model is as follows:

$$ln\_Q_{ijt} = \beta_0 + \beta_1 Tiers_{jt} + \beta_2 ln\_Pb_{jt} + \beta_3 ln\_Income_{it} + \alpha X_{it} + \theta X_{jt} + \sum \delta_j city_j + \sum \gamma_t year_t + \varepsilon_{it} \qquad (2)$$

The results of this alternative model are presented in column (2) of Table 6. The price coefficient becomes smaller in absolute value, but every additional tier (a proxy for higher average prices) helps decrease annual household water consumption by 2.3%, on average. This is similar to, but somewhat smaller than, derived by *Piper* [2013] who estimated that an additional tier would decrease consumption by 4-5% for a U.S. dataset. Also note that $Tiers_{jt}$ effectively just augments the constant term for cities under uniform pricing; and recall that the typical IBR structure has three blocks (two more than a uniform structure under our model specification). At 2.3% per block, a typical IBR structure would reduce demand by 4.6% relative to a uniform structure after controlling for the base price level. This is roughly 1% larger than the previous estimates of 3.3%-3.8%.

4.3 Long term effect

We also consider potential differences in the short- versus long-run when evaluating the effect of the pricing reform. There are multiple reasons why short- and long-run responses to pricing changes may differ. For example, consumers may not pay close attention to their water bills until after they have received multiple high bills under a new rate structure. *Baerenklau et al.* [2014] found evidence of such behavior in a southern California application. Alternatively, short-run responses may be modest due to the fixed nature of water-using durable goods maintained by consumers [*Griffin et al.*, 2000]. But in the long-run, those durable goods are more likely to be replaced with more efficient models which translate into potentially larger overall adjustments in water consumption [*Wlodarz and Griffin*, 2014]. To evaluate whether the response to IBR increases with time, we split our sample according to the number of years since IBR was introduced. Based on the findings in *Baerenklau et al.* [2014], we considered a short-run effect to be only 1 or 2 years after IBR was introduced and a long-run effect to be 3 years or more. We then estimated various regressions to address this question. Columns (3) and (4) in Table 7 provide evidence that adoption of IBR does have a stronger influence on water demand in the longer-term: there is a 2.9% decrease during the first two years, whereas the effect grows to 5.0% after 3 years or more. In Column (5), we convert the IBR policy dummy in our basic model into an integer corresponding to the number of years since IBR pricing was introduced (set equal to 3 for all observations that have at least 3 years post-IBR adoption). Results suggest that another year passing since the adoption of IBR leads to a 1.5% decrease in residential water demand on average, for an estimated "long-run" (3-year) effect of 4.4%. We also perform a robustness check by defining the long-run as 2 years or more, rather than 3. Columns (1) and (2) of Table 7 show the estimated effect of IBR under this assumption: the long-run impact is slightly smaller at 4.0%, which provides additional evidence of an increasing demand effect through time.

4.4 The impact of IBR structure

Finally, rather than grouping disparate types of IBR structures together into a single treatment group, we examine whether specific features of the rate structures might have noticeable effects on consumption [*Piper,* 2013]. To do this, we focus only on the cities that adopted IBR policies and we use those policies to derive three variables: number of tiers, price ratio between the highest and basic blocks, and amount of consumption allowed in the basic block. Our new model is as follows:

$$ln\_Q_{ijt} = \beta_0 + \beta_1 IBR_{Tiers_{jt}, Diff_{jt}, Range_{it}} + \beta_2 ln\_Ap_{it} + \beta_3 ln\_Income_{it} + \alpha X_{it} + \theta X_{jt} + \sum \delta_j city_j + \sum \gamma_t year_t + \varepsilon_{it} \qquad (3)$$

Here, we use the simplified notation $IBR_{Tiers_{jt}, Diff_{jt}, Range_{it}}$ to represent various features of different IBR structures. As noted above, $Tiers_{jt}$ is the number of tiers. $Diff_{jt}$ refers to the ratio of the prices between the highest and basic blocks. The IBR pricing policy for city j is considered to be stricter as each of these two variables increase in size. $Range_{it}$ refers to the size of the basic block (the amount of water that may be consumed at the lowest price). The other variables are the same as in the basic model. This model uses only the 20,132 observations in the IBR cities. Both year and city fixed effects as well as the exogenous covariates are included.

Table 8 summarizes the estimation results for six regressions with different combinations of the three rate structure attributes. The table shows that some control variables lose their significance under this specification while number of family members, residence size, employment rate, and ownership of water heaters still have significant effects on water consumption. As for the rate structure attributes, the number of tiers still has a negative influence on water consumption. However, the coefficients for price difference and size of the basic block do not have the expected signs and exhibit weak (if any) statistical significance at typical levels.

One possible explanation for these unexpected results could be the endogenous nature of the rate designs. Rather than using true experimental structures, water agency staff determine their rate structures given the characteristics of their districts. Thus, the size of the basic block (and/or the price differential between the basic and highest blocks) may be small in areas where demand is stubbornly high, thus producing the negative relationship. Another possible explanation is that the IBR structures implemented in these cities may be rather generous relative to customer demands, and thus they may not truly function as inclining price schedules for many customers. Our data suggests that this may be the case. For example, Table 3 shows that the average size of the basic block is 14.3 cubic meters; thus, for a modal family of three, IBR pricing would be functional only when monthly per capita water consumption exceeds 4.75 cubic meters. However, consider that the Chinese National Development and Reform Commission presented official recommendations on the block designs for each province [*National Development and Reform Commission.*, 2013]. Even the highest recommended value for per capita water use in block one (4.6 for southeast Chinese provinces) is still below 4.75; thus, another potential explanation may be that the block designs in Chinese cities are not sufficiently strict to realize the conservation potential of IBR pricing.

5. Conclusions

By using micro-level data from the Chinese Urban Household Survey, augmented with weather and water rate information, we find that the water policy reforms of the Chinese central government that promoted the adoption of IBR water pricing led to a modest 3-5% decrease in urban residential water demand. We also find that this reduction was not achieved immediately; rather the short-run demand response to the policy change increases through time at a rate of about 1.5% per year during the first few years. However, we are unable to find clear evidence that differing attributes of IBR structures across Chinese cities lead to differing effects on water demand, aside from the number of blocks which has a significantly negative effect on water consumption.

A 3-5% overall reduction in demand, achieved over multiple years, is relatively small and suggests that the IBR policies that have been implemented so far by Chinese cities are relatively lenient. This observation is consistent with findings by the *National Development and Reform Commission* [2013] which estimated that while the richest 5% of households would pay at least three times the base rate of water, the lowest tier—roughly 80% of urban households—wouldn't be affected by the changes. If the water policy reform undertaken by the Chinese central government is to achieve a substantial reduction in demand, our research suggests that Chinese cities that have not yet implemented IBR should consider adopting stricter policies with smaller basic blocks so that more households will be affected by the higher prices of the upper tiers. Moreover, the prices of the upper tiers may need to be substantially higher than those of past IBR adopters to effectively encourage households to reduce water consumption.

Smaller blocks and higher prices, however justified by concerns about growing water scarcity, are certainly not what municipalities would otherwise want to impose on their citizens. Water districts in the United States are all-too familiar with the unfortunate cycle of higher rates, lower consumption, net operating losses, and higher rates. The cities of Santa Cruz, Stockton, and Yorba Linda, California found themselves in this cycle during the latest California drought. In Yorba Linda, customers sued and board members lost their jobs (Stevens 2016; Salazar 2016). However, alleviating water scarcity through supply augmentation is typically more costly than through demand management, and so the question often becomes how best to reduce demand. Recent work by Baerenklau (2015) shows for a United States example, that when faced with targets for water conservation and sales revenue, achieving these targets with block pricing creates smaller customer welfare losses than either uniform rate increases or across-the-board consumption restrictions. Block pricing thus seems to have much to offer, despite the inherent challenges associated with using prices to attenuate demand.

Future work on related topics could extend and improve the present analysis in multiple ways. With appropriate billing or survey data, our cross-sectional dataset could be replaced by a panel that would permit tracking changes in individual household water consumption through time—notably before and after a policy change—in the next Chinese cities to undertake pricing reforms. Data on marginal prices paid by Chinese households also might be collected and used to investigate both consumer price sensitivity and whether the estimated policy effect depends upon whether marginal or average prices are used in the analysis. Seasonal fluctuations in water use might be exploited to investigate whether IBR pricing has a greater effect on household consumption during the peak summer season. And finally, it may be worthwhile to examine billing formats across cities to determine if different approaches to information provision might be utilized to promote greater water conservation among Chinese urban residents.

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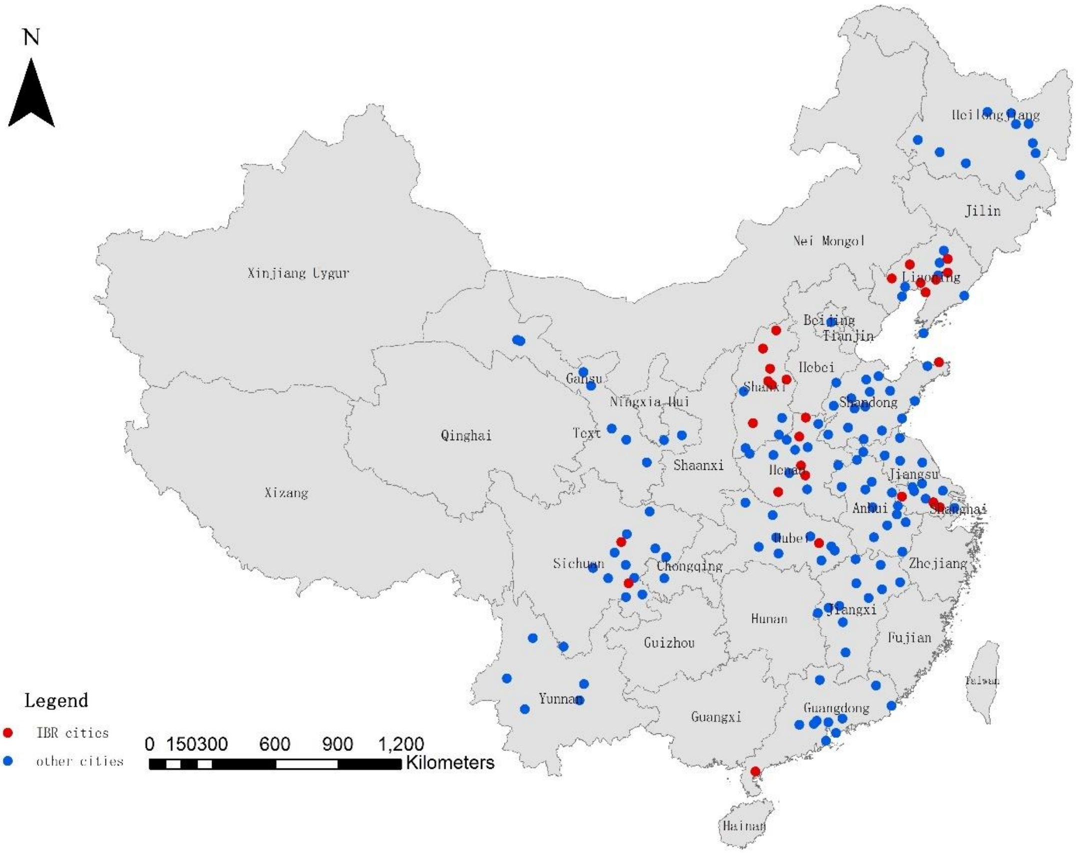

Figure 1: Selected cities during 2002-2009 according to the Chinese Urban Household Survey

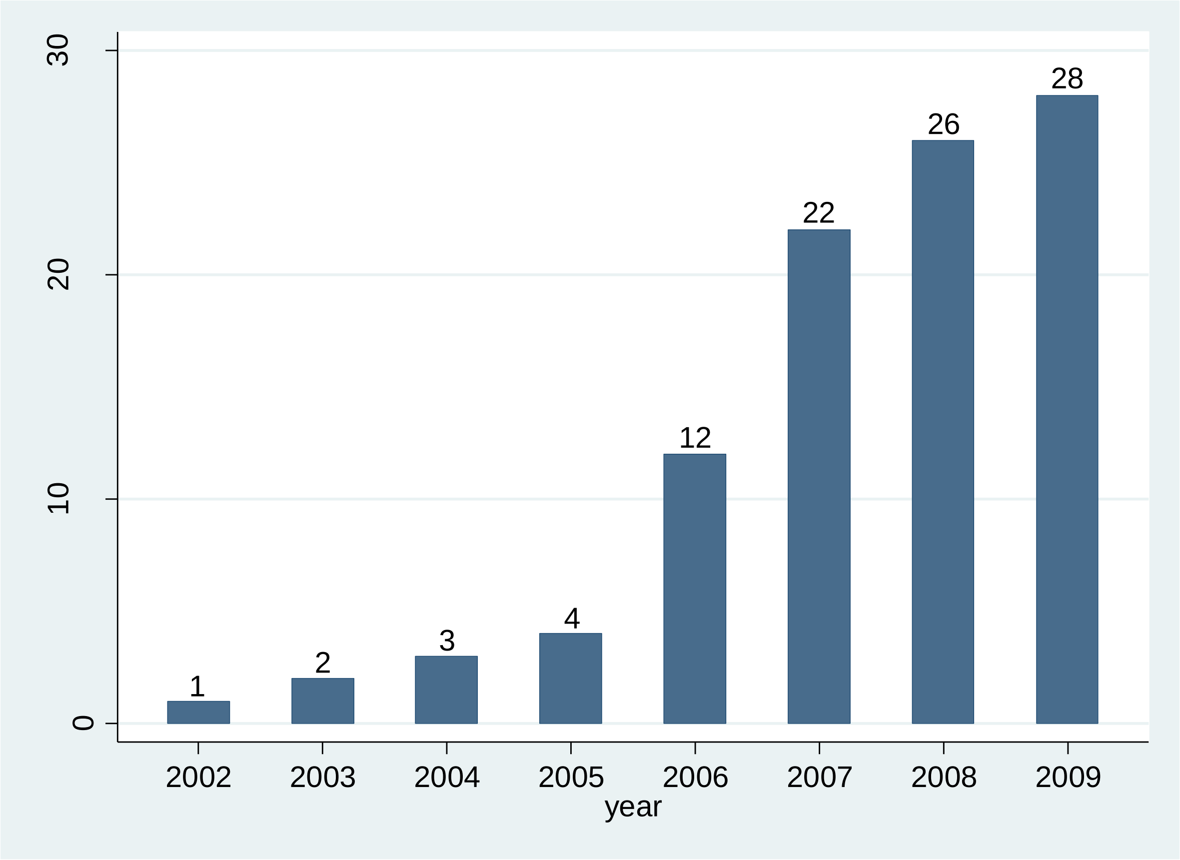

Figure 2: Number of cities with IBR price

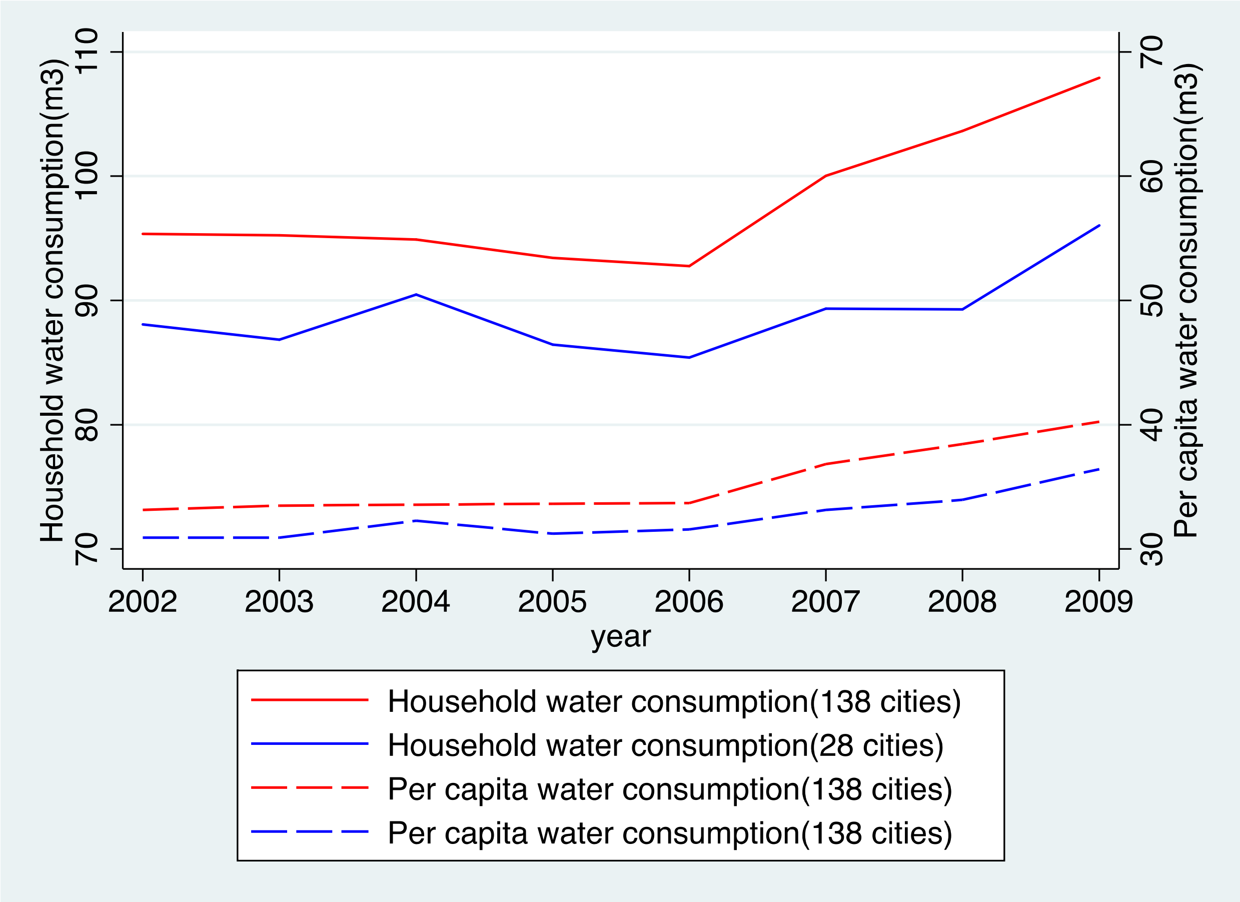

Figure 3: Water consumption over the study period

Table 1. Basic Information for the 28 IBR cities

City	IBR Starting Time (Month-Year)	Mean Water Consumption Under Uniform Pricing (m^3/year)		Mean Water Consumption Under IBR Pricing (m^3/year)		Differences	
		Per household	Per capita	Per household	Per capita	Per household	Per capita
Taiyuan	Sep-08	58.35	22.57	68.08	27.71	9.73	5.14
Datong	Dec-08	53.43	20.29	48.18	18.49	*-5.25*	*-1.79*
Yangquan	Nov-06	51.18	18.17	67.59	26.76	16.41	8.58
Shuozhou	Jul-07	57.23	18.92	68.54	22.60	11.32	3.67
Jinzhong	Apr-07	77.17	28.59	113.69	45.40	36.53	16.81
Xinzhou	Nov-04	72.86	25.20	67.99	24.69	*-4.87*	*-0.51*
Linfen	Jan-07	80.47	27.06	90.93	31.99	10.46	4.92
Anshan	Jan-06	70.23	24.91	62.29	25.29	*-7.93*	0.38
Fushun	Apr-04	63.78	23.72	60.09	23.50	*-3.68*	*-0.22*
Benxi	May-07	48.15	17.84	68.79	26.00	20.65	8.16
Yingkou	Nov-06	57.11	20.33	84.22	32.43	27.11	12.11
Fuxin	Jun-05	47.01	16.57	46.56	17.80	*-0.45*	1.23
Panjin	Jan-07	87.45	33.36	80.22	31.96	*-7.23*	*-1.40*
Chaoyang	Oct-08	51.64	18.75	51.70	20.01	0.05	1.25
Nanjing	Jul-07	102.43	38.06	99.12	39.19	*-3.31*	1.13
Wuxi	Jan-08	85.12	32.45	103.24	40.89	18.12	8.43
Suzhou	Sep-07	101.11	37.64	104.35	39.52	3.24	1.89
Weihai	Jan-07	72.96	27.11	87.47	32.02	14.52	4.91

Anyang	May-05	93.49	33.23	85.39	32.51	<u>*-8.09*</u>	<u>*-0.72*</u>
Xinxiang	Mar-03	84.82	29.21	88.43	31.73	3.60	2.52
Xuchang	Jun-06	79.53	28.92	81.34	29.48	1.81	0.56
Luohe	Nov-03	98.29	33.94	90.25	31.46	<u>*-8.04*</u>	<u>*-2.48*</u>
Nanyang	Oct-05	112.98	40.55	101.11	39.00	<u>*-11.87*</u>	<u>*-1.55*</u>
Wuhan	May-06	153.87	54.25	144.54	52.33	<u>*-9.34*</u>	<u>*-1.92*</u>
Zhanjiang	Jul-06	183.96	53.93	220.44	67.83	36.47	13.90
Zigong	Jan-06	78.96	27.93	111.56	40.60	32.61	12.67
Deyang	Apr-06	92.59	34.13	88.53	35.36	<u>*-4.05*</u>	1.23
Total	-	84.56	28.97	103.83	36.39	19.27	7.42

Table 2. Descriptions of key variables

Variables	Description
Q	Household annual water consumption (cubic meters)
Qper	Annual water consumption per capita(cubic meters)
Income	Household income (CNY, based on year 2002)
Ap	Annual costs of household average unit water (CNY, based on year 2002)
Tem>30	Number of days hotter than 30°C
Precipitation	Annual total precipitation (mm)
IBR	Dummy =1 if the city has IBR pricing, =0 otherwise
Tiers	Number of price tiers
Diff	Price in highest block divided by price in lowest block
Range	Range of block one (amount of water use)
Washing Machine	Number of washing machines
Water Heater	Number of water heaters
Member	Number of family members
Size	Size of residence (square meters)
Style	Dummy =1 if the residence is a detached house, =0 otherwise
Employment	Ratio of employed family members

Table 3. Summary statistics

Variable	Mean	Std. Dev.	Min	Max
Q	98.25	92.40	1.00	2945.2
Qper	35.67	33.94	0.20	969.67
Income	33011.14	25829.86	55.54	1539328.00
Ap	1.58	0.52	0.55	2.98
Tem>30	6.19	7.98	0.00	40.00
Precipitation	877.73	389.32	64.30	2733.80
IBR	0.12	0.33	0.00	1.00
Tiers	3.00	0.40	2.00	4.00
Diff	2.06	0.52	1.30	4.00
Range	14.30	5.99	2.50	30.00
Washing Machine	0.95	0.33	0.00	4.00
Water Heater	0.71	0.51	0.00	5.00
Member	3.00	0.85	1.00	6.00
Size	77.22	39.70	6.00	1986.00
Style	0.02	0.14	0.00	1.00
Employment	0.51	0.29	0.00	1.00

Table 4. Results for various specifications of the basic model

Dependent Variable	(1) 2sls ln_Q	(2) 2sls ln_Q	(3) 2sls ln_Q	(4) 2sls ln_Q	(5) 2sls ln_Q
IBR	-0.0357***	-0.0322***	-0.0322***	-0.0330***	-0.0331***
	(0.00838)	(0.00835)	(0.00834)	(0.00834)	(0.00833)
ln_Ap	-0.540***	-0.546***	-0.547***	-0.546***	-0.545***
	(0.0215)	(0.0214)	(0.0214)	(0.0214)	(0.0214)
ln_Income	0.337***	0.311***	0.293***	0.301***	0.301***
	(0.00314)	(0.00322)	(0.00334)	(0.00344)	(0.00344)
Member	0.0794***	0.0729***	0.0745***	0.0742***	0.0744***
	(0.00210)	(0.00210)	(0.00210)	(0.00210)	(0.00210)
Size		0.00168***	0.00151***	0.00148***	0.00148***
		(4.92e-05)	(4.99e-05)	(5.41e-05)	(5.41e-05)
Washing Machine			0.0312***	0.0313***	0.0301***
			(0.00549)	(0.00549)	(0.00550)
Water Heater			0.0778***	0.0787***	0.0795***
			(0.00406)	(0.00406)	(0.00406)
Style				0.00629	0.00626
				(0.0139)	(0.0139)
Employment				-0.0599***	-0.0593***
				(0.00608)	(0.00609)
Precipitation					-2.96e-05***
					(1.02e-05)
Tem>30					0.00197***
					(0.000383)
Constant	0.764***	0.944***	1.072***	1.027***	1.042***
	(0.0362)	(0.0364)	(0.0370)	(0.0372)	(0.0379)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes
City fixed-effect	Yes	Yes	Yes	Yes	Yes
Observations	184,466	184,466	184,466	184,466	183,479
R-squared	0.307	0.311	0.313	0.313	0.312

Robust standard errors are provided in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5. Effect of alternative cut-off date for IBR adoption timing

Dependent Variable	(1) ln_Q	(2) ln_Q	(3) ln_Q	(4) ln_Q	(5) ln_Q
IBR	-0.0387***	-0.0352***	-0.0353***	-0.0361***	-0.0358***
	(0.00822)	(0.00820)	(0.00819)	(0.00819)	(0.00818)
ln_Ap	-0.541***	-0.547***	-0.549***	-0.547***	-0.546***
	(0.0215)	(0.0214)	(0.0214)	(0.0214)	(0.0214)
ln_Income	0.337***	0.311***	0.293***	0.301***	0.301***
	(0.00314)	(0.00322)	(0.00334)	(0.00344)	(0.00344)
Member	0.0794***	0.0729***	0.0745***	0.0742***	0.0744***
	(0.00210)	(0.00210)	(0.00210)	(0.00210)	(0.00210)
Size		0.00168***	0.00150***	0.00148***	0.00148***
		(4.92e-05)	(4.99e-05)	(5.41e-05)	(5.41e-05)
Washing Machine			0.0311***	0.0313***	0.0300***
			(0.00549)	(0.00549)	(0.00550)
Water Heater			0.0778***	0.0787***	0.0795***
			(0.00406)	(0.00406)	(0.00406)
Style				0.00636	0.00634
				(0.0139)	(0.0139)
Employment				-0.0599***	-0.0593***
				(0.00608)	(0.00609)
Precipitation					-2.94e-05***
					(1.02e-05)
Tem>30					0.00195***
					(0.000383)
Constant	0.766***	0.945***	1.074***	1.028***	1.043***
	(0.0362)	(0.0364)	(0.0370)	(0.0372)	(0.0379)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes
City fixed-effect	Yes	Yes	Yes	Yes	Yes

Observations	184,466	184,466	184,466	184,466	183,479
R-squared	0.307	0.311	0.313	0.313	0.312

Robust standard errors are provided in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6. Water price measurement and household water consumption

Dependent Variable	(1) ln_Q	(2) ln_Q
Regional price	-0.517***	
	(0.0214)	
IBR	-0.0378***	
	(0.00794)	
Published price		-0.139***
(block 1 price for IBR)		(0.0175)
Tiers		-0.0230***
		(0.00397)
ln_Income	0.297***	0.297***
	(0.00390)	(0.00392)
Year fixed-effect	Yes	Yes
City fixed-effect	Yes	Yes
Observations	183,479	182,933
R-squared	0.300	0.299

Robust standard errors are provided in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7. Short- and long-run effects of IBR pricing on household water consumption

Dependent Variable	(1) ln_Q	(2) ln_Q	(3) ln_Q	(4) ln_Q	(5) ln_Q
ln_Ap	-0.553***	-0.519***	-0.537***	-0.539***	-0.546***
	(0.0217)	(0.0224)	(0.0220)	(0.0221)	(0.0214)
ln_Income	0.303***	0.300***	0.301***	0.301***	0.301***
	(0.00350)	(0.00361)	(0.00354)	(0.00356)	(0.00344)
IBR(<2 year)	**-0.0302*** **				
	(0.00963)				
IBR(>=2 years)		-0.0399***			
		(0.0114)			
IBR(<3 years)			-0.0290***		
			(0.00919)		
IBR(>=3 years)				-0.0503***	
				(0.0121)	
IBRyears					-0.0145***
					(0.00366)
Member	0.0732***	0.0737***	0.0727***	0.0740***	0.0744***
	(0.00214)	(0.00216)	(0.00217)	(0.00218)	(0.00210)
Size	0.00148***	0.00137***	0.00148***	0.00147***	0.00148***
	(5.49e-05)	(5.76e-05)	(5.41e-05)	(5.59e-05)	(5.41e-05)
Washing Machine	0.0303***	0.0336***	0.0301***	0.0307***	0.0301***
	(0.00559)	(0.00575)	(0.00550)	(0.00568)	(0.00550)
Water Heater	0.0787***	0.0804***	0.0796***	0.0785***	0.0796***
	(0.00414)	(0.00426)	(0.00406)	(0.00421)	(0.00406)
Style	0.00737	0.0184	0.00615	0.00847	0.00615
	(0.0140)	(0.0144)	(0.0139)	(0.0142)	(0.0139)
Employment	-0.0615***	-0.0610***	-0.0593***	-0.0617***	-0.0593***
	(0.00621)	(0.00641)	(0.00609)	(0.00633)	(0.00609)
Precipitation	-2.65e-05***	-4.26e-05***	-2.90e-05***	-3.37e-05***	-2.90e-05***
	(1.03e-05)	(1.05e-05)	(1.02e-05)	(1.04e-05)	(1.02e-05)
Tem>30	0.00200***	0.00171***	0.00195***	0.00186***	0.00195***
	(0.000388)	(0.000396)	(0.000383)	(0.000393)	(0.000383)
Constant	1.032***	1.091***	1.045***	1.077***	1.044***
	(0.0389)	(0.0421)	(0.0405)	(0.0400)	(0.0380)
Observations	177,719	169,107	174,519	172,307	183,479
R-squared	0.313	0.315	0.314	0.315	0.312

Robust standard errors are provided in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 8.IBR design attributes and household water consumption

Dependent Variable	(1) ln_Q	(2) ln_Q	(3) ln_Q	(4) ln_Q	(5) ln_Q	(6) lnQ
ln_Ap	-0.540***	-0.577***	-0.577***	-0.533***	-0.538***	-0.577***
	(0.118)	(0.118)	(0.118)	(0.119)	(0.119)	(0.118)
ln_Income	0.288***	0.289***	0.289***	0.288***	0.288***	0.289***
	(0.00995)	(0.00995)	(0.00995)	(0.00995)	(0.00996)	(0.00995)
Tiers	-0.0984*			-0.204**	-0.180**	
	(0.0567)			(0.0798)	(0.0763)	
Diff		0.00644		0.150*		0.00702
		(0.0565)		(0.0795)		(0.0638)
Range			-0.000274		-0.0164	0.000166
			(0.00755)		(0.0102)	(0.00854)
Member	0.0887***	0.0884***	0.0885***	0.0887***	0.0908***	0.0884***
	(0.00576)	(0.00576)	(0.00584)	(0.00576)	(0.00592)	(0.00586)
Size	0.00218***	0.00217***	0.00217***	0.00218***	0.00217***	0.00217***
	(0.000143)	(0.000144)	(0.000143)	(0.000143)	(0.000143)	(0.000143)
Washing Machine	0.00411	0.00335	0.00340	0.00364	0.00433	0.00335
	(0.0159)	(0.0159)	(0.0159)	(0.0159)	(0.0159)	(0.0159)
Water Heater	0.0799***	0.0800***	0.0799***	0.0803***	0.0798***	0.0800***
	(0.0115)	(0.0115)	(0.0115)	(0.0115)	(0.0115)	(0.0115)
Style	-0.101**	-0.102**	-0.102**	-0.102**	-0.101**	-0.102**
	(0.0485)	(0.0485)	(0.0485)	(0.0485)	(0.0485)	(0.0485)
Employment	-0.0384**	-0.0393**	-0.0393**	-0.0377**	-0.0385**	-0.0393**
	(0.0166)	(0.0166)	(0.0166)	(0.0166)	(0.0166)	(0.0166)
Precipitation	4.95e-05	4.62e-05	4.49e-05	8.19e-05	4.92e-05	4.63e-05
	(5.05e-05)	(5.10e-05)	(5.04e-05)	(5.30e-05)	(5.05e-05)	(5.17e-05)
Tem>30	0.00107	0.000723	0.000731	0.00114	0.00106	0.000725
	(0.00177)	(0.00176)	(0.00176)	(0.00177)	(0.00177)	(0.00176)
Constant	1.243***	1.043***	1.053***	1.318***	1.651***	1.040***
	(0.164)	(0.128)	(0.160)	(0.168)	(0.300)	(0.199)
Year fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
City fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes

Observations	20,132	20,132	20,132	20,132	20,132	20,132
R-squared	0.276	0.275	0.275	0.276	0.276	0.275

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1