Residential Water Consumption in Chile: Economic Development and Climate Change

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Abstract

The importance of competition between rural and urban uses for water will likely increase, especially in developing countries. We examine residential water demand in the context of a developing country facing the potential climate change effects, with significant changes in incomes, household size, poverty rates and levels of urbanization. Using Chilean municipal-level panel data (1998-2010), we estimate price and income elasticities, and the water-demand response to climate and socio-demographic variables. Impacts of variation in season averages of precipitation and temperature are statistically significant, but only the variation of seasonal average temperature, the temperature deviations about seasonal averages, and the average seasonal rainfall in northern Chile appear to be of practical, economic significance. More urbanized localities have higher per-household water use and reduced sensitivity to temperature variations. Projected water use on average would increase due to climate changes, but by small amounts in the order of one to two percent.

Key words: block pricing, Chile, climate change, residential water demand.

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1. Introduction

The competition between rural (mainly agricultural) and urban uses for water resources is likely to be of increasing importance, especially in developing countries. This paper presents evidence of the factors underlying recent trends in residential water use in Chile, emphasizing climate-related and demographic variables, in addition to prices and income. This study addresses the case of a rapidly developing country that has experienced significant shifts in income levels, household size, rates of poverty and levels of urbanization. As with other less-developed countries, Chile has only recently had available reliable data on residential water use from which one could derive estimates of demand elasticities and quantify the relationships between water consumption and non-price factors determining observed trends. The study here, the first of its kind for Chile, makes use of monthly data on per-household consumption at the level of the municipality (*comuna*), data only available since 1998, when residential water companies were required to report consumption, value of sales and price structures to the appropriate state supervisory agency (*Superintendencia de Servicios Sanitarios*). The availability of local climate data for monthly precipitation and temperature is also a novelty, permitting an improved model both of the geographic variation of water consumption and of deviations of water use around seasonal patterns.

Water demand studies using household data are available for the United States and Europe, most focusing on the estimation of price and income elasticities, often under block pricing. In developing countries the literature is scarcer, understandably given typical data limitations, and the questions addressed are more to do with delivery and sanitation. Nauges and Whittington (2010) do develop a meta-analysis of the estimation of consumer water demand in developing countries, citing among other studies evidence from Central America as reported in Nauges and Strand (2007). But such developing country studies emphasize the vulnerability of households to adequate water access and various water sources (well water versus piped). Analysis of water demand in Chile specifically is often in a regulatory context, where costs of delivery are the focus (Valenzuela and Jouravlev, 2007; Ferro, Lentini and Romero, 2011).

There are four basic data considerations to the estimation of residential water demand in a developing country such as Chile. First, the evidence is usually from surveys offering a cross-section snapshot of the relationship between water use and household characteristics. Trends in water consumption and its relation to evolving price structures, climate variables and other factors are often observed only at levels beyond the household, such as at the town or national level. Second, as noted by Nauges and Thomas (2000), while consumption data might be forthcoming, information is usually imprecise with respect to prices paid (average and marginal). Third, control variables, such as various demographic indicators, and temperature and precipitation, are difficult to obtain at the level of disaggregation and with the frequencies that might make such data interesting or informative. And fourth, when panel data are available, which is not always the case, they are infrequently exploited to the degree they might be.

This present study makes use of thirteen years of data of monthly residential water consumption for 42 municipalities. These municipalities, with vary degrees of population density and urban development, are distributed throughout Chile and are used because they have weather stations that provide appropriate climate data. Furthermore, as Hoglund (1999) notes, when household-level data are unavailable, more aggregated data, such as that at the community level, appears to yield reasonable results with respect to household demand. The analysis is of per-household consumption. Household counts and average characteristics are available from the Chilean periodic household survey (CASEN), which is available every two or three years. Municipal characteristics, such as poverty rates, employment levels and urbanity are also derived from the CASEN surveys.

Monthly real average and marginal water prices are available and determined at the municipal level by private utility companies regulated by a state agency. Such prices are specific to each locality, varying in the level of fixed costs, variable charges, and whether or not block pricing is implemented. The analysis makes use of these panel data to estimate price and income elasticities, and to quantify the importance of urbanization and the impact of climate-related variables. We exploit the estimated climate effects to project the possible effects of future climate change, making use of the Hadley Center's PRECIS climate projections for 2070 to 2100.

In the following section of this paper, we first review models of residential water demand, noting the use of block pricing and the role of temperature and precipitation, and then turn to the application to the Chilean case. The third section presents a brief discussion of the data sources, model specification and error structure. The fourth section shows the regression results and the projections of changes in per-household water-use in the far future due to two scenarios of projected climate. Finally, the fifth section offers some discussion and conclusions.

2. The basic model of residential water demand

2.1 Modeling water demand

The usual specification of residential water demand at the household level, Q, begins as a simple function of the good's price, P, and a vector of other factors, Z, such as household income, location, rural or urban dwelling, level of education, number of adults and children and other variables: $Q = f(P, Z)$ (see, for example, Arbués, Garcia-Valiñas and Martinez-Espiñeira, 2003; Arbués, Barberán and Villanúa, 2004; Fielding et al., 2012; and House-Peters and Chang, 2011, for a review of urban water demand modelling over the last three decades). There is nothing special about water demand that makes it theoretically different than the demand for other goods. Nevertheless, there are some empirical difficulties to the estimation of water demand; in particular, block pricing of water by utility companies introduces some econometric complications in estimation. One issue to address is the response of quantities demanded to price and income changes, because income effects can become confounded with margin price effects (Martinez-Espiñeira, 2002). In the recent literature, studies have used a combination of marginal prices and a difference variable to accommodate this difficulty (Hewitt and Hanemann, 1995; Agthe and Billings, 1997; Renwick and Archibald, 1998).[1] Another econometric issue is that block pricing introduces endogeneity of the marginal price faced by the household, even if the pricing schedule is fixed.

[1] This difference variable, also called Nordin's specification, is included to represent an income effect induced by the tariff structure and is composed of the difference between the total charges in some period and what the consumer would have paid if all units were priced at the marginal price (Nordin, 1976). The use of this variable requires household level information to observe the consumption in every priced block. But there are some studies with aggregate data that have applied this approach.

Following Olmstead, Hanemann and Stavins (2007), residential water pricing takes three forms: uniform marginal pricing, an increasing block structure, or a decreasing block structure. Usually consumers also pay fixed base rates as well. Under a uniform marginal price structure, households pay a single marginal price per unit volume of water consumed, regardless of total consumption. With incremental block tariffs, total consumption determines the marginal price of the last unit consumed. Usually, the marginal priced paid increases, resulting in a marginal cost function rising with quantity in a stair-step fashion, as shown in Figure 1. Although economic theory recommends the use of marginal prices at the level of the household, some studies make use of *average* prices, especially those using aggregate data of water consumption across many household (see the discussion in Arbués, Garcia-Valiñas and Martinez-Espiñeira, 2003). Aggregate data mix consumers responding to prices in various blocks and so average consumption often remains in a range responding to the price of a single block (the first block). This situation is illustrated by the thick, dotted line in Figure 1.

[Figure 1 here]

Although most studies of water demand are focused on the influence of prices and socio-demographic variables on consumption, there are studies that include season climate variables such as temperature and precipitation (e.g., Wong, 1972; Nieswiadomy and Molina, 1989; Espiñeira, 2000; Neale, 2005; Martinez-Espiñeira, 2002; Olmstead and Hanemann, 2007). These studies find strong correlations between water demand and temperature. (The Neale study, 2005, is notable in the present context because of the focus on the projection of the water demand under different climate-change scenarios.) There are some studies that show that residential consumption, especially outdoor use (gardens, swimming pool, lawn care, etc.) is dependent on climatic variables (Akuoko-Asibey, Nkemdirim and Draper, 1993; Cohen, 1985; Dandy, Nguyen and Davies, 1997; Espey, Espey and Shaw, 1997; and the literature review of House-Peters and Chang, 2011).

2.2 Some specific considerations in the case of Chile

While Chile is now, by World Bank standards, a high-income economy,[2] it is still considered a developing country, and compared to the United States and Europe there is a relatively weak informational base on which to estimate the determinants of water demand, especially from historical data. In the last decade the total residential consumption in Chile increased from 928 million cubic meters in 2000 to 1086 million in 2013, a yearly increase of approximately 1.2 percent. Average per-capita water consumption, however, has decreased from 22.7 to 18.6 cubic meters (SISS, 2013; SISS, 2012; SISS, 2000). Although individual household consumption is unavailable, we follow a community-level approach (e.g., Höglund, 1999) and assemble a panel of 42 municipalities with 13 years of monthly consumption levels, prices and weather variables. Each water utility has its own rate structure, some aspects of which we discuss in the following paragraphs.

In Chile the basic rate structure of "real" water prices is set by a process defined by law and re-structured every four years; real prices are maintained by adjusting nominal prices monthly to price indices, including the consumer price index.[3] When municipalities do use block pricing, it is a two-block scheme applied only during the "peak period" of summer (December to March). In this scheme the prices for the first block is termed the variable rate, and for the second block the "overconsumption" rate. During the rest of the year, consumers face a uniform marginal rate. There are some municipalities, mainly in the south, which maintain a single tariff throughout the year. Figure 2 shows the differences in the tariff structure of three example municipalities. The red line represents the highest marginal price in real terms, and blue line represents per-household consumption. The price spikes for Concepción are due to the peak-period second block price. Note that Puerto Montt does not have block prices throughout the thirteen-year period, while Chile Chico had block prices until 2001, and then adopted a single marginal tariff.

[2] Chile's gross nation income per capita in 2013 was US$ 15,230 (as references, the GNI per capita of the United States was US$ 53,670 and of Uruguay US$ 15,180). Per-capita GNI data for international comparisons can be found at http://data.worldbank.org/indicator/NY.GNP.PCAP.CD

[3] The month-by-month adjustment formulas are given by law as presented by the Economics Ministry. One can see the tariff formulas decrees at the web site of the Superintendencia de Servicios Sanitarios http://www.siss.gob.cl/577/w3-propertyvalue-3511.html. Note that weights on various price indices used in adjusting monthly nominal prices depend on region.

[Figure 2 here]

During peak periods, the correlation between the two block prices (the variable and the overconsumption rate) reach 99%, because they are fixed by formula, and so it is impossible with the data available to distinguish their distinct impacts on average per-household consumption at the municipal level. Although the second block price is ostensibly intended to discourage consumption during the drier summer months, the proportion of all households that surpass the consumption limit is small.[4] In any case, the nature of the data does not allow distinguishing the effects of the two block prices on the marginal liter of water consumed. We introduce both prices as separate variables in municipal per-household demand, when appropriate, because not all municipalities use such a tariff structure.

Another interesting aspect to the Chilean case is the diverse range of climates, from the warm, arid north, to the temperate, dry-season center, to the cooler, rainy south. In other words, there is notable cross-sectional variation in the data. One can also observe that rural municipalities have higher volatility in consumption than their urbanized counterparts. This is illustrated in Figure 3 for two geographically-close municipalities in the same climate zone: Yerbas Buenas and Talca (see the second panel of Figure 4). The level of urbanization is correlated with greater regularity in the yearly cycle of water consumption, owing in part to a smaller fraction of water consumption going to outdoors uses (gardens, irrigation, etc.), and making them less sensitive to climate variations.

[Figure 3 here]

3. Data sources and the regression model

We explore a monthly panel of 42 municipalities scattered along the vertical axis that is Chile (Figure 4), from 1998 to 2010. The panel is unbalanced due to a lack of a complete series of weather-related data for some municipalities. Consumption and water price information was collected from the state regulatory agency SISS (*Superintendencia de*

[4] The largest water company in Chile (Aguas Andinas) charges prices in the second block to less than 10 percent of its clients, all located in the high-income neighborhoods in Santiago. A small company (Aguas Chañar) charges in the second block to less than 3 percent of its clients in the arid north.

Servicios Sanitarios). The periodic national household survey (CASEN) and the National Institute of Statistics (INE) are the sources of the socio-economic and demographic variables at the municipal level, such as average household size, income and so on (see Table 1). The CASEN survey is completed every two or three years, and so five surveys are available during the 1998-2010 period. INE produces annual information on demographic characteristics at the municipal level. Interpolation was used to translate these data into monthly observations. The climate-related information comes from the databases of the Chilean Meteorological Administration (*Dirección Meteorológica de Chile*, DMC), which manages daily level data for at least one weather station within the 42 municipalities of the study.

[Figure 4 here]

[Table 1 here]

The basic model of per-household water consumption to be estimate is in log-log form with fixed effects:

$$Q_{it} = \beta X_{it} + \nu_i + \varepsilon_{it}$$

where ν_i is the idiosyncratic fixed effect for municipality i, and ε_{it} is the error that represents unexplained variations at each municipality and month, *t*. After some appropriate tests,[5] this error is modeled as a first-order autoregressive process. Table 1 presents the explanatory variables in the estimated model, which has the following form:[6]

$$lnQ_{it} = \alpha + \beta_1 lnT_{it}^{v} + \beta_2 lnT_{it}^{sc} * d_{it}^{p} * d_{it}^{sc} + \gamma' Cl_{it} + \delta' Z_{it} + \varphi' D_{it} + \nu_i + \varepsilon_{it}$$

where T^{v} represents the first-block variable tariff and T^{sc} the second-block overconsumption tariff, which is only appropriate during the summer months ($d^{p} = 1$, 0

[5] The estimated model reported in this paper is for fixed municipality effects. The random effects model was rejected using the Hausman test (p-value < 0.001), although the results from the fixed effects and random effects models are very close. The Wooldridge test for serial correlation leads to the rejection of no autocorrelation (p-value < 0.001). In addition, the Cochrane-Orcutt correction to control for the AR (1) process appears appropriate, because the modified Durbin-Watson and Baltagui-Wu statistics always show values less than one.

[6] For specific aspects related to estimation, especially the AR correction, see page 478, xtregar, in the longitudinal-data/panel-data reference manual, StataCorp. 2009. Stata: Release 11. Statistical Software. College Station, TX: StataCorp LP.

otherwise) and for the municipalities that make use of block pricing ($d^{sc} = 1$, 0 otherwise). The vector of weather variables is represented by *Cl*. Household and municipal characteristics (*Z*) include average household income and education, average household size, average number of bathrooms and washing machines per-household, poverty rates, urbanity (the proportion of households living in urban areas), and population per square kilometer. Seasonal and monthly dummies (*D*) are introduced to control for demand seasonality not captured by the weather variables.

Based on the raw daily data of temperature and precipitation, we differentiate between changes across municipalities in seasonal averages (for the whole period), representing the "climate" or the longer-term weather component, and within-season changes around these municipal-specific seasonal averages. Such within-season changes represent the "weather" component or the short-term volatility around the seasonal (climate) averages. This separation of effects allows for a projection of the impact of a change in the longer-term component. This longer term component is calculated as the seasonal aggregate of the weather variable for municipality *i*, and season *s*, $\bar{m}_{i,s}$. The short term volatility or climate anomaly is calculated as:

$$M_{it} = m_{i,t} - \bar{m}_{i,s}$$

where $m_{i,t}$ is the weather variable (temperature or precipitation) for municipality *i* and month *t*.

For the temperature seasonal aggregate we use each municipality's average daily mean temperature across all years in our data. For the short-term weather variable we make use of the monthly average daily maximum temperature anomalies. This monthly average daily maximum temperature variable, was employed, because it varies over the year significantly more than the average minimum, which is quite stable, and the average daily mean. The short-term maximum temperature anomaly is defined as a deviation about the municipality-specific average for each season.

Alternative specifications of the variable representing short-term temperature fluctuations were tested: anomalies of each month's average daily mean around the long-run average daily mean for that month and for the season, and anomalies of each month's average

minimum around its long-run average for that month and for the season. The econometric results for the main variables of interest (price, income, long-run average temperature, etc.) were robust to the use of these alternatives.[7]

The reader should note that there is a high correlation between temperature and precipitation; in the Chilean sample here, the correlation coefficient between the average monthly maximum temperature and the monthly total precipitation is a *negative* 0.43. This is due to latitude and the vertical nature of the country's geography: climate changes from almost no rainfall and high temperatures in the north to extremely high rainfalls and more moderate temperatures in the south, much like the west coast of North America, except flipped south to north.

Different forms of the monthly precipitation variables were tried: monthly observed total precipitation, anomalies of precipitation (around annual means), and interaction between monthly total precipitation and urbanization. In the presence of the maximum temperature anomaly variable, various forms of introducing the monthly precipitation data usually resulted in statistically insignificant coefficients, thus no short term precipitation variable is included in the model.

The municipality-specific monthly precipitation averaged by season, averaged over all 13 years, however, does contribute to explaining water consumption. This measure reflects long-term climate differences.[8] There is a notable pattern to the amount and frequency of precipitation across municipalities, from north to south, which can be grouped in the three macro-geographical zones usually defined by climatologist, as shown in Figure 5. Precipitation patterns were incorporated into the model as an interaction between the seasonal average monthly precipitation and a dummy variable indicating the geographic area.

[Figure 5 here.]

[7] These results are not presented due to space limitations, but are available from the authors upon request.
[8] For a given municipality, for each season (winter, summer, spring and autumn), a monthly average precipitation was calculated using all thirteen years.

4. Estimation and some projections under future climate scenarios

4.1 Results

Table 2 shows the results of the fixed-effect estimation of five models. The basic model contains the price and income variables, the demographic variables and the seasonal and monthly dummies. The introduction of the climate-related variables notably increases the goodness of fit of the estimated model. Note that the estimated coefficients of the basic model with only the economic variables are robust in sign and order of magnitude with respect to the inclusion of additional variables, although their absolute values decline somewhat. The (positive) coefficient on average household income declines with the introduction of variables describing average household and municipal characteristics, such as the poverty rate and the average number of household bathrooms, falling from an income elasticity of 0.28 without these variables to an elasticity of 0.18. The price elasticity is approximately – 0.11, quite consistent with the evidence from the literature.[9] The coefficient on the "overconsumption" – the second block – price is statistically significant but, practically speaking, very small, close to -0.004, in all models.

The introduction of the weather-related variables captures the seasonality of demand. The coefficient associated with long-term temperature – the seasonal mean temperature – is approximately 0.007 in the simple "climate model" reported in the second column of results in Table 2; and the coefficient remains at that value when one adds the municipal, socio-economic variables, as reported in the third column. This value implies about a one percent increase in per-household water consumption for a one-degree-Celsius increase in the (long-term) seasonal average temperature. The coefficient associated with the monthly temperature variations around the seasonal average – maximum temperature anomalies – is small (0.002): a two-standard deviation increase of temperature above the seasonal average would lead to slightly less than a one percent increase in water consumption.

The variation in average seasonal rainfall – seasonal precipitation – has a statistically significant impact in the north, but the practical effect appears very small in the center and the south. In the north, an increase in one millimeter of precipitation leads to a one-half

[9] Höglund (1999); Martinez-Espiñeira (2002); Arbués, Garcia-Valiñas and Martinez-Espiñeira, (2003); Espiñeira and Nauges (2004); and Arbués and Villanúa (2006).

percentage point decline in water consumption. For most municipalities in the far north the range of the means of precipitation between the dry and wet seasons is usually less than one millimeter. There are, however, a few municipalities abutting the Andes where the change in precipitation from one season to another is large, in Ovalle for example mean summer precipitation is less than one-half millimeter and the mean in winter is 16 millimeters, which would translate into approximately a 8 percentage point decrease in per household water demand during the winter simply due to the precipitation cycle. There are two other northern municipalities where the practical impact on water demand of the swings in mean seasonal precipitation is pronounced, but for most communities across Chile the marginal impact of precipitation is small, if not, as in the center and southern zones, effectively zero.

Turning to the estimated models in columns 3, 4 and 5 in Table 2, with respect to household and municipal characteristics, the estimated coefficients are significant at the 5 percent level (usually much less) in all models. The average number of persons per household has a positive effect on water consumption; a one-person increase translates into a 10% increase in water consumption. We found similar magnitude in the effect of an additional bathroom, though only significant at a 5 percent significance level. At the margin, an increase in the level of poverty would have a positive impact on water use; this latter result is a ceteris paribus one, holding constant income levels, household inhabitants, average number of bathrooms and washing machines, etc.; it does not imply that one would observe the average poor household consuming more water than the average richer household, all other characteristics changing in correlation with income; poverty rates are likely correlated across municipalities and through time with the lower average efficiency of household water use by the poor.

The coefficient on the municipality urbanization level is positive and statistically significant, and notably large in a practical sense. The more complete models presented in columns 4 and 5 include interactions between the urbanization level and the two temperature variables. Using these estimates, one finds that an increase in urbanization from a rural municipality of 10 percent urban households to an urban municipality of 90 percent leads to an increase in average consumption per-household of approximately 40 percent. The conclusion is that Chile's trend toward greater urbanization is driving higher

water consumption – but, again, *ceteris paribus*: in observations, other factors are working simultaneously to reduce per-household consumption over time. Interestingly, both coefficients on the interaction terms (between mean temperature and urbanization and between temperature deviation and seasonal average temperature) are negative and on the order of about one percent per one degree Celsius. These results confirm the suspicion, arising from simple graphical inspections of the variability of water use, that water consumption in more-urbanized municipalities is indeed less sensitive to changes in temperature, holding all else constant. The longer run effect of greater urbanization in Chile is therefore toward increased and more stable water consumption patterns.

Finally, using the estimates from the model in column 4 of Table 2, Figure 6 presents observed and projected average monthly, per-household water consumption, averaged across the entire panel of municipalities for the period 1998-2010. The overall goodness of fit of this model relative to that of column 5 is enhanced by the introduction of monthly dummies, which, although they do not appreciably affect the estimated coefficients on the variables of interest, do help in fitting the regression line in the case of the crest and troughs in consumption, revealing that demand seasonality is not completely explained by our climate variables The estimated model in column 4 serves as the basis for projecting household water consumption under future climate scenarios, a subject to which we now turn.

[Table 2 here]

[Figure 6 here]

4.2 Long-term future residential demand: likely small impacts overall of climate change

To evaluate the impacts of climate change on Chilean residential water use, we employ monthly averages based on the climate projections from the PRECIS model developed by the Hadley Center and adapted for use in Chile by the Department of Geophysics of the University of Chile (CONAMA, 2007). These projections, which are at the level of 25 square kilometers, are for months between the years 2070 and 2100. We break the projections into average water use by season for the three decades 2070-2080, 2080-2090 and 2090-2100. In addition to the base line, there are two change scenarios, one more

extreme than the other. The reference is the set of monthly averages during the period 1961-1990. The change scenarios simulate the supposed effects until 2100 of projected greenhouse gas emissions SRES A2 (severe) and B2 (moderate). (See the IPCC's Special Report on Emissions Scenarios, 2007.) Figure 7 summarizes for each of the three projection decades the average changes over baseline of monthly precipitation and the average changes over baseline of the monthly mean temperature.

Average temperatures increase (2 to 4 degrees, under scenario A2), most notably during the summer, and precipitation rates tend to decline across Chile, with the exception of the arid north during the summer and the extreme south during the winter. We average monthly simulations for temperature and precipitation from the PRECIS to obtain four seasonal averages by decade for both climate variables, introducing these average projections into the estimated model (column 4 in Table 2) and holding all other variables constant at their means of the three last years of observations. Table 3 presents the percentage changes in per-household consumption compared to the baseline. One notes that the greatest impact on per-household residential consumption is projected to occur in the arid north, although the increase over the baseline is under 2.5 percent. Across all 42 municipalities, the average increase in water use in both scenarios is less than 1.5 percent. For some individual municipalities, the impact is much greater. Figure 8 shows the projected water consumption increases averaged over all four seasons for the three decades. A few municipalities in the arid north have average increases of approximately 5 percent, although the increase in per-household water use in Combarbalá under scenario B2 reaches 7.8 percent during the summer season. These greater consumption increases in these northern municipalities is due both to increased average temperatures and, importantly, decreased precipitation.

[Table 3 here.]

[Figure 7 here.]

[Figure 8 here.]

5. Conclusions

Using a panel data of 42 municipalities, between 1998 and 2010, we have estimated the effects of various factors on per-household residential water consumption. We find that the price elasticity of demand in the Chilean case (-0.11) is somewhat smaller than that found in the literature on residential water demand in various countries, but close to the range estimated by Martinez-Espiñeira (2002) in the case of Spain (-0.12 to -0.16). The income elasticity of approximately 0.2 is also in the range of that found in the literature (between 0.1 and 0.4, as summarized in Arbués, Garcia-Valiñas and Martinez-Espiñeira, 2003). The effect of higher marginal water prices for "overconsumption" during summer months appears to be small, although statistically significant. In practical terms the most important price is the base rate, which for many municipalities is the only rate charged. Future research using household-level data (not as yet available) should be carried out to verify or undermine this finding.

The level of urbanization is an important determinant of the variation of household water use across municipalities, and urbanization tends to reduce the sensitivity of residential water consumption to weather shocks. This has important implications for future water consumption as Chile turns more urban. The average number of persons per household increases average per-household water consumption, but at a decreasing rate, a finding in agreement with other studies showing that household size decreases per-capita consumption (e.g., Schleich & Hillenbrend, 2009). As Chile's economic development continues average household size is decreasing, and so per-household consumption will fall, ceteris paribus.

Weather variables are found important in explaining seasonal patterns of consumption and deviations around these patterns. Temperature variations, both across seasons and deviations around seasonal averages appear to be more important than precipitation in determining consumption, although in the case of Chile precipitation is highly correlated with temperature. In some areas in the arid north of Chile, however, precipitation does play a more important role in determining water consumption. While the influence of weather variables is important, the impacts of future climate changes are, on average, relatively small, taking the entire country into account. Under the most severe climate projections for the end of the century, per-household water use likely rises by about 2.5 percent. The

estimated impacts of weather variables on household water consumption are important but on average small in part because the short-term weather fluctuations across seasons tend to dominate and in part because, in the case of Chile, the projected climate changes are effectively small. In some rural municipalities in the arid north, the projected impacts of climate change are more interesting and economically significant, but nevertheless do not exceed 10 percent increases in water use under the most severe projected climate scenario. Because no good projections on long-term future weather variability are yet available we have not used them. Although future prognostication might change, given the data to date the general conclusion is that historically other factors than weather-related variables have dominated the trends in per-household water use, which has been declining overall. Urbanization and income tends to increase consumption, but prices have increased significantly in real terms. Moreover, poverty rates, which are ceteris paribus positively related to consumption levels (likely due to efficiency-related factors), have been falling.

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Figures and Tables

Figure 1. Increasing block pricing

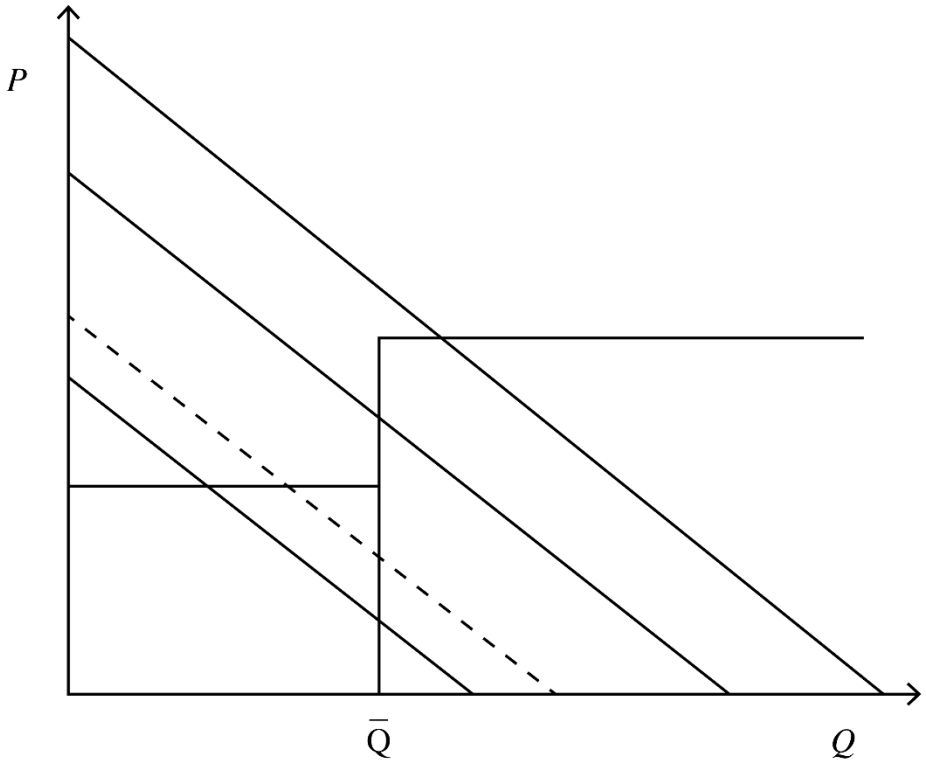
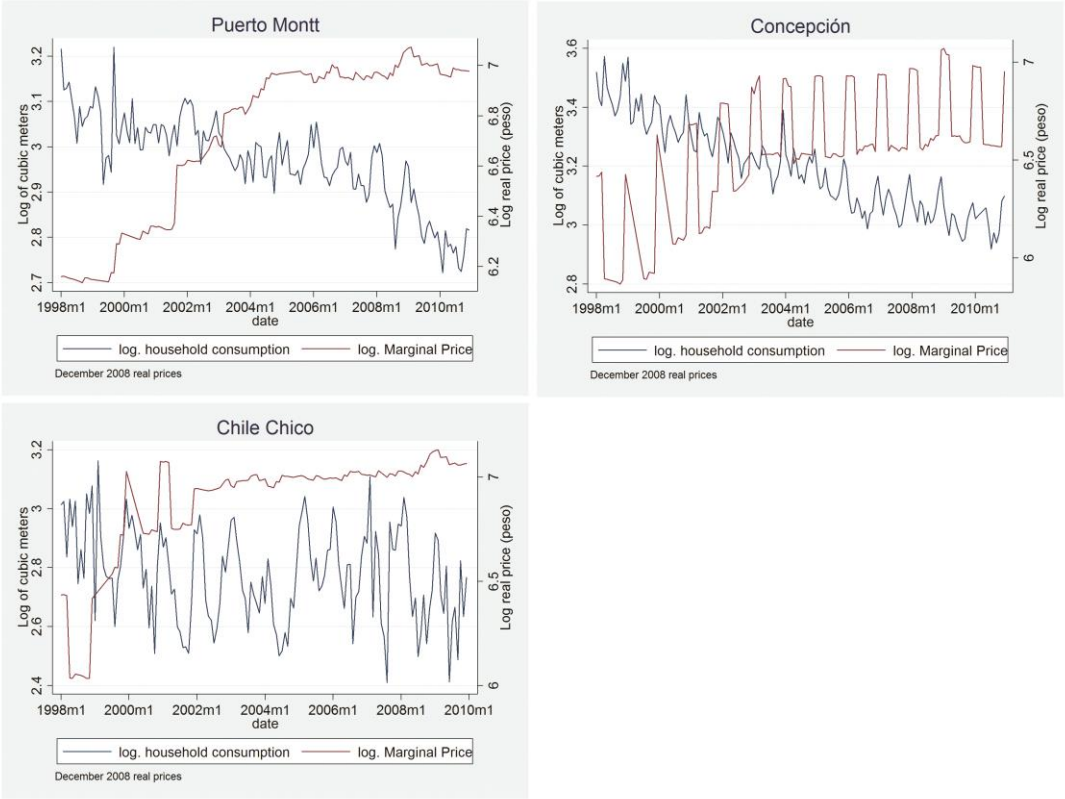
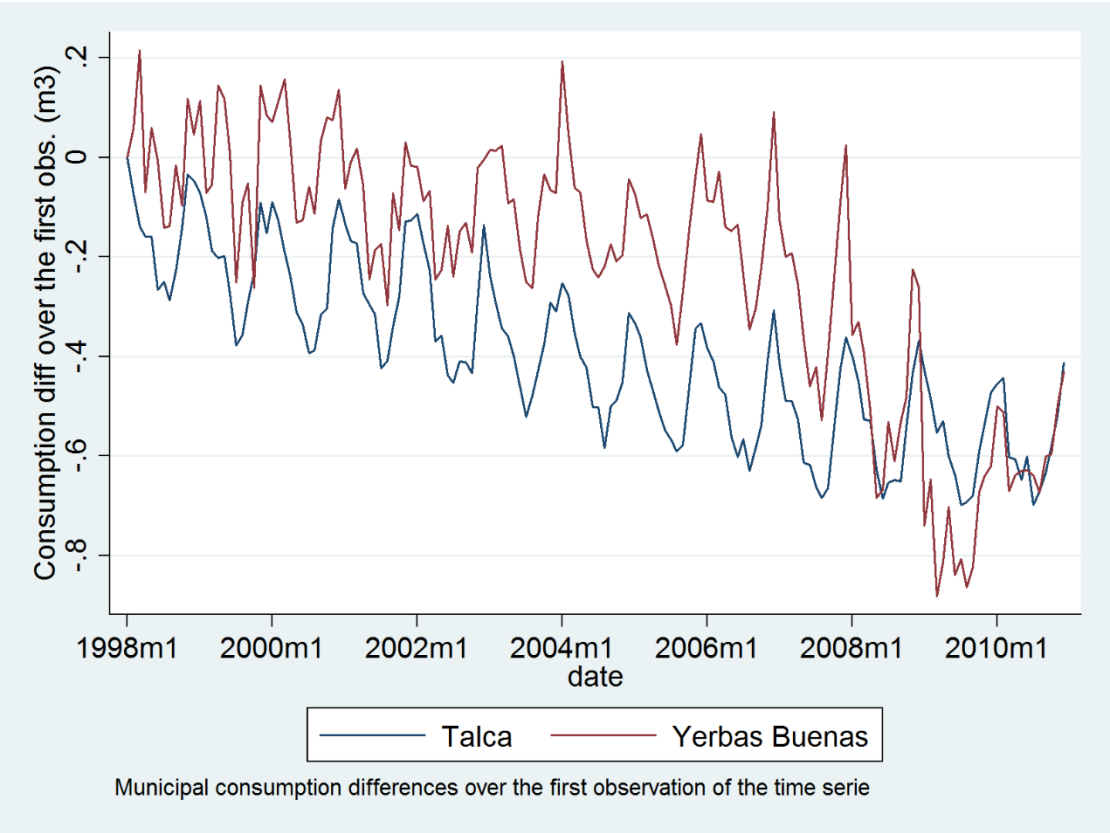


Figure 2. Residential water consumption and tariff, characteristic examples.



Source: Authors calculations from data from SISS. Note that the red lines represent the highest marginal price in real terms, and blue lines represent per-household consumption at the municipal level.

Figure 3. Consumption volatility of two geographically close municipalities but very different in their urbanization indices.



Source: Authors calculations from data from SISS.

Figure 4. Chilean municipalities used the study sample.

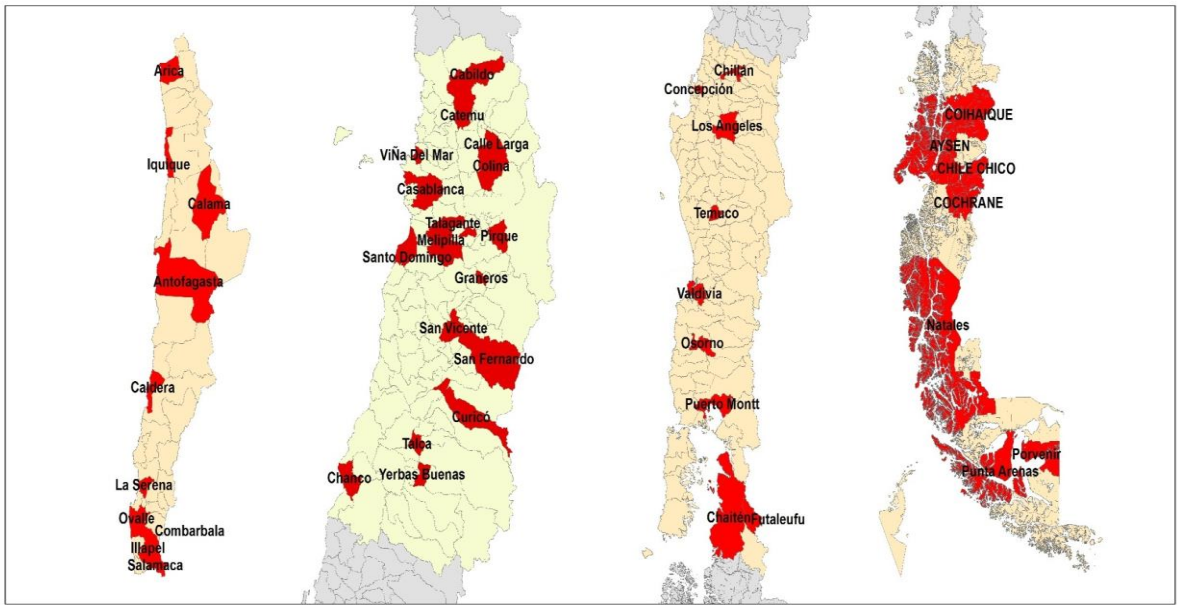
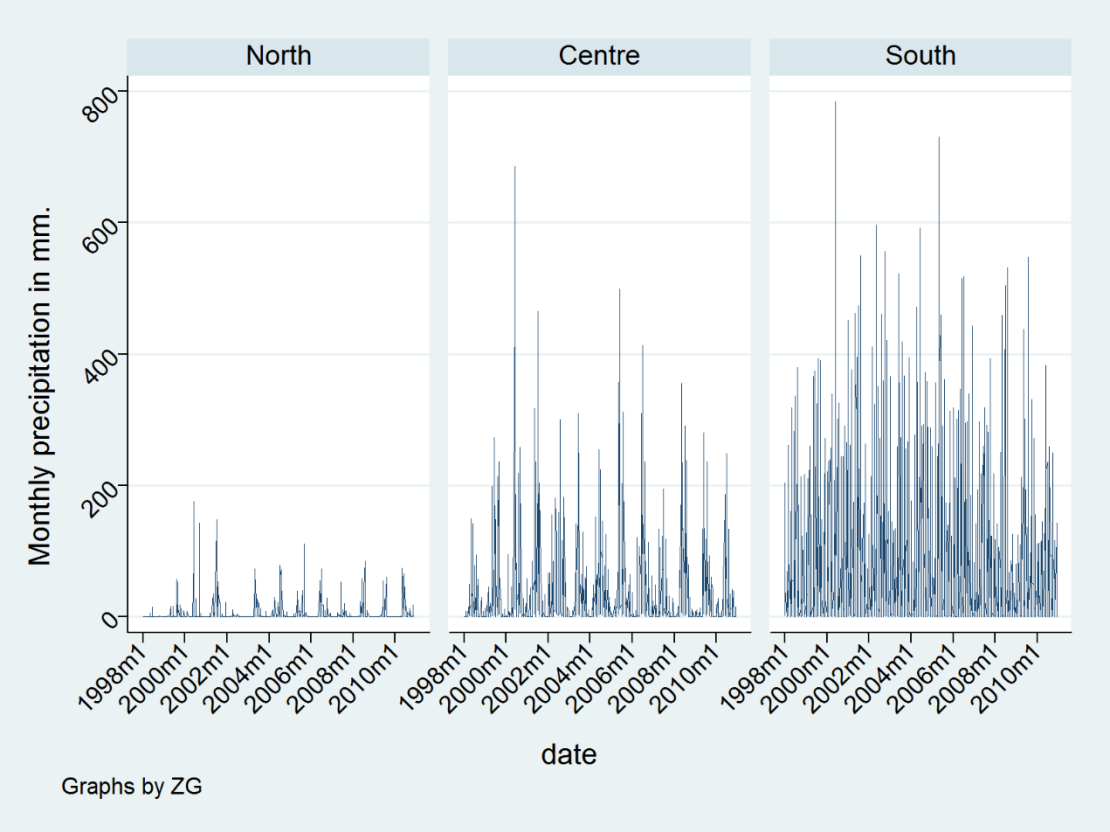
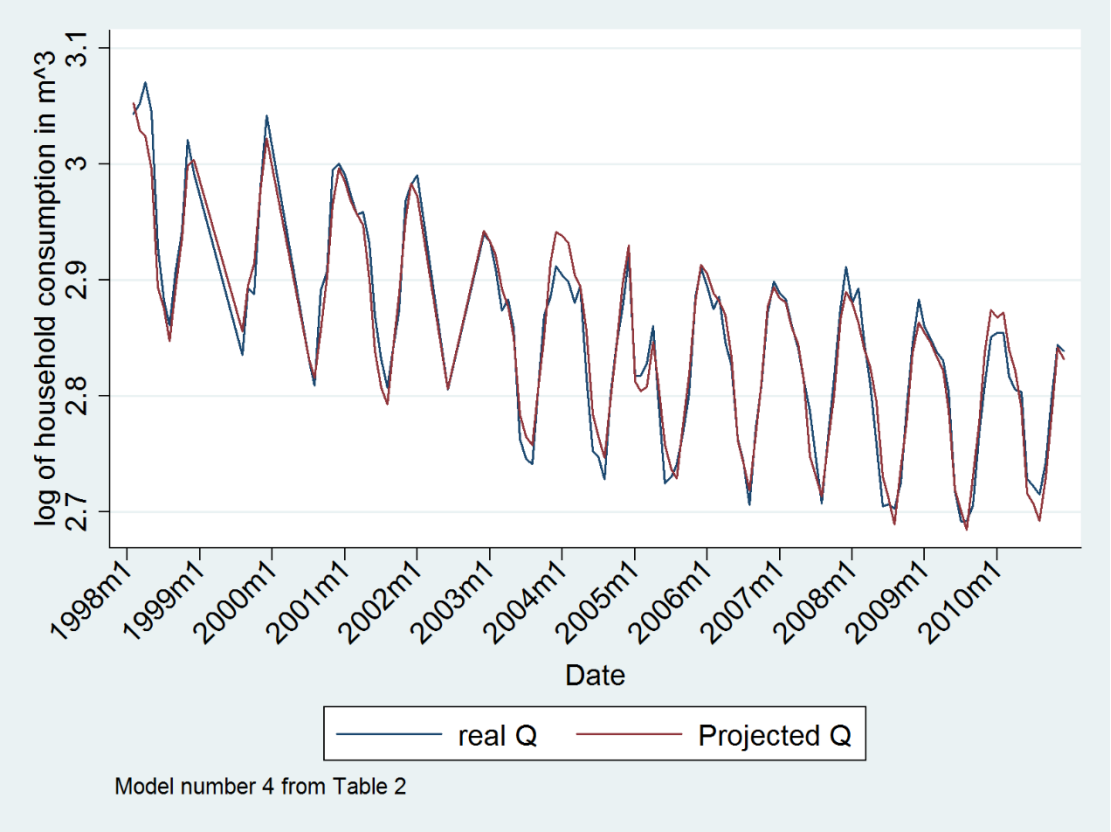


Figure 5. Monthly total precipitation by Chilean geographic zone.



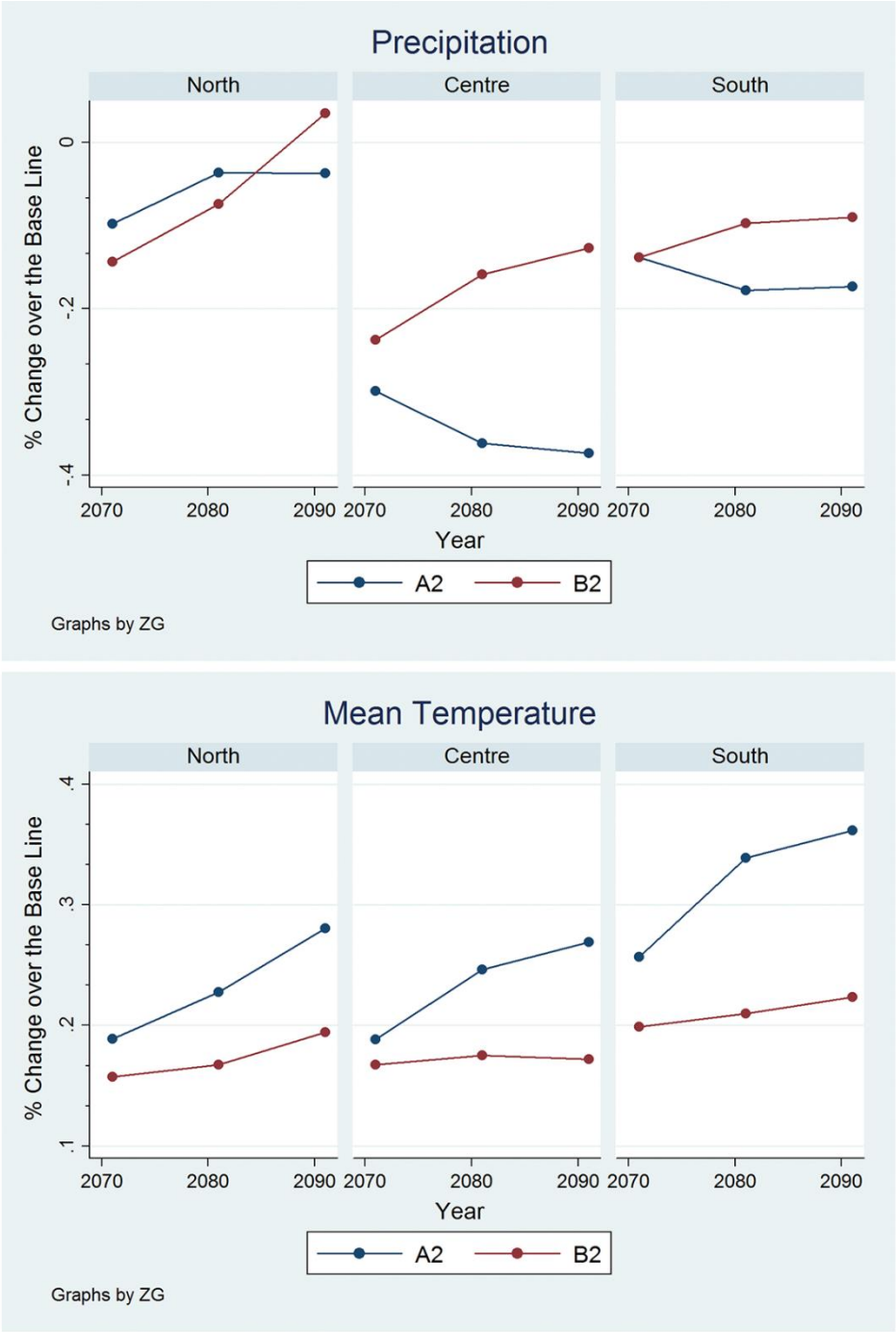
Source: Authors' calculations from meteorological data from Dirección Meteorologíca de Chile (DMC).

Figure 6. Observed and projected average consumption 1998-2010



Source: Authors' elaboration based on the results in Table 2, column 4.

Figure 7. Percent changes over baseline of projected average monthly precipitation and mean temperature for three future decades



Source: Authors' elaboration based on monthly averages of climate projections from Hadley Center PRECIS adapted for use in Chile by Dept. of Geophysics, U. Chile (CONAMA, 2007).

Figure 8. Projected impacts on average monthly per-household water use of projected climate change by decade and municipality: North to South

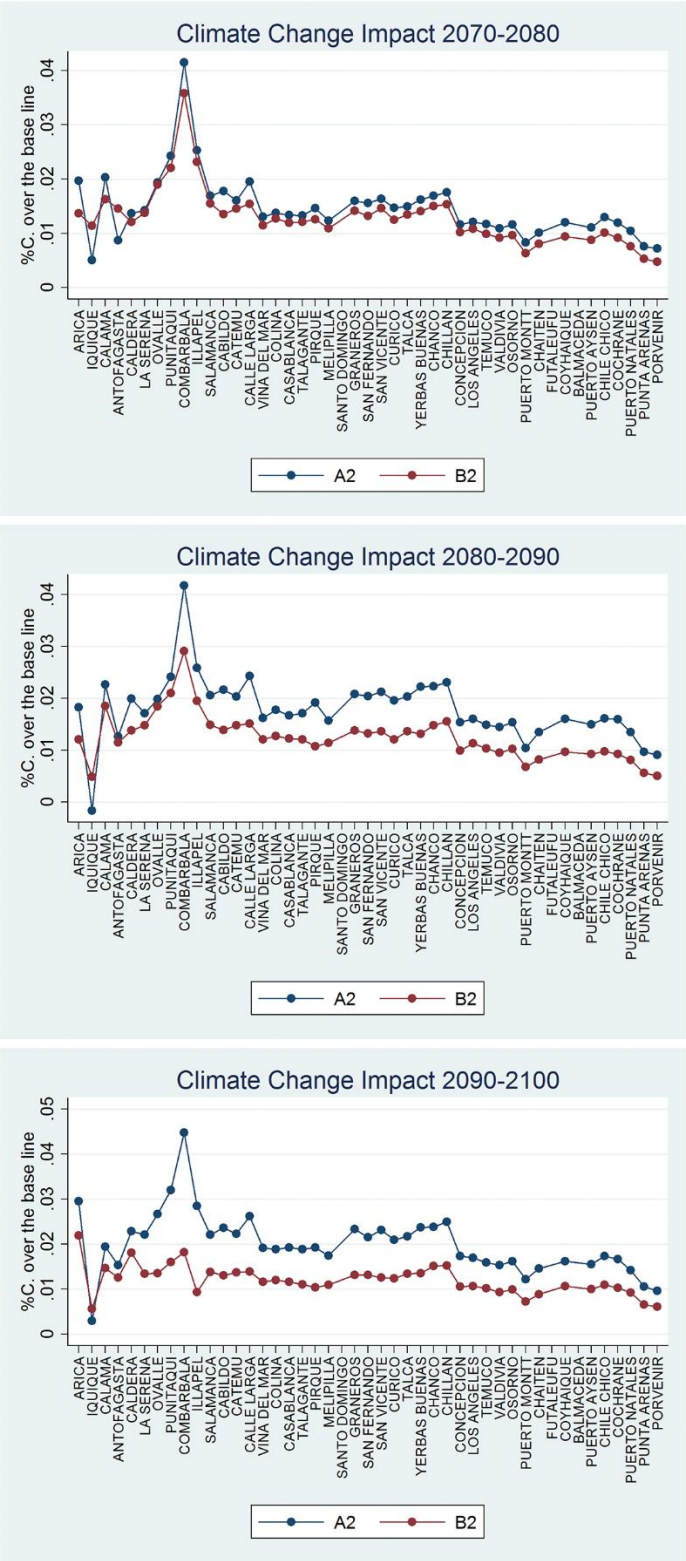


Table 1. Variables use in modeling residential water demand in Chile.

Variable Description	Source	Mean	Standard Deviation
Log monthly household water consumption (cubic meters)	SISS	2.84	0.31
Log variable rate of water and sewage (clp/cubic meters)	SISS	6.66	0.37
Log overconsumption rate of water and sewage in summer (clp/cubic meters)	SISS	7.147	0.424
Log average household income (clp)	CASEN	13.36	0.32
Log population per square kilometer	INE / SINIM	3.31	2.20
Seasonal mean of the average temperature (ºC)	DMC	12.96	4.37
Maximum temperature anomalies over the season average.	DMC	0.00	2.202
Seasonal mean of the precipitation national (millimeters per month)	DMC	44.306	61.632
Seasonal mean of the precipitation North (millimeters per month)	DMC	4.800	8.243
Seasonal mean of the precipitation Centre (millimeters per month)	DMC	38.055	39.598
Seasonal mean of the precipitation South (millimeters per month)	DMC	81.759	83.679
Employment rate (%)	CASEN	0.91	0.03
Urbanization rate (%)	CASEN	0.76	0.2
Poverty rate (%)	CASEN	0.136	0.061
Percentage persons under 15 years per household (%)	CASEN	0.2	0.04
Percentage persons older than 65 years per household (%)	CASEN	0.14	0.05
Average number of bedrooms per household	CASEN	2.6	0.19
Average number of persons per household	CASEN	3.647	0.352
Average number of bathrooms per Household	CASEN	0.98	0.19
Average school years in the municipality	CASEN	8.34	1.41
Average number of washing machines per household	CASEN	0.45	0.18
Interaction between Tmax anomalies and urbanization rate.	DMC / CASEN	0.001	1.716
Interaction between seasonal mean temperature and urbanization rate.	DMC / CASEN	10.29	4.36
Dummy for summer (1 from December to march, 0 from April to November)	-	-	-
Dummy for the use of overconsumption prices (1, if the municipality applies two block part tariff, 0 if not)	-	-	-
Categorical variable of geographic zone. 1-North, 2-Centre, 3-South	-	-	-

Notes/ Seasonal means of precipitation are from averages across years and municipalities in the zone of interest. Urbanization rate: Percentage of households in an urban zone per municipality. Urban zone is defined as the set of households concentrated with population of more than 2000 people, or between 1001 and 2000 people with at least 50% of economically active population working on secondary or tertiary activity. For more information about demographic and socio demographic variables review the web page of the CASEN survey.
http://observatorio.ministeriodesarrollosocial.gob.cl/casen/casen_obj.php

Table 2. Final models estimated (p-values in parentheses)

	Basic	With Climate variables	With HH and Municipal variables	With interaction	With interaction (No monthly dummies)
VARIABLES			Log HH water consumption		
Log Variable rate	-0.14	-0.17	-0.11	-0.11	-0.10
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Over-consumption*Dp*Dsc	-0.003	-0.004	-0.003	-0.004	-0.004
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Income	0.282	0.287	0.183	0.179	0.173
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log habitants per km2	0.039	0.025	0.011	0.012	0.009
	(0.000)	(0.003)	(0.193)	(0.164)	(0.297)
Max Temperature Anomalies		0.002	0.002	0.010	0.017
		(0.018)	(0.023)	(0.000)	(0.000)
Seasonal mean temp.		0.007	0.007	0.013	0.016
		(0.000)	(0.000)	(0.000)	(0.000)
Seasonal Precipitation		-0.005	-0.005	-0.004	-0.005
		(0.000)	(0.000)	(0.000)	(0.000)
Seasonal Precipitation * Centre		0.004	0.004	0.004	0.004
		(0.000)	(0.000)	(0.000)	(0.000)
Seasonal Precipitation * South		0.005	0.005	0.004	0.005
		(0.000)	(0.000)	(0.000)	(0.000)
Urbanization rate			0.467	0.555	0.540
			(0.000)	(0.000)	(0.000)
Poverty rate			0.241	0.240	0.253
			(0.005)	(0.005)	(0.003)
Household habitants			0.097	0.098	0.094
			(0.000)	(0.000)	(0.000)
Household bathrooms			0.111	0.106	0.112
			(0.021)	(0.025)	(0.019)
School years			0.013	0.013	0.012
			(0.031)	(0.026)	(0.046)
Household Washing machines			0.208	0.205	0.205
			(0.000)	(0.000)	(0.000)
Max Temperature Anomalies*Urbanization Rate				-0.011	-0.009
				(0.000)	(0.000)
Intra- seasonal mean temp.*Urbanization Rate				-0.009	-0.009
				(0.000)	(0.000)
Dummy summer (Dp)	0.035	0.016	0.018	0.023	0.018
	(0.000)	(0.050)	(0.026)	(0.005)	(0.004)
Dummy seaside municipality on February	0.050	0.037	0.037	0.038	0.039
	(0.000)	(0.002)	(0.002)	(0.002)	(0.002)
Monthly Dummies	yes	yes	yes	yes	No
Constant	-0.0551	-0.0265	0.00151	0.00204	0.00647
	(0.000)	(0.000)	(0.802)	(0.736)	(0.324)
Observations	5741	5164	5164	5164	5164
Municipalities	42	42	42	42	42
R^2 Adj.	75.3%	82.3%	84.7%	84.8%	83.7%
R^2 Within	75.5%	82.5%	84.9%	85.1%	83.9%
R^2 Between	39.6%	46.7%	23.7%	24.6%	22.9%
R^2 Overall	36.5%	43.2%	27.3%	28.4%	26.2%

Table 3. Percent change over the baseline by Geographic Zone.

Geographic zone	Scenario	2070	2080	2090
North	A2	1.92%	2.01%	2.44%
	B2	1.82%	1.64%	1.43%
Centre	A2	1.53%	1.97%	2.14%
	B2	1.34%	1.32%	1.27%
South	A2	1.06%	1.38%	1.47%
	B2	0.84%	0.87%	0.93%

Source: Authors' calculations based on estimated coefficients in Table 1 and PRECIS climate projections as discussed in text.