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RESEARCH ARTICLE

Economic development and residential water consumption in Chile

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Abstract
A better understanding of the relative importance of factors related to climate change and to changes associated with economic growth would serve to inform water policy and to focus scarce public resources on anticipated problems arising from distinct sources of changes in water demand. This article investigates the determinants of residential water consumption in Chile, a developing country that has seen noteworthy changes in incomes, household size, poverty rates and levels of urbanization, and which is projected to experience significant climatic but varied changes, depending on the region of the country. Panel data for 1998-2010 at the municipal level is used to analyze the sensitivity of residential water demand to climate and development-related factors. In the case of Chile, the effect on water consumption of these development-related changes is estimated to be several times that of the changes associated with climate projections for 50 to 80 years in the future.

Keywords: Chile; climate change; economic development; panel data; residential water consumption; water demand elasticities

1. Introduction

This paper presents evidence of the factors underlying recent trends in residential water use in Chile, emphasizing demographic factors, prices, income and climate-related variables. This study addresses the case of a rapidly developing country that has experienced significant development-related shifts in income levels, household size, rates of poverty and levels of urbanization. A better understanding of the determinants of residential water demand is important to anticipate the possible impacts of climate change, not only in Chile but more generally, because the degree of water scarcity is a potentially critical factor affecting economic development (e.g., Blignaut and van Heerden, 2009; Hertel and Liu, 2016; Zhou *et al.*, 2017).

Adequate drinking water availability can affect development via household members' health and income (Donoso and Melo, 2004). Certainly climate changes will

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influence water availability due to changes in precipitation and temperature, although the direction of such changes in availability will depend on specific regions, some enjoying increases in water supply and others suffering increased scarcity. Precipitation and temperature not only affect the supply of water, but are determinants of demand, especially that linked to residential outdoor use, as in, for example, garden irrigation to offset greater evaporation and lower precipitation during the summer. Areas that will be particularly affected negatively are currently Mediterranean climate zones, such as along the western coasts of the Americas. For example, Madulu (2003) reports that climatic change, population growth and economic development have caused an increase in water demand which was not met by increases in supply, a problem especially prominent in rural areas. The evidence-based management of residential water in urban areas has been emphasized as an important component to adaption to climate change (e.g., McDonald *et al.*, 2011).

In addition, more heated political conflicts are a potential outcome of increased water scarcity and/or the deterioration in water quality (Arbués *et al.*, 2003) which can be mitigated or avoided by efficient water demand management (OECD, 2010). Changes in residential water demand are likely to come both from population growth (Schewe *et al.*, 2014) and – especially important in growing economies – from altered patterns of household water use associated with higher incomes, such as an increase in the average number of toilets/bathrooms per household (e.g., see WaterAid (2015) for a revealing review of toilet facilities in the developing world). In practical terms of where the scarce resources of policy makers' time and attention should be focussed in developing countries, there is a question of the relative importance of impending, nearly-certain development-related changes to residential water demand in comparison to possible climate-change-induced changes under potential scenarios. Moreover, in developing countries with growing urban populations and an emphasis on improving urban water delivery, there will be a demand for a more sophisticated understanding of the demand side, which is different from management of watersheds of dispersed population oriented to agriculture (Mujumdar, 2013).

This present study addresses the case of residential water demand in Chile, which can serve as an instructive example due to recurrent water scarcity problems in much of the country, especially in the semi-arid centre where the bulk of the population and export-oriented agriculture is located. During the last four decades, Chile has experienced rapid development, reduced poverty, and changes in water demand associated with urbanization and higher incomes. While population growth rates have declined and the population is ageing, there are still a growing number of households as younger cohorts enter the workforce, become independent of parents and begin families. Although eventually expected to stabilize over the next two decades, the total population will nevertheless continue to increase, albeit slowly, from the present 17 million to slightly over 20 million by 2030 (as current mortality rates remain lower than birth rates and assuming no significant future immigration shocks).[1] This expansion of population and number of households with higher incomes, anticipated especially in the already-populated, semi-arid zones, will put more pressure on water resources in areas where water management will likely have the most difficulty in satisfying demand without radically altering prices to influence consumption patterns.

Future potential climate changes will affect Chile's water resources, particularly in basins dependent on snowmelt, which have been recognized as some of the most

[1]For recent Chilean demographic changes, population growth rates and other indicators, and for population projections for the next 30 years, see http://datatopics.worldbank.org/health/population.

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vulnerable regions in the world (Barnett *et al.*, 2005; Vicuña *et al.*, 2011; Ahumada *et al.*, 2013). These basins will be affected both by increased temperature and by changes in precipitation patterns; the latter will make its impacts felt via changes to snowmelt-fed river flow and aquifer replenishment (Melo *et al.*, 2010). Both reservoirs and aquifers serve as important sources of urban water in Chile. While rainfall patterns have not changed dramatically, water availability does vary considerably by region and climate projections of future scenarios raise the possibility of altered water use as the semi-arid zones of the country shift southward. Due to the economic changes associated with development, the analysis presented here will focus on the impacts on water demand related to urbanization rates, income levels and longer-term weather patterns. As with other developing 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 the 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.

There are four basic data considerations in 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 demographics 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 13 years of data of monthly residential water consumption for 42 municipalities. These municipalities are distributed throughout Chile and are used because they have weather stations that provide appropriate temperature and precipitation data. 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. As an application of the estimated model, the estimated climate effects are used to project the possible influence on water demand of future climate change, making use of the Hadley Centre's PRECIS climate projections for 2070 to 2100.

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In section 2 of this paper, residential water demand models are briefly reviewed, noting the use of block pricing and the role of socioeconomic variables, temperature and precipitation; we then turn to the Chilean case. Section 3 presents a brief discussion of the data sources, model specification and error structure. Section 4 shows the regression results and an application of the model for projecting changes in per-household water use in the far future resulting from two scenarios of projected climate. Finally, section 5 offers some discussion and conclusions.

2. The basic model of residential water demand and the Chilean context

Water demand studies using household level data are available for the United States and Europe, most focusing on the estimation of price and income elasticities, often under block pricing (e.g., Lopez-Mayan, 2014; Romano *et al.*, 2016; Marzano *et al.*, 2018). In developing countries, the literature is scarcer and typically uses cross-section data (e.g., Jiménez *et al.*, 2017; Ojeda de la Cruz *et al.*, 2017) – 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 with a regulatory motivation, where costs of delivery are the focus (Valenzuela and Jouravlev, 2007; Ferro *et al.*, 2011).

The usual specification of residential water demand at the household level begins as a simple function of the good's price and other factors, such as household income, location, rural or urban dwelling, level of education, number of adults and children and other variables (see, for example, Arbués *et al.*, 2003). Block pricing of water by utility companies introduces some econometric complications in estimation.[2] Following Olmstead *et al.* (2007), residential water pricing takes three forms in practice: uniform marginal pricing, an increasing block structure, or a decreasing block structure. Usually consumers also pay fixed base rates as well. With incremental block tariffs, total consumption determines the marginal price of the last unit consumed, resulting in a marginal cost function rising with quantity in a stair-step fashion. 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 households (see the discussion in Arbués *et al.*, 2003). Aggregate data, which are the type used in this Chilean study, mix consumers responding to prices in various

[2]One issue to address is the response of quantities demanded to price and income changes, because income effects can become confounded with marginal 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). 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. Another econometric issue in models at the individual household level, which is not the case in the present study, is that block pricing introduces endogeneity of the marginal price faced by the household, even if the pricing schedule is fixed.

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blocks and so average consumption often remains in a range responding to the price of a single block.

While Chile has crossed the World Bank's per-capita GDP threshold to become a high-income economy,[3] it is still considered a developing country, with a per-capita GNI approximately a quarter of that of the United States; and residential water demand will likely continue to converge to developed-country patterns with economic growth. For example, the sample average number of indoor flush toilets is slightly less than one per household (see table 1) but will almost certainly increase in the future. Compared to the United States and Europe there is a relatively weak informational base on which to estimate and project Chilean residential water demand, especially using historical data. Although to date, taken as a whole, Chile is considered to have a high per capita water availability on average (53,953 m^3/hab/yr according to Valdés-Pineda *et al.* (2014), presented in World Bank (2011)), there are large differences in practical water availability in specific regions. In the arid north (Antofagasta), water availability is only 52 m^3/hab/yr, and there are ongoing investments in desalinization; in the rainy south (Aysén), inhabitants enjoy water availability close to 3 million m^3/hab/yr. In the Mediterranean climate of the populated and agriculturally-rich central valley, on average the availability is 13,222 m^3/hab/yr, but is highly variable from year to year.

Although individual household consumption is unavailable, a panel of 42 municipalities with 13 years of monthly consumption levels, prices and weather variables was assembled for this study. Each water utility has its own rate structure. The basic rate structure of 'real' water prices is set by a process defined by law and re-structured every five years; real prices are maintained by adjusting nominal prices monthly to price indices, including the consumer price index.[4] When block pricing is present in a municipality, 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. Although block-pricing structures are in place in some municipalities, and they are ostensibly intended to discourage consumption during the drier summer months, in reality the proportion of all households that surpass the consumption limit is small and concentrated in a few municipalities of our sample in one high-income geographic area.[5]

[3]Chile's gross national income (GNI) per capita in 2017 was US$13,610 (as a reference, the GNI per capita of the United States was US$58,270). Per-capita GNI data for international comparisons can be found at http://data.worldbank.org/indicator/NY.GNP.PCAP.CD.

[4]The month-by-month adjustment formulas are given by law as presented by the Economics Ministry. The tariff formulas decrees can be seen on 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 the region.

[5]During peak periods, the correlation between the two block prices (the variable and the overconsumption rate) reach 99 per cent, 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. As noted, although there are second-block prices that might discourage consumption during the drier summer months, the proportion of all households influenced by such prices is limited. The largest water company in Chile (*Aguas Andinas*) charges prices in the second block to less than 10 per cent of its clients, all located in a few, geographically-contiguous, high-income neighbourhoods in northeast Santiago. A small company (*Aguas Chañar*) charges in the second block to less than 3 per cent of its clients in the arid north. In any case, the nature of the data does not allow us to distinguish the effects of the two block prices on the marginal litre

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

Variable Description	Source	Mean	σ
Log monthly household water consumption (m^3)	SISS	2.84	0.31
Log variable rate of water and sewage (clp/m^3)	SISS	6.66	0.37
Log overconsumption rate of water and sewage	SISS	7.147	0.424
in summer (clp/m^3)	SISS	7.147	0.424
Log average household income (clp)	CASEN	13.36	0.32
Log population per square kilometre	INE/SINIM	3.31	2.2
Seasonal mean of the average temperature (C)	DMC	12.96	4.37
Maximum temperature anomalies over the season average.	DMC	0	2.202
Seasonal mean of the precipitation national (mm/month)	DMC	44.306	61.632
Seasonal mean of the precipitation North (mm/month)	DMC	4.8	8.243
Seasonal mean of the precipitation Centre (mm/month)	DMC	38.055	39.598
Seasonal mean of the precipitation South (mm/month)	DMC	81.759	83.679
Employment rate (%)	CASEN	0.91	0.03
Degree of urbanization (%)	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 T_{max} 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)	–	–	–

(*continued*)

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Table 1. Continued

Variable Description	Source	Mean	σ
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.

Although most studies of water demand are focused on the influence of prices and socio-demographic variables on consumption, there are studies that include weather-related variables such as temperature and precipitation as well as socioeconomic household characteristics (e.g., Nieswiadomy and Molina, 1989; Martinez-Espiñeira, 2002; Neale, 2005; Olmstead *et al.*, 2007). These studies find strong correlations between water demand and temperature. There are some studies that show that residential consumption, especially outdoor use (gardens, swimming pool, lawn care, etc.) is dependent on climatic variables (Cohen, 1985; Akuoko-Asibey *et al.*, 1993; Dandy *et al.*, 1997). Worthington and Hoffman (2008), in a survey of residential water demand modelling, conclude that there is no strong empirical evidence of scale economies with respect to household size. In addition, higher proportions of older and younger populations may cause an increase in water demand (Nauges and Thomas, 2000; Martinez-Espiñeira, 2003). With respect to the Chilean case, the country has a diverse range of climates, from the warm, arid north, to the temperate, dry-season centre, to the cooler, rainy south, resulting in a notable cross-sectional variation in the data. Interestingly, in our sample, less-urbanized municipalities have higher volatility in consumption than their more-urbanized counterparts. This is illustrated in figure 1 for two geographically-close municipalities in the same climate zone: Yerbas Buenas and Talca. The level of urbanization is correlated with greater regularity in the yearly cycle of water consumption, owing in part to a smaller fraction of drinking water consumption going to outdoors uses (gardens, irrigation, etc.), and making them less sensitive to climate variations.

3. Data sources and the regression model

In this study we make use of a monthly panel from 1998 to 2010 of 42 municipalities scattered along the vertical axis that is Chile (figure 2). The panel is unbalanced due to the 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 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

of water consumed. Both prices are introduced as separate variables in municipal per-household demand, when appropriate, because not all municipalities use such a tariff structure.

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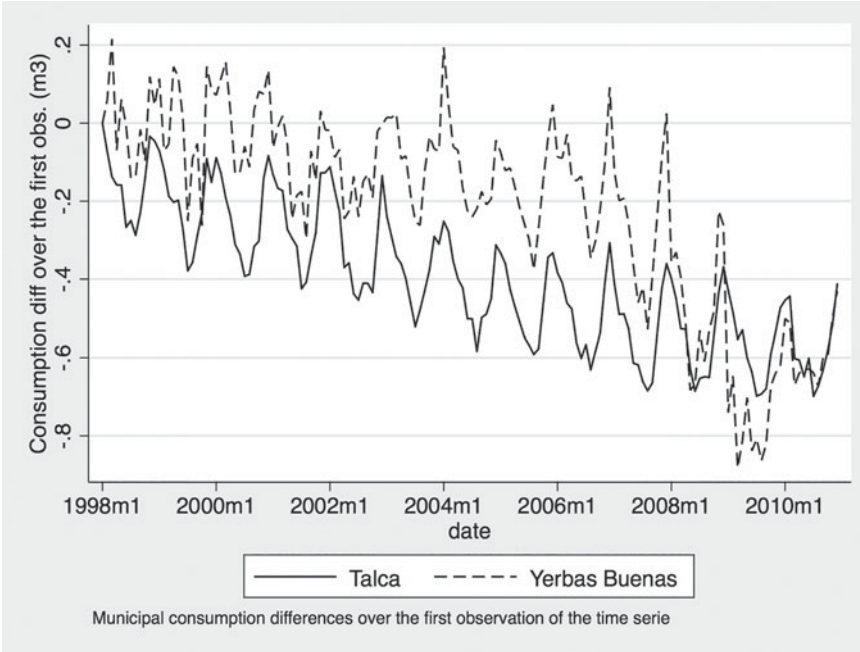


Figure 1. Consumption volatility of two municipalities, geographically close but very different in their urbanization indices.
Source: Authors calculations from data from SISS.

and so on (see table 1 for summary statistics of variables in our sample included in the modelling effort). The CASEN survey is completed every two or three years, and so five surveys are available for the 1998–2010 period. INE produces annual information on demographic characteristics at the municipal level. Simple linear 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; these data were aggregated to produce synthetic monthly observations. In interpreting the results below with respect to monthly average residential water use per household, the reader should keep in mind the possible additional error that might be generated by the interpolation of household characteristics.

The basic model of per-household water consumption (Q) to be estimated is in log-log form with idiosyncratic effects and a purely random shock:

$$Q_{it} = \beta x_{it} + \nu_i + \varepsilon_{it}, \tag{1}$$

where ν_i is the idiosyncratic effect for municipality i, and ε_{it} is the error that represents unexplained variations at each municipality i and month, t. After some appropriate tests, this error is modelled as a first-order autoregressive process.[6] Table 1 presents the

[6]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

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Figure 2. Chilean municipalities in the study sample.

explanatory variables in the estimated model, which has the following form:

$$lnQ_{it} = \alpha + \beta_1 lnT^{v}_{it} + \beta_2 lnT^{sc}_{it} * d^{p}_{it} * d^{sc}_{it} + \gamma' Cl_{it} + \delta' Z_{it} + \theta' D_{it} + \nu_i + \varepsilon_{it}, \quad (2)$$

where T^{v}_{it} represents the first-block variable tariff and T^{sc}_{it} the second-block overconsumption tariff, which is only appropriate during the summer months ($d^{p}_{it} = 1, 0$ otherwise) and for the municipalities that make use of block pricing ($d^{sc}_{it} = 1, 0$ otherwise). The vector of climate and weather variables is represented by Cl_{it}. Household and municipal characteristics (Z_{it}) 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 within each municipality), and population per square kilometre. Dummies (D_{it}) for each month, the summer season and a municipality's seaside location are introduced to control for aspects of demand not captured by the other controls. The municipality idiosyncratic effects (ν_i) account for all excluded municipality characteristics relevant to water demand. After comparing and testing random- and fixed-effects, we opt for fixed effects.[7]

the modified Durbin-Watson and Baltagui and Wu (1999) statistics always show values less than one. In response to reviewers' comments, we also estimated a series of dynamic panel models, but the results were frequently unsatisfactory with respect to what our priors would strongly predict (e.g., positive coefficients on prices), and sensitive to changes in the model specification and to changes in the number of past periods used as instruments. One reason for these results could be that, although the data are monthly, there is a cycle of water demand during the year (which we account for by seasonal weather variables, summer dummies, monthly dummies, etc.), and there are only approximately 12 years (cycles) per municipality in the data set. Because the inertia in water demand appears to be adequately accounted for by the AR(1) specification in the fixed effects model, and due to the largely disappointing results of the dynamic approach, we have opted for the latter, simpler model. We thank the anonymous reviewers for the suggestions regarding alternative model specifications.

[7]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.

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Based on the raw daily data of temperature and precipitation, this study differentiates 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 anomaly around the seasonal (climate) averages. This separation of effects also 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 climate variable for season s of the observed month (four seasons per year) and municipality i, (m = temperature or precipitation). The short-term anomaly of both climate measures is calculated as:

$$M_{it} = m_{it} - \bar{m}_{it}, \tag{3}$$

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

To be clear, the two long-run measures of each municipality's climate (mean temperature and precipitation) vary by season. That is, for any observation of, for example, mean temperature, there are four different values possible for each municipality, but these values will repeat year to year. The reader should note that these are not seasonal dummies. The seasonal temperature mean has an estimated coefficient associated with it which is the same regardless of whether the season is, for example, summer or winter.[8] Precipitation is measured straightforwardly as millimetres per month, and the average is calculated using all 13 years for each of the three-month seasons.[9] For the temperature seasonal aggregate, each municipality's average daily mean temperature across all years of the data is used. For the short-term weather variable, this study makes use of the monthly average daily maximum temperature anomalies. This variable of monthly average daily maximum temperatures 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. The season average climate and short-term weather anomalies variables (for both temperature and precipitation) enter the above regression equation in the following way: $\gamma' Cl_{it} = \gamma_{\bar{m}} \bar{m}_{is} + \gamma_M M_{it}$. Note that in the panel-data analysis, the introduction of municipality-specific effects does not eliminate the season-dependent climate variables. 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, demographic, etc.) were robust to the use of these alternatives.[10]

[8] A possible alternative specification might be that each of the four seasonal averages (of temperature or precipitation) for each municipality enter the regression as separate variables, each with a unique coefficient that was invariant across municipalities. But these effects would disappear with the introduction of a municipality-specific effect. We choose to model the within-year normal pattern of climate variables at the municipal level in a way that allows municipal dummies to capture the effects on water consumption of other, excluded municipal-level idiosyncratic variables.

[9] For a given municipality, for each season (winter, summer, spring and autumn), a monthly average precipitation was calculated using all 13 years.

[10] These results are not presented due to space limitations, but are available from the authors upon request.

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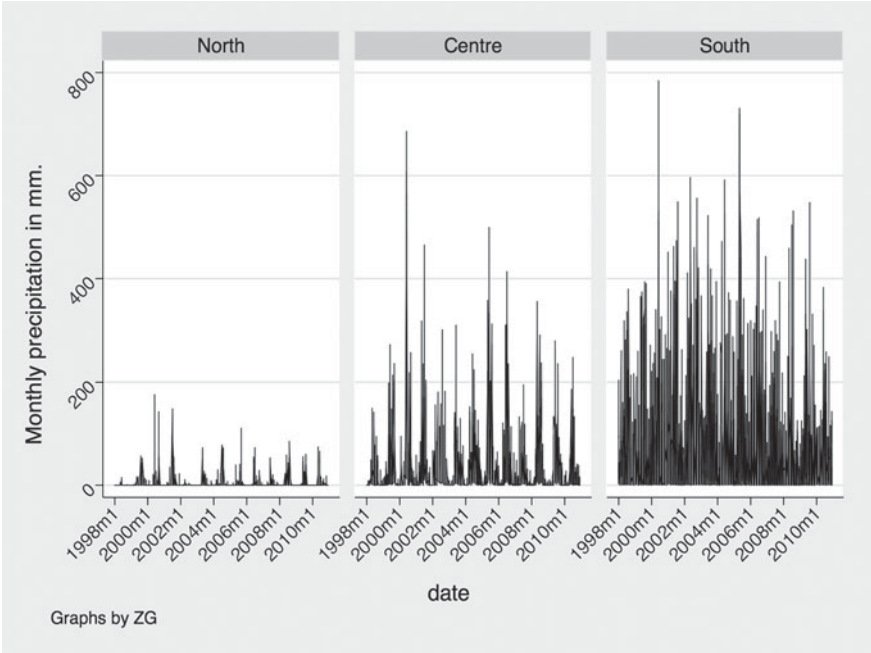


Figure 3. Monthly total precipitation by Chilean geographic zone.
Source: Authors' calculations from meteorological data from Dirección Meteorológica de Chile (DMC).

In addition, to account for possible non-linearity of effects of the climate and weather variables, we also test for the inclusion of quadratic terms (including a temperature-precipitation interaction). Non-linear effects would be of particular interest for projecting the possible influence on residential water demand of future climate change. As climate begins to move from its accustomed pattern, towards, say, higher average temperatures and less precipitation, households would alter their water use within the constraint given by former technologies and habits adapted to prior conditions. But, as expected temperatures and precipitation deviate farther from the former pattern, households would invest in what would become more appropriate technologies and develop new routines and habits of water consumption. For example, in the case of the central semi-arid zone of Chile, there would likely be households which would move from what is now the frequently observed handheld-hose watering of grass lawns toward drip-irrigation of arid-garden plants, a change which would tend to stabilize and insulate water demand from further temperature and precipitation changes. In short, the marginal effects of mean temperature increases and mean precipitation decreases could decline as climate change progresses.

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 3. Precipitation patterns were incorporated into the model as an interaction between the seasonal average monthly precipitation and a dummy variable indicating the geographic area (Centre and South). Also, an interaction between temperature variables and urbanization rate was

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incorporated to test if consumption in more-urbanized municipalities is less sensitive to changes in temperature.

4. Estimation results

Table 2 shows the results of the fixed-effect estimation of three models and of a pooled model (without municipality and time effects) for comparison.[11] The basic models (columns 1 and 2) contain the price, income and demographic variables, the climate and weather variables in linear form, and the monthly, year and seasonal dummies. Column 2 differs from column 1 only in that the weather variables are included (the anomalies around the long-run seasonal averages).[12] Note that the estimated coefficients associated with the economic variables (prices and income) are robust in sign and order of magnitude with respect to the inclusion of additional variables in columns 2 and 3, although the absolute value of the over-consumption price increases somewhat when the quadratic terms of the climate and weather variables are included in the model of column 3. The results indicate an income elasticity of approximately 0.18 and a price elasticity of approximately −0.08. The values of these elasticity estimates are quite consistent with the evidence from the literature (Martinez-Espiñeira, 2002; Arbués *et al.*, 2003; Martinez-Espiñeira and Nauges, 2004; Arbués and Villanúa, 2006). Nevertheless, it is worth noting that, in comparing these results to other estimated models not shown here, the introduction of the year fixed effects reduces the absolute value of the price elasticity, suggesting trends in water consumption not accounted for by the inclusion of socio-economic variables which have shown significant trends in the case of Chile during the period of study (income, density of inhabitants, and washing machines and bathrooms per household). Likely there are other factors contributing to a trend in reduced water use, perhaps associated with increased country-wide efficiency as real water prices have drifted upward. The coefficient on the 'overconsumption' – the second block – price is statistically significant but, practically speaking, very small, close to −0.004, in all models with municipal and time dummies. As noted previously, the overconsumption price is paid by only a small fraction of users, and so a small effect on average residential household water use is unsurprising. Nevertheless, the results do imply that there could be policy-induced reductions, although small, in water demand via either raising the overconsumption price or reducing the trigger level of consumption or a combination of both measures.

We note that the introduction of the climate and weather-related variables in a linear manner (columns 1 and 2) captures the seasonality of demand. The coefficient associated with long-term temperature – the seasonal mean temperature – is approximately 0.013 in this simple linear model (and we note, although not reported here, that the coefficient remains at that value regardless of the inclusion of municipal, socio-economic variables). This value implies slightly more than a one per cent increase in per-household water consumption for a 1° Celsius increase in the (long-term) seasonal average temperature. The coefficient associated with the monthly temperature variations around the seasonal

[11] 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.

[12] The introduction of the climate-related variables notably increases the goodness of fit of the estimated model in comparison to simpler specifications with only prices, income, demographic variables and other non-climate related controls.

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Table 2. Estimation results

	(1) Basic model with linear climate effects (weather excluded)	(2) Linear climate effects with weather anomalies around the climate averages (used in projections)	(3) Climate Polynomial includes temperature	(4) Pooled model (OLS) of model 3
Log Variable Price	$-8.396 \times 10^{-2***}$ [0.000]	$-8.783 \times 10^{-2***}$ [0.000]	$-8.270 \times 10^{-02***}$ [0.000]	$-3.492 \times 10^{-1***}$ [0.000]
Log Over-consumption Price*Dp*Dsc	$-3.450 \times 10^{-3***}$ [0.000]	$-3.714 \times 10^{-3***}$ [0.000]	$-4.749 \times 10^{-3***}$ [0.000]	$-1.649 \times 10^{-2***}$ [0.000]
Log Income	$1.749 \times 10^{-1***}$ [0.000]	$1.804 \times 10^{-1***}$ [0.000]	$1.834 \times 10^{-1***}$ [0.000]	$4.782 \times 10^{-1***}$ [0.000]
Log Inhabitants per Km2	1.30×10^{-2} [0.127]	7.98×10^{-3} [0.356]	$1.623 \times 10^{-2*}$ [0.065]	$-7.910 \times 10^{-3***}$ [0.005]
Seasonal Mean Temperature	$8.077 \times 10^{-3***}$ [0.000]	$1.256 \times 10^{-2***}$ [0.000]	3.83×10^{-3} [0.289]	$-2.693 \times 10^{-2***}$ [0.000]
Seasonal Mean Precipitation	$-4.285 \times 10^{-3***}$ [0.000]	$-4.273 \times 10^{-3***}$ [0.000]	$-5.833 \times 10^{-3*}$ [0.098]	$-6.039 \times 10^{-2***}$ [0.000]
Seasonal Precipitation * Centre	$3.920 \times 10^{-3***}$ [0.000]	$3.921 \times 10^{-3***}$ [0.000]	3.71×10^{-3} [0.290]	$5.181 \times 10^{-2***}$ [0.000]
Seasonal Precipitation* South	$4.241 \times 10^{-3***}$ [0.000]	$4.244 \times 10^{-3***}$ [0.000]	5.19×10^{-3} [0.139]	$5.775 \times 10^{-2***}$ [0.000]
Urbanization Rate	$4.754 \times 10^{-1***}$ [0.000]	$4.221 \times 10^{-1***}$ [0.000]	$4.026 \times 10^{-1***}$ [0.000]	$-5.092 \times 10^{-1***}$ [0.000]
Poverty Rate	$2.698 \times 10^{-1***}$ [0.004]	$2.369 \times 10^{-1**}$ [0.013]	$2.331 \times 10^{-1**}$ [0.014]	$2.880 \times 10^{-1***}$ [0.000]
Household Inhabitants	$9.074 \times 10^{-2***}$ [0.000]	$9.964 \times 10^{-2***}$ [0.000]	$1.036 \times 10^{-1***}$ [0.000]	$2.112 \times 10^{-1***}$ [0.000]

(*continued*)

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Table 2. Continued

	(1) Basic model with linear climate effects (weather excluded)	(2) Linear climate effects with weather anomalies around the climate averages (used in projections)	(3) Climate Polynomial includes temperature	(4) Pooled model (OLS) of model 3
Households Bathrooms	$1.163 \times 10^{-1**}$ [0.018]	$1.239 \times 10^{-1**}$ [0.015]	$1.253 \times 10^{-1**}$ [0.013]	$2.760 \times 10^{-1***}$ [0.000]
School Years	$1.496 \times 10^{-2**}$ [0.013]	$1.274 \times 10^{-2**}$ [0.037]	$1.201 \times 10^{-2**}$ [0.048]	$3.610 \times 10^{-2***}$ [0.000]
Household Washing Machines	$1.435 \times 10^{-1**}$ [0.023]	$1.450 \times 10^{-1**}$ [0.029]	$1.601 \times 10^{-1**}$ [0.015]	$-2.766 \times 10^{-1***}$ [0.000]
Seasonal mean temp*Urban Rate	$-3.894 \times 10^{-3*}$ [0.056]	$-8.963 \times 10^{-3***}$ [0.000]	$-8.381 \times 10^{-3***}$ [0.001]	$-9.890 \times 10^{-3**}$ [0.011]
Dummy Summer (Dp)	$2.813 \times 10^{-2***}$ [0.001]	$2.796 \times 10^{-2***}$ [0.001]	$4.256 \times 10^{-2***}$ [0.000]	$1.455 \times 10^{-1***}$ [0.000]
Dummy Seaside in Feb.	$3.699 \times 10^{-2***}$ [0.002]	$3.996 \times 10^{-2***}$ [0.002]	$3.970 \times 10^{-2***}$ [0.002]	-4.40×10^{-3} [0.919]
Max Temperature anomalies		$1.096 \times 10^{-2***}$ [0.000]	$1.119 \times 10^{-2***}$ [0.000]	$1.220 \times 10^{-2**}$ [0.014]
Precipitation anomalies		$4.038 \times 10^{-5**}$ [0.018]	$6.154 \times 10^{-5***}$ [0.004]	7.13×10^{-7} [0.992]
Max Temp anomalies*Urban Rate		$-1.236 \times 10^{-2***}$ [0.000]	$-1.250 \times 10^{-2***}$ [0.000]	-4.43×10^{-3} [0.482]
Max Temp anomalies squared			5.15×10^{-5} [0.709]	$-6.737 \times 10^{-4*}$ [0.083]
Precipitation anomalies squared			-1.56×10^{-7} [0.124]	2.30×10^{-7} [0.452]
Seasonal Mean Temp squared			1.14×10^{-4} [0.260]	$1.092 \times 10^{-3***}$ [0.000]
Seasonal Precipitation squared			-1.45×10^{-5} [0.761]	$4.132 \times 10^{-4***}$ [0.000]

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Seasonal Precip squared * Centre			2.13×10^{-5} [0.656]	$-3.938 \times 10^{-4***}$ [0.000]
Seasonal Precip squared * South			1.67×10^{-5} [0.727]	$-4.081 \times 10^{-4***}$ [0.000]
Seasonal Mean Temp*Precipitation			1.43×10^{-4} [0.586]	$3.262 \times 10^{-3***}$ [0.000]
Seasonal Temp*Precip*Centre			-4.88×10^{-5} [0.850]	$-2.685 \times 10^{-3***}$ [0.000]
Seasonal Temp* Precip*South			-1.43×10^{-4} [0.584]	$-3.143 \times 10^{-3***}$ [0.000]
Constant	6.69×10^{-3} [0.317]	-8.05×10^{-3} [0.218]	-8.48×10^{-3} [0.198]	$-1.798 \times 10^{***}$ [0.000]
Observations	5,164	4,908	4,908	4,950
Number of municipality	42	42	42	
Municipality FE	YES	YES	YES	NO
Month FE	YES	YES	YES	NO
Year FE	YES	YES	YES	NO
F-test inclusion of fixed effects	86.79	84.88	83.32	
F-statistic	738	732.2	608.9	252.5
Stan dev of random error	0.0687	0.0691	0.0689	
Idiosyncratic error fraction of variance	0.933	0.928	0.928	
Panel-level standard deviation	0.257	0.249	0.247	
ρ:AR(1) autocorrelation coefficient	0.687	0.683	0.682	
R^2				0.598
R^2 adjusted	0.848	0.862	0.863	0.596
R^2 within	0.85	0.864	0.866	

t statistics in parentheses, and * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

average – maximum temperature anomalies – is approximately of the same order magnitude (0.011), which would imply that water demand reacts to short-term temperature increases in a similar manner as it does to longer-term temperature increases associated with climate changes.

The variation in average seasonal precipitation has a statistically significant impact in the north, but the practical effects of average precipitation changes appear very small in the centre and the south. In the north, an increase in one millimetre of precipitation leads to slightly less than a one-half 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 millimetre. There are, however, a few municipalities abutting the Andes where the change in precipitation from one season to another is large; in the municipality of Ovalle for example (see the first panel of figure 2), mean summer precipitation is less than one-half millimetre and the mean in winter is 16 millimetres, which would translate into an approximately 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 centre and southern zones – effectively zero.

A more realistic specification, which would account for possible non-linear effects of the climate and weather variables (and possible interaction effects between temperature and precipitation), is given in column 3 in table 2. The reader will note that the estimated coefficients on the quadratic and interaction terms appear not to be statistically significantly different from zero using standard t-tests. Nonetheless, F-tests for the inclusion of the quadratic and interaction terms indicate rejection of the hypotheses that they added no additional information despite the large individual p-values. Although in some specifications without year effects (not shown here), results indicate that these quadratic terms have relatively small effects on goodness-of-fit measures, the more complete specification with non-linear terms leads to noteworthy differences in the projection results, as shown below.

With respect to household and municipal characteristics, the estimated coefficients are significant at the 5 per cent 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 per cent increase in water consumption. A similar magnitude in the effect of an additional bathroom is found, though only significant at a 5 per cent significance level. At the margin, a decrease in the level of poverty would have a negative impact on water use (a decline of poverty of 5 percentage points would reduce water consumption by slightly more than 1 per cent). But note that 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. It should also be noted that the existence of a means-tested subsidy to poor households that reduced the tariff up to a certain limit (Gómez-Lobo and Contreras, 2003) may be inducing higher consumption.

Of particular note is the coefficient on the municipality urbanization level, which is positive and statistically significant, and notably large in a practical sense. The models presented here include interactions between the urbanization level and the two

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temperature variables. Using these estimates, one finds that an increase in urbanization from a rural municipality of 10 per cent urban households to an urban municipality of 90 per cent would lead to an expected increase in average consumption per household of approximately 24 per cent. The conclusion is that Chile's trend toward greater urbanization is driving higher water consumption – but, again, *ceteris paribus*: in real-world 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 max temperature anomalies and urbanization) are negative and on the order of about one per cent per 1°Celsius, in models of column 2 and 3. 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. What might be driving these results? The definition of urban versus rural in Chile (as applied by the official household surveys) is based on the number of people living in settlements (towns), with some adjustment for the degree of the working population engaged in agriculture. An urban designation is correlated with population density and, given the low population limit for switching between zones, a rural designation is highly correlated with proximity to agricultural activities. We are accounting for various other household attributes that might be correlated with urban residency, such as income levels, washing machines, number of bathrooms, etc. But we do not have data on potential non-potable water use in rural areas. Chilean rural zones are served by various canals and aquifer wells, due to the extensive infrastructure necessary for agriculture to capture water fed by snowmelt runoff. Lawns that would otherwise be irrigated by metered, potable water from a piped network in urban zones would be more likely irrigated by non-potable water from canals or pumps in rural areas. Although more speculative, there could also be more household utility gained by lawn upkeep in urban settings as compared to rural settings, which potentially could also be a source of this urbanization effect on water demand.

Finally, using the estimates from the models in column 3 of table 2, figure 4 presents observed and projected average monthly, per-household water consumption, averaged across the entire panel of municipalities for the period 1998–2010. We should note that the overall goodness of fit of the models in columns 1, 2 and 3 of table 2 in comparison with the pooled model in column 4 is enhanced by the introduction of monthly dummies, which not only affect the estimated coefficients on the variables of interest, but also 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 models without and with non-linear effects of climate (columns 2 and 3) serve as the basis for projecting household water consumption under future climate scenarios, an application that is presented in the next section.

4.1 Application to the possible impacts of climate change on Chilean residential water use

As an application of the estimation results, an evaluation of the possible impacts of climate change on Chilean residential water use is presented (Neale (2005) is an example of the projection of the water demand under different climate-change scenarios). The projections are constructed on monthly averages based on the climate projections from

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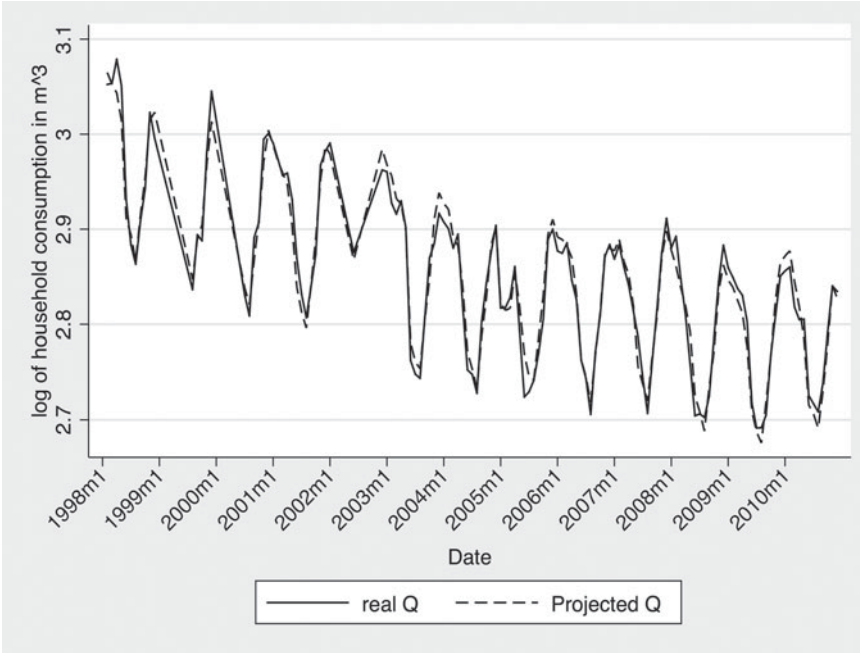


Figure 4. Observed and projected average consumption 1998–2010.
Source: Authors' elaboration based on the results in table 2, column 3.

the Providing Regional Climates for Impact Studies (PRECIS) model developed by the Hadley Centre of the United Kingdom Meteorological Office and adapted for use in Chile by the Department of Geophysics of the University of Chile (CONAMA, 2006).[13] The regional model PRECIS was used to derive information with greater spatial detail, in which the calculation domain covers only a part of the globe, and can be described with better resolution (25 km in this case) covering the entire continental territory of Chile. Such resolution is the maximum attainable with this model (CONAMA, 2006). These projections, which are at the level of 25 square kilometres, are for months between the years 2070 and 2100. The projections are broken into average water use by season for the three decades 2070–2080, 2080–2090 and 2090–2100. In addition to the baseline, 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

[13]The PRECIS model is a regional climate model that provides high-resolution outcomes. According to Jones *et al.* (2017): 'many of these physical processes take place on much smaller spatial scales than the model grid and cannot be modelled and resolved explicitly. Their effects are taken into account using parametrizations, by which the process is represented by relationships between the area or time averaged effect of such sub-grid scale processes and the large scale flow.' For more details and limitations of the PRECIS model, see Jones *et al.* (2017) and visit https://www.metoffice.gov.uk/research/applied/international-development/precis.

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supposed effects until 2100 of projected greenhouse gas emissions SRES A2 (severe) and SRES B2 (moderate).[14]

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. Monthly simulations for temperature and precipitation from the PRECIS are averaged to obtain four seasonal averages by decade for both climate variables, introducing these average projections into the estimated models (columns 2 and 3 in table 2) and holding all other variables constant at their means of the three last years of observations (temperature and weather anomalies are set to zero). Table 3 presents the percentage changes in per-household consumption compared to the baseline. In the case of both linear and non-linear climate effects models, one notes that the greatest impact on per-household residential consumption is projected to occur in the arid north. The maximum average increase over the baseline, however, in the linear-climate-effect model is under 2.5 per cent, and in the non-linear case, under 1 per cent. Across all 42 municipalities, the national average increase in water use in both scenarios in the linear-effect is less than 1.5 per cent, and even smaller in the non-linear model. A few municipalities in the arid north have average increases of approximately 4–5 per cent in both cases. These greater consumption increases in these northern municipalities would be attributable both to increased average temperatures and, importantly, decreased precipitation.

Water use projections based on the model specification with the non-linear climate effects show on average negligible changes (in fact, slightly *negative* value) in average consumption per household in the southern third of the country, where rainfall is currently relatively plentiful and temperatures lower compared to the arid and semi-arid zones to the north. These results underline the importance of the specification used for projecting future climate effects. Nevertheless, in both the linear and non-linear climate effect models these projected increases in water use due to climate are small compared to projections associated with likely increases in urbanization, decreases in poverty and other development-related changes. For example, an increase in the urbanization proportion of only 3 per cent (a small gain compared to recent history) would yield the same average increase as the climate projection in the stronger case of linear effects. A decline in poverty rates from 20 to 10 per cent (approximately the national decline during the 2000 s), *ceteris paribus*, would decrease average household consumption by 2.5. Using the point estimate of its coefficient in column 3 of table 2 (0.125), the addition of one extra bathroom on average – moving from the current sample average of slightly less than one bathroom to two per household (a reasonable projection for over the next generation) – would increase average water use by over six times the highest average projected increase linked to climate change (12.5 percent versus 2 per cent). Again, using the point estimate

[14] According to IPCC (2000), 'the A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.. . .The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.'

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Table 3. Percentage change over the baseline by Geographic Zone

Geographic Zone	Scenario	2070 (%)	2080(%)	2090(%)
Linear climate effects				
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
Non-linear (quadratic) climate effects				
North	A2	0.89	0.77	0.93
	B2	0.96	0.72	0.34
Centre	A2	0.19	0.36	0.33
	B2	0.29	0.39	0.51
South	A2	−0.07	−0.11	−0.16
	B2	−0.13	−0.01	−0.09

Source: Authors' calculations based on estimated coefficients in table 2 (columns 2 and 3) and PRECIS climate projections as discussed in text.

of its coefficient in column 3 of table 2 (0.160), moving from the current national average of 0.45 washing machines to 0.8, which would also be a reasonable increase in the coming generation, would be expected to increase average water use by over twice the highest projected increases in consumption associated with climate change over the next half-century ($0.35 * 16.0 = 5.6$ per cent versus 2 per cent).

5. Conclusion

This paper has presented estimates of the effects of various factors on per-household residential water consumption in Chile using a panel data of 42 municipalities, between 1998 and 2010. Several of the results with respect to demographic factors and water prices are unsurprising given previous studies. The average number of persons per household increases average water consumption, but at a decreasing rate, a finding in agreement with the (scarce) literature showing that household size decreases per-capita consumption (e.g., Schleich and Hillenbrand, 2009). As Chile's economic development continues, average household size is decreasing, and so per-household consumption would likely fall, *ceteris paribus*. The price elasticity of demand in the Chilean case (−0.08) 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 0.18 is also in the range of that found in the literature (between 0.1 and 0.4, as summarized in Arbués *et al.*, 2003). The effect of higher marginal water prices for 'overconsumption' during summer months appears to be small, although statistically significant, and is explained by the very small and geographically-concentrated proportion of the population that pays that higher rate. 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 yet available) should be carried out to test this finding at a disaggregated level.

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More interestingly, household and municipality characteristics likely to change with economic development have been shown to be significant factors in residential water demand, especially in comparison to projected impacts on water use due to potential future climate changes. For example, although on average poor households consume less water than wealthier households, all characteristics changing in correlation with income, anticipated decreases in poverty rates of 5 percentage points over the next decade would, *ceteris paribus* (holding constant, say, the average number per household of bathrooms and washing machines) be expected to *decrease* average household water consumption. And this decrease in water consumption is in approximately the same proportion (1–2 per cent) as that expected to be produced by projected climate changes 50 years hence. The *ceteris paribus* negative correlation between poverty rates and household water consumption is likely due to the decreased efficiency on-average of water use in poorer homes (e.g., due to toilet efficiency, use of hand washing and rinsing of dishes relative to dishwashing machines).

More striking, and related to changes correlated with income growth and decreased poverty, is the effect on residential water use of the growth in the average number of bathrooms and washing machines per households. Again, *ceteris paribus*, moving from the current national average of slightly less than one bathroom per household to two, which is likely in line within the aspirations of the next generation over the next several decades, would be expected to increase average water use by six times the highest projected increases in consumption due to the extreme scenario of increased temperatures and decreased precipitation associated with climate change over the next half-century. Of course, as noted previously, the interpretation of these results should be additionally tempered by possible errors introduced both by interpolating the demographic data from periodic household surveys and by aggregating daily weather data to explain monthly average residential water use per household.

Also associated with future economic development, 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. In addition to differences (*ceteris paribus*) in household water-use patterns between urban and rural families (e.g., differences in the importance of green front lawns), a possible explanation of the importance of urbanization is linked to the residential use of non-potable (and unmetered) water use in rural areas served by canals and wells (for which, unfortunately, we have no data). This is likely of more importance in Chile than other countries with more plentiful, year-round rainfall due to the historical importance to Chilean farming of infrastructure investments to make use of Andean snowmelt runoff into rivers, streams and aquifers. Higher urbanization rates are likely associated with fewer households making use of these unmetered, non-treated sources for lawn irrigation and, in some cases, other household uses.

Although economic-development-related factors will likely most strongly determine future trends in Chilean residential water use, we should emphasize that climate and weather variables are nevertheless 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 (negatively) correlated with temperature. In some areas in the arid north of Chile, however, precipitation does play a more important role in determining water consumption. As noted, while the influence of climate and weather variables is important

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to explain current consumption patterns, the results of the linear- and non-linear-climate-effects models strongly suggest that the impacts of future climate changes on residential water use likely would be, on average, relatively small. Although future prognostications might change, given the water-use data to date the general conclusion is that development-related factors rather than climate-related variables would dominate future trends in per-household water use.

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