Convergence of Residential Water Consumption across Chilean localities

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Abstract

We find β-convergence in per household consumption across Chilean localities, given that low consumption localities tend to increase their consumption faster than high consumption localities. We also find evidence of σ-convergence, since the per household consumption distribution is becoming less unequal. However, the convergence is heading towards a greater level of consumption, which is undesirable from the point of view of sustainable development. The main causes of convergence are the change in income, size of the households and the decreasing rainfall levels.

Keywords: residential water consumption, convergence, water demand.

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1. Introduction

Water supply is an important issue for sustainable development, given the rapid increase of consumption for residential and non-residential uses, and the effects of the extended drought affecting the central zone of Chile. Climate change is also being an issue, since it is reducing rainfall and increasing temperatures in the most populated regions of the country, a situation that should increase water demand.

Sala-i-Martin (1996b) describes convergence as the process of equalization of development levels across geographic units (countries or regions within a country). For instance, there can be convergence in income, consumption or poverty rates. In the case of water consumption, convergence means that, in the long run, localities with different levels of initial consumption will tend to consume similar amounts of water.

In Chile, there are localities with increasing and decreasing water consumption levels, although the annual average is increasing. We believe there is convergence in residential water consumption, associated to the increasing standards of living that allows poor people to consume more water. However, convergence across regions is not guaranteed, given that Chile has an important and distinctive structural characteristic: the climate variability. The country comprises a wide range of climate zones across its large territory, extended across 38 degrees in latitude. It has a desert climate in the north, Mediterranean climate in Central Chile, and oceanic and tundra climate in the south. Besides, there are four seasons in most of the country. Therefore, we believe that the climate variability makes Chile an interesting place to study convergence in water consumption.

We structure the reminder of the paper as follows. In Section 2 we review the literature on convergence and residential water demand. In section 3 we describe the data. In Section 4 we describe the methodology used to analyse convergence and its causes. Section 6 show the results of the analysis. In Section 7 we perform a simulation of the process of convergence and, finally, in Section 7 we summarize the main conclusions.

2. Literature review

2.1 Convergence

Economic convergence has been a relevant concept in the field of economic growth. There is the hypothesis that various economies showing different levels of income will converge in the long run to similar levels of income (for useful literature reviews see, for example, Chatterji 1992; Barro and Sala-i-Martin 1995; Canova and Marcet 1995; de la Fuente 1997; Galor 1996; Sala-i-Martin 1996a; Martin and Sunley 1998). Sala-i-Martin (1996a) shows that convergence is a result of the neoclassical model of Ramsey (1928), Solow (1956) and Swan (1956): the diminishing returns to capital in the production function predicts that the rate of return to capital (and therefore its growth rate) is very large when the stock of capital is small, and vice versa. Therefore, if the only difference across countries is their initial levels of capital, the model predicts that countries with little capital will be poor and will grow faster than rich countries with large capital stocks.

According to Sala-i-Martin (1996a), two types of convergence are analysed. There is absolute *β-convergence* in a cross-section of economies when we find a negative relation between the growth rate of per capita income and the initial level of income, that is, if poor economies tend to grow faster than wealthy ones. On the other hand, there is *σ-convergence* when the dispersion of per capita income across economies tends to decrease over time. In other words, while σ-convergence studies how the distribution of income evolves over time, β-convergence studies the mobility of income within the same distribution. Sala-i-Martin (1996a) shows that β-convergence is a necessary but not a sufficient condition for σ-convergence.

Absolute β-convergence is predicted by the neoclassical model when the assumption that the only difference across countries is their initial levels of capital holds, however, Sala-i-Martin (1996a) points out that economies may differ in their structural characteristics, like their societal preferences, their technologies or rates of population growth. Therefore, if economies have different initial parameters, they will have different steady states (and absolute β-convergence may not be found).

In this context, a third concept arises: *conditional β-convergence*, which means that economies converge but to their own steady state (the growth rate of an economy will be positively related to the distance that separates it from its own steady state). To test the hypothesis of conditional convergence the steady state of each economy must be constant, for example, by conditioning by a set of variables that holds constant the steady state (see, for example, Sala-i-Martin 1996a; Barro and Sala-i-Martin 1992; Mankiw, Romer and Weil 1992).

Another type of convergence is *club convergence*, which means that "clubs" or groups of economies that are similar should have similar growth trajectories, so the hypothesis of similar steady states is not unrealistic (see, for example, Chatterji 1992; Canova and Marcet 1995; Galor 1996; Quah 1996).

Sala-i-Martin (1996a) analyses convergence in a variety of data sets, including a large cross-section of 110 countries, the OECD countries, the states of US, the prefectures of Japan, and regions within several European countries. He finds absolute β-convergence and σ-convergence in all cases except for the large cross-section, that exhibits conditional β-convergence and sigma-divergence. Sala-i-martin (1996b) finds empirical evidence of regional income convergence across the United States, Japan and five European nations. He also finds that the estimated speeds of convergence were surprisingly (slow and) similar across data sets, about 2% per year, which means that the half-life of convergence is around 35 years[1], and that the distribution of income in all countries has shrunk over time. Barro and Sala-i-Martin (1995) also find that the speed of regional convergence in the United States, Europe and Japan has varied over time, and they find divergence in regional per capita income in some periods. Coulombe and Lee (1995) find evidence off convergence across Canadian localities between 1961 and 1991, according to six different measures of per capita income and output.

Mankiw, Romer and Weil (1992) interpret these empiric results within the framework of an augmented Solow growth model (that incorporates human capital as a factor of production), explicitly relating the rate of convergence to the coefficients of the aggregate production function and other structural parameters. Thus, the slow rate of convergence is an indication that the production technology exhibits almost constant returns to scale. However, authors like Canova and Marcet (1995), Islam (1995) and Caselli, Esquivel and Lefort (1996) estimate rates of convergence ranging between 4.3% and 12% by using a panel data specification with fixed country effects, a set of results that cast doubt on the implications of the Solow model. These results imply that the diminishing returns to capital are not enough to explain convergence, and additional convergence mechanisms must be considered, for example, technological diffusion and reallocation of resources across regions.

Convergence in consumption can also be studied, since consumption level is an indicator of economic development. In the case of water consumption, there would be β-convergence if localities with low per capita water consumption tend to increase their consumption faster than localities with high per capita consumption. There would be σ-convergence if the distribution of per capita water consumption decreases its dispersion over time, that is, if the water consumption inequality decreases over time.

Portnov & Meir (2007) find β-convergence of residential water consumption in Israel, and β-divergence in consumption of the non-residential sector. They explained that the convergence trend in the residential sector stems from two main factors: (1) the saturation of

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[1] According to Martin and Sunley (1998), the half-life, or time required for one-half of the initial deviation of relative regional per capita income from its steady-state value to be eliminated, is given by $H = \ln 2 / -\ln(1-\beta)$.

water consumption in wealthy localities, and (2) the rising standards of living in poor localities, which enable them to consume more water for household use. It must be taken into account that the main climates of Israel are Mediterranean, semi-arid and desert, thus, the limited climate variability could help to make convergence possible (since Israel localities are similar in their structural characteristics), a condition that does not hold in Chile.

2.2 Residential water demand

Residential water demand has become an important concern for policymakers and researchers, since it is an increasing proportion of total water demand in both, developed and developing economies. The literature of residential water demand focuses mainly in provide suitable methods to estimate price and income elasticities, as well as to measure the effect of other determinants of water demand. In this section, we briefly review some important aspects of the literature. For useful and complete literature reviews see Arbúes, Garcia-Valinas and Martinez-Espineira (2003) and Worthington and Hoffman (2008).

The findings about water prices are controversial, since some researchers argue that a well-designed price structure is an effective tool to manage water demand (for reducing consumption during periods of scarcity), but others argue that water demand is price inelastic, so non-price schemes would be more effective.

The typical econometric model is one of the form $Q_D = f(P, Z)$, where Q_D is the quantity of residential water consumed, P is some measure of price, and Z is a set of other variables affecting residential water demand, like income, and sociodemographic and climate variables. The data can be cross-sectional, time-series or panel data, and about consumption of individual households or aggregate consumption (by geographic units).

Regarding prices, Worthington and Hoffman (2008) indicate that they are characterized by three features: (1) individual or collective metering; (2) price structure (fixed charge plus variable prices); and (3) billing frequency. The price structure can be complex, including a fixed charge, which is independent of the level of consumption, and a variable price that depends on the amount of consumption. The variable price can be non-linear if the price per additional consumption units varies when consumption reaches certain thresholds, that define different marginal prices for different consumption blocks. With increasing block pricing, a higher marginal price is charged for consumption beyond a certain threshold, so there are at least two price tiers in the rate structure (Dahan and Nisan 2007; Olmstead, Hanemann and Stavins 2007; Schoengold and Zilberman 2014). The marginal prices are typically flat or increasing, but there are also decreasing price structures.

Water is a commodity with few substitutes, so the price elasticity of demand is inelastic. When there are consumption blocks, price is determined simultaneously with the quantity demanded, so it is endogenous. To address this issue, a popular method is to include an additional price variable that reflects the income effect imposed by decreasing or increasing price block structures in the water demand equations (Taylor 1975; Nordin 1976). This specification has been the subject of much controversy, with some authors recognising its importance (Espey, Espey and Shaw 1997), while others find it is unnecessary (Shin 1985; Chicoine, Deller and Ramamurthy 1986; Nieswiadomy and Molina 1991; Arbúes, Garcia-Valinas and Martinez-Espineira 2003). The price specification is varied across literature; while some authors specify marginal prices, others use the Nordin's specification, the average price or other variants, however, in most studies price elasticity is estimated to be in the range 0.25 to 0.75.

Estimates of income elasticity of water demand are positive and inelastic, and small in magnitude, because water bills are typically a lower proportion of the income of households, especially in the case of high-income households (Arbúes, Garcia-Valinas and Martinez-Espineira 2003). Income data is income per capita or per household, or the actual income in the case household-based studies.

Residential water demand is highly sensitive to seasonal variables. It increases in summer months, because outside uses like watering gardens, filling swimming pools and washing cars, and inside uses like more frequent showers. These seasonal factors can be measured in many ways, like temperature (Griffin and Chang 1990), minutes of sunshine, accumulated rainfall, the number of rainy days and evotranspiration (Billings and Agthe 1980, Nieswiadomy and Molina 1991; Hewitt and Hanemann 1995). With monthly or quarterly data, dummy variables are used to control for seasonal consumption.

On the other hand, if the dependent variable is water consumption per household, the household size should be positively related to water consumption (Arbúes, Garcia-Valinas and Martinez-Espineira 2003). Besides, Nauges and Thomas (2000) argue that water consumption in areas with higher proportion of younger persons is likely to be higher due to more frequent laundering and use of water-intensive outdoor activities. Similarly, Martinez-Espineira (2003) argue that areas with higher proportion of older persons is like to consume more due to more gardening activity.

Arbúes, Garcia-Valinas and Martinez-Espineira (2003) indicates that housing characteristics are also important determinants of water demand. For example, the proportion of secondary residences might help identify areas where seasonal use can have a greater impact. Besides, the proportion of individual houses is a proxy of the average size of gardens and of the level of penetration of individual metering. Finally, housing features like the number of bathrooms and the stock of appliances could help to distinguish between short-run and long-run effects of water demand.

The estimation methods are varied, including OLS, GLS, 2SLS, 3SLS, logit, GMM, IV and cointegration. OLS methods are the most commonly used, despite they yield inconsistent estimates when there are block pricing (consumption and price are simultaneously determined). Several IV techniques have been suggested to addressed this issue (see, for example, Nieswiadomy and Molina 1991; Hewitt and Hanemann 1995; Olmstead, Hanemann and Stavins 2007).

3. Data

3.1 Variables

The database is a yearly panel of 344 Chilean localities from year 2010 to 2015, thus, it is a panel data set with N = 344 and T = 6. Consumption and water prices data are collected from the regulatory agency SISS (Superintendencia de Servicios Sanitarios), for 30 water utilities.

Consumption data is complemented with socioeconomic and demographic data taken from the Casen survey, a national household survey, available for years 2009, 2011, 2013 and 2015. Data for years 2010, 2012 and 2014 is imputed by interpolation. The database has climate data from the DMC (Dirección Meteorológica de Chile) and DGA (Dirección General de Aguas), assembled by the Center of Climate Science and Resilience (CR2).

In the following paragraphs we describe the variables used in this study.

Average consumption is the annual average of the households' monthly consumption of water. The households' monthly consumption is calculated by dividing total consumption (m^3/month) by the total number of households in each locality. Next, the monthly series are averaged by year to obtain annual series for each locality.

The other variables are determinants of consumption, that can be classified in three types: (1) economic variables (water price and income of the households), (2) sociodemographic variables (household and dwelling characteristics), and (3) climate variables (accumulated rainfall and average temperature).

Regarding water prices, in Chile each water utility has its own rate structure and only some of them use incremental block pricing, that is a two-block structure which is valid only during summer months, the "peak period" (from December to March), while during the rest of the year consumers face a uniform marginal rate. The limit between the two blocks of prices is about 40 m^3, a substantial amount of consumption, greater than the actual consumption of most of the households. Thus, only a few households end consuming in the second block of prices, around the 4% of our sample.

Despite there is a price structure, in this study the relevant price measure is the average price of water, since there is evidence that consumers do not devote much time of effort to study the structure of changes in intramarginal rates (Billings and Agthe 1980; Bacharach and Vaughan 1994) because of information costs, so they use the average price to decide how much water they consume. Besides, some papers have shown that consumers tend to respond to average prices for water demand rather than marginal prices (Foster and Beattie 1979, 1981; Griffin and Chang, 1990; Martinez-Espineira, 2003; Gaudin 2006), and for electricity demand (Shin 1985; van Helden, Leeflang and Sterken 1987).

The **average price** is calculated by dividing the monthly total spending in water by total consumption in m^3, so we obtained the average price in monetary units per m^3 (Gaudin, Griffin and Sickles 2001; Gaudin 2006). Next, the monthly series are averaged by year to obtain annual series for each locality.

Income is the average per household income by locality. Per household income is the total (monthly) income divided by the number of people in the household. Total income is the sum of monetary earnings from labour, wealth and transfers from the state, including subsidies to water consumption and the imputed rent of the house (given that house owners do not have to pay a rent, they have more disposable income to consume). Thus, an increase in income consider the decrease in subsidies. This variable is thus endogenous in the water demand equation, since the amount of water consumption subsidies depends on the level of consumption.

Price and income are both in real terms, deflated by the consumer price index (CPI, 2013 = 100).

Two variables are used to control for **household characteristics**, (1) the number of people in the household (average by locality), since more numerous households should consume more water (Arbúes, Garcia-Valinas and Martinez-Espineira 2003), and (2) the number of youngsters in the household, where youngster are people below 15 years old, since households with more youngster should consume more water, because a higher frequency of laundering (Nauges and Thomas 2000).

To control by differences in **dwellings characteristics**, two variables are used: the number of bedrooms and the number of bathrooms in the dwelling. These variables are positively related to water consumption, since it should be higher the larger the dwelling.

Climate variables also drive water consumption, since consumption should be higher in warm and dry localities. Two variables are used to control for climate factors: the annual accumulated rainfall and the monthly average temperature by locality.

Finally, there is a set of dummies for the natural regions of Chile, which are 5 territorial units created on the basis of geographic and economic criteria. The natural regions are ordered from north to south, and each has its own natural characteristics. The *Far North* has mainly a desert climate, the *Near North* has a semi-arid climate, *Central Chile* has a Mediterranean climate, the *Southern Zone* has a temperate oceanic climate, and the *Austral Zone* has a subpolar oceanic climate. The limits between the natural regions are the parallels 27, 33, 37 and 42 (°S). In this research, we have data of localities separated by 34 degrees in latitude.

Table 1 summarize the list of variables, their abbreviations, sources and descriptions.

Table 1. List of variables

Variable	Abbreviation	Source	Description
Average consumption	consumption	SISS	Households' average monthly consumption of water, averaged by locality and year (m^3/month)
Average price	price	SISS	Average price paid for the m^3 of water (average by locality and year), in real terms ($CLP/$m^3$/month)
Income	income	Casen	The average per household (total) income by locality, in real terms (average by locality) ($CLP)
Number of people	npeople	Casen	Number of people in the household (average by locality)
Number of youngsters	nyoungsters	Casen	Number of people in the household below 15 years old (average by locality)
Number of bedrooms	nbedrooms	Casen	The number of bedrooms in the dwelling (average by locality)
Number of bathrooms	nbathrooms	Casen	The number of bathrooms in the dwelling (average by locality)
Accumulated rainfall	rainfall	DMC; DGA	Annual accumulated rainfall (mm^3) by locality
Average temperature	temperature	DMC; DGA	Monthly average temperature (°C), averaged by locality and year
Natural regions	natreg	Own elab.	Dummies for each of the 5 natural regions of the country

3.2 Descriptive statistics

Table 2 show the summary of descriptive statistics of the main variables used in this study. The coefficient of variation (CV) show that the variables with more dispersion are rainfall, consumption and income, while the variables with least dispersion are nbedrooms, npeople and temperature. Besides, all variables have more cross-sectional variation (between) than temporal (within).

Table 2. Summary of descriptive statistics

Variable	Obs	Mean	SD	CV	Min	Max
consumption	2064	14.03	10.12	0.72	4.25	107.89
price	2064	968.21	304.77	0.31	252.16	1986.40
income	2058	248,707	150,552	0.61	91,854	1,602,867
npeople	2058	3.31	0.29	0.09	2.13	4.39
nyoungsters	2058	0.70	0.15	0.21	0.17	1.57
nbedrooms	2058	2.75	0.24	0.09	1.95	4.71
nbathrooms	2058	1.08	0.28	0.25	0.39	2.99
rainfall	2064	588.07	570.08	0.97	0.00	3,360.24
temperature	1920	13.06	2.19	0.17	3.62	20.11

The average consumption is around 14 m^3, while the median is 11.65 m^3. Figure 1 show the distribution of the natural logarithm of consumption by year. As may be seen, consumption dispersion is decreasing, while the median appears to be increasing. The differences are clearer when comparing consumption of years 2010 and 2015.

Figure 1. Consumption (ln) distribution by year

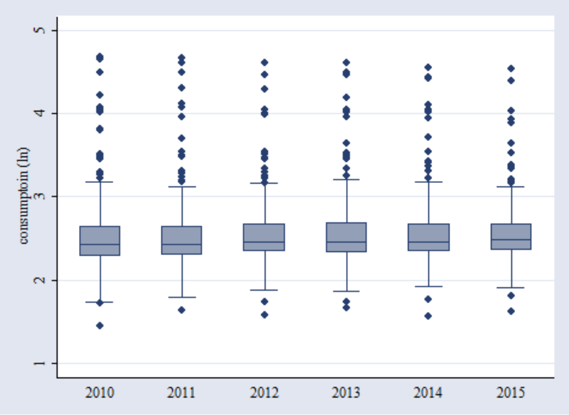
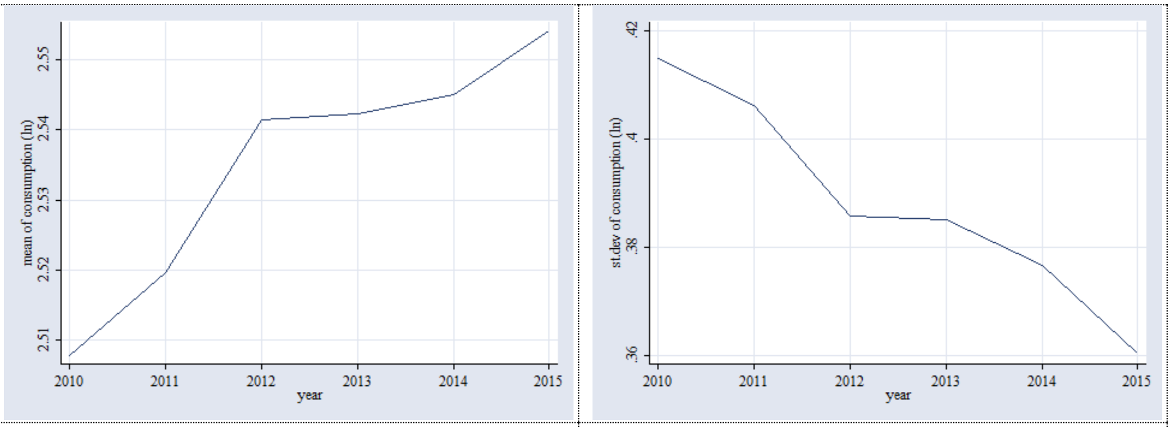


Table 3 and Figure 2 show the mean and standard deviation (SD) of consumption (ln) by year. There is an increase in consumption and a decrease in standard deviation in every year. The decrease in SD imply that there is σ-convergence and, therefore, there is β-convergence, since β-convergence is a necessary condition for σ-convergence (Sala-i-Martin, Xavier, 1996a).

Table 3. Mean and SD of consumption by year

Year	Mean	SD
2010	2.5078	0.4149
2011	2.5197	0.4062
2012	2.5415	0.3857
2013	2.5423	0.3851
2014	2.5451	0.3766
2015	2.5542	0.3603

Figure 2. Consumption (ln) distribution by year



(a) Mean by year

(b) SD by year

The average consumption has increased over time; however, some localities have increased their consumption during the period while others decreased it. A total of 245 localities have increased their water consumption level, while 99 decreased it.

Table 4 compares the consumption levels (in m^3) of localities with positive and negative growth during the period 2010-2015. The average consumption of localities with negative growth was higher than the one of localities with positive growth, and vice versa. Thus, the greater number of localities with positive growth explain the upward trend in water consumption.

Table 4. Consumption levels and growth rates of localities with positive and negative total growth between 2010-2015

Consumption Growth	Mean 2010	Mean 2015	Change %
Total	13.85	14.07	1.6%
Negative	19.91	18.03	-9.4%
Positive	11.41	12.47	9.3%

Appendix 1 show similar comparisons (to table 4) for the determinants of water demand.

The average price is around 968 CLP/m^3, with a minimum of 252 CLP/m^3 and a maximum of 1986 CLP/m^3, which is an amount 8 times larger than the minimum. Price elasticity of water demand is around -0.40 (negative and inelastic)[2]. Price is higher in localities with positive growth of consumption, but it increased less than the price of localities with negative growth.

The average income is around 248,000 CLP/month, with a maximum that is 17 times greater than the minimum. Chile is one of the most unequal countries in the world, however, income inequality is decreasing (there is convergence in income) according to a study published by PNUD (2017), that reports a decrease in income inequality in Chile during the last years. Table 5 shows a set of income inequality indicators for the period 1990-2015. There is a decrease in income inequality indicators since year 2000, while poverty has decreased every year. During the period 2009-2010, a span of time similar to the one analysed in this study, the Gini index decreased from 50% to 47.6%, the Palma index decreased from 3.2% to 2.8%, and the ratio Q1/Q5 decreased from 12.8% to 10.8%. On the other hand, poverty decreased from 25.3% to 11.7%.[3]

Sapelli (2016) points out that the decrease in income inequality is explained by the expansion in education coverage, that have allowed to reduce the differences in years of schooling of the younger cohorts, and therefore, in earnings from labour income. Consequently, younger

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[2] See appendix 2: estimation of a demand equation.

[3] Gini index ranges from 0 to 100%, with 0% representing perfect equality and 100% representing perfect inequality. The Palma ratio is the income of the richest 10% of the population divided by the income of the poorest 40%. The Quintiles ratio is the average income of the richest 20% of the population divided by the average income of the poorest 20%.

cohorts are less unequal than the older ones, and continuous improvements in income inequality indicators are expected for the Chilean economy in the future.

Table 5. Income inequality from 1990 to 2015

Year	Gini	Palma	Q5/Q1	% Poverty
1990	52.1	3.6	14.8	68.0
1996	52.2	3.6	15.2	42.1
2000	54.9	4.2	17.5	36.0
2003	52.8	3.7	15.3	35.4
2006	50.4	3.3	13.3	29.1
2009	50.0	3.2	12.8	25.3
2011	49.1	3.0	12.2	22.4
2013	48.8	3.0	11.6	14.4
2015	47.6	2.8	10.8	11.7

Source: PNUD (2017)

In our sample, localities with negative growth of consumption have a higher income than those with positive growth. Income increased in both type of localities, but it increased more in localities with positive growth. Table 6 show the consumption levels and growth rates between 2010 and 2010 of localities belonging to the first and fifth quintile of income in 2010. The poorest localities increased their consumption while the wealthiest decreased it.

Table 6. Consumption levels and growth rates by quintiles of income (2010) between 2010-2015

Quintiles	Mean 2010	Mean 2015	Change %
Total	13.85	14.07	1.6%
1	10.13	10.96	8.2%
5	18.24	17.62	-3.4%

Our estimations indicate that income-elasticity of water demand is around 0.20 (positive and inelastic).

In the case of npeople and nyoungsters, there are not important differences between groups. In both cases, localities with positive and negative growth of consumption, these variables decreased, while the decrease in npeople of localities with positive growth was the greater.

There are not substantial differences between groups in nbedrooms, but there are differences in nbathrooms, a variable that is more correlated to income than nbedrooms (see appendix 3), since localities with negative growth have more bathrooms than localities with positive growth, and the increase in nbathrooms was greater in localities with positive growth.

Localities with positive growth in consumption have greater levels of accumulated rainfall than those with negative growth. Rainfall decreased in both types of localities, but the decrease was greater in localities with positive growth. In the case of temperature, it is similar in both groups, and it decreased on average during the period of analysis.

Next, we characterize the natural regions of Chile in terms of the climate variables (Table 7). The temperature decreases from north to south, while the accumulated rainfall increases but then decreases from north to south. Therefore, if climatic variables were important structural factors explaining water demand, we should not find absolute convergence in water consumption, but only conditional (or club) convergence. Given that we already show that there is absolute β-convergence in every year, we suspect that climate variables are not the most important variables that determines the long run consumption of Chilean localities.

Table 7. Climatic statistics by natural regions

	rainfall	temperature
Far North	11.22	16.53
Near North	131.53	13.50
Central Chile	380.91	14.01
Southern Zone	1245.78	11.57
Austral Zone	1127.35	8.41

In summary, there appears to be convergent and divergent forces driving water consumption. Among the convergent forces are the changes in income, nbathrooms and rainfall, while the change in npeople is a divergent force. The other variables: price, nyoungsters, nbedrooms and temperature, cannot be assigned with certainty to any group of forces.

4. Methodology

There is β-convergence in average consumption when there is a negative relation between the growth rate and the initial level of per household consumption across localities. Thus, following the explanation of Caselli, Esquivel and Lefort (1996), to analyse if there is absolute β-convergence, the following *growth equation* is estimated:

$$\ln\left(C_{i,t}\right) - \ln\left(C_{i,t-\tau}\right) = \alpha + \beta \ln\left(C_{i,t-\tau}\right) + \epsilon_{i,t} \tag{1}$$

Where $C_{i,t}$ is the consumption of locality i in period t; α is a constant; the coefficient on lagged consumption, β, is the speed of convergence; and $\epsilon_{i,t}$ is an error term. If β is significantly negative, then there is absolute β-convergence, since localities close to their steady-state consumption level will experience a slowdown in growth.

On the other hand, to analyse if there is conditional β-convergence, the following growth equation is estimated:

$$\ln\left(C_{i,t}\right) - \ln\left(C_{i,t-\tau}\right) = \alpha + \beta \ln\left(C_{i,t-\tau}\right) + W_{i,t-\tau}\delta + \eta_i + \xi_t + \epsilon_{i,t} \tag{2}$$

Where $W_{i,t}$ is a row vector of determinants of water consumption; η_i is a fixed-individual-effect by locality, and ξ_t is a fixed-time-effect by year. These variables are proxies for the long-run level of consumption the locality is converging to.

The list of variables included in $W_{i,t}$ are the determinants of water consumption that could explain the consumption level in the long-run, while η_i captures the effect of other determinants that are not included in $W_{i,t}$.

On the other hand, τ could vary depending of the period for which convergence is analysed. There could be convergence for the whole period, but not for some sub-periods. In this paper we test different values for τ, so the dependent variable is the growth rate of water consumption between $(t-\tau)$ and τ. Control variables ($W_{i,t}$) are the initial levels of the water determinants in each period, that characterize the corresponding initial conditions.

Caselli, Esquivel and Lefort (1996) noted that equation (2) could be rewritten as:

$$\ln\left(C_{i,t}\right) = \alpha + \tilde{\beta}\ln\left(C_{i,t-\tau}\right) + W_{i,t-\tau}\delta + \eta_i + \xi_t + \epsilon_{i,t} \qquad (3)$$

Where $\tilde{\beta} = (1+\beta)$, so there is convergence if $\tilde{\beta} < 1$. Equation (3) makes it clear that estimating (2) is equivalent to estimating a dynamic equation with a lagged dependent variable of the right-hand side.

Caselli, Esquivel and Lefort (1996) show that in a dynamic equation the fixed-locality-effect is correlated with the other right-hand side variables, so the standard cross-section estimators are inconsistent (an error that explains the small coefficients found in most of the income convergence literature). The second criticism has to do with the disregarded issue of endogeneity, given that is clear that some of the variables in $W_{i,t}$ are endogenous. These authors addressed these two issues by using the GMM estimator proposed by Holtz-Eakin, Newey and Rosen (1988) and Arellano and Bond (1991). This estimator, called the Arellano-Bond estimator, estimate a first-difference transformation of the equation, that eliminates the individual effects, and use past values of the explanatory variables as instruments to control for endogeneity. We use the Arellando-Bond estimator to estimate equation (3), by using all variables as deviations from year means, so the time effects could also be eliminated.

In the case of water consumption, at least 2 variables are endogenous (water price and income). However, given that we use past values of the determinants as regressors, we treat all variables as exogenous, while prince and income are treated as predetermined (weakly exogenous). The model specification was tested (for autocorrelation and overidentifying restrictions) using the tests proposed by Arellando and Bond (1991). We use robust standard errors.

Next, we analyse the sources of convergence, using a methodology proposed by De La Fuente (2002). The purpose is to decompose the measure of beta convergence into a serie of additive factors that capture the effect of water demand determinants on the evolution of the cross-sectional distribution of consumption.

We first calculate the average growth rates of all variables during the sample period, and then compute the deviations from year averages. Thus, we work with growth differentials relative to the average growth. Next, we estimate the following equation:

$$\Delta \ln(C_i) = \alpha + \Delta W_i \delta + \epsilon_i \quad (4)$$

Where the average growth rate of consumption, $\Delta \ln(C_i) = (1/\tau)\left(\ln\left(C_{i,t}\right) - \ln\left(C_{i,t-\tau}\right)\right)$, with $\tau = 5$, depends on the average growth of the water demand determinants (differentials relative to the mean value).

On the other hand, the speed of convergence is estimated using equation (5):

$$\Delta \ln(C_i) = \alpha + \beta C_{0i} + \epsilon_i \quad (5)$$

As De La Fuente (2002) explains, to decompose the rate of beta convergence we will make use of the following fact. Let y_i and x_i, with $i = 1, \dots, n$ be two series, where y_i can be written as the sum of its components, $y_i = \sum_k y_{ik}$. Then, if we regress y_i and each of its componentes on x_i, the coefficients of these regressions are related by $b = \sum_k b_k$, where b_k is the coefficient of the *kth* component regression and b is the coefficient of the "total" regression of y_i on x_i.

In practice, the speed of convergence (β) estimated by regressing average consumption growth (over the whole sample period) on initial consumption, can be written as the sum of the components convergence coefficients (β_k) obtained by regressing each component on initial consumption. Thus, if w_k is the *kth* component of the vector of determinants W, then:

$$\delta_k w_{ki} = \alpha + \beta_k C_{0i} + \epsilon_i \quad (6)$$

Where $\delta_k w_{ki}$ is the *kth* component of consumption growth, derived of the estimation of equation (4). Finally, it is noted that, to obtain a sum of components equal to the actual consumption growth, the residuals of the estimation should be considered as an additional component (the fraction of the variation in consumption growth not explained by the evolution of the water demand determinants).

5. Results

We first estimate equation (1) using OLS for different values of τ. Thus, when $\tau = 1$, we analyse if there is absolute β-convergence in every pair of consecutive years, while, when $\tau = 5$, we analyse if there is convergence in the complete period of analysis[4]. We find convergence for all values of τ. The result for $\tau = 1$, an estimated speed of convergence of 0.0353, implies a "half-life" of about 19 years. Besides, the estimated values imply that consumption is converging to a value of 16.33 m^3/month.[5]

Table 8. Estimates of absolute β-convergence

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[4] To compare the speeds of convergence when $\tau = 1$ *or* 5, the estimated β must be divided by τ. Thus, when $\tau = 5$, the estimated average annual speed of convergence is 0.0320.

[5] In 2015, average consumption was 14.07 m^3, with a minimum of 5.08 and a maximum of 93.24. A value of 16.3 m^3 would be placed it in the percentile 83th of the consumption distribution. The steady-state consumption is calculated using the expression $\exp(-(\alpha/\beta))$.

	T=1	T=2	T=3	T=4	T=5
ln(C(t-T))	-0.0353***	-0.0677***	-0.0890***	-0.1243***	-0.1602***
	(0.0060)	(0.0040)	(0.0050)	(0.0030)	(0.0050)
constant	0.0986***	0.1890***	0.2487***	0.3484***	0.4482***
	(0.0060)	(0.0040)	(0.0050)	(0.0030)	(0.0050)
N	1720	1376	1032	688	344
R2	0.0800	0.1477	0.1918	0.2846	0.3435

p-values in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Despite the finding of absolute β-convergence, we estimate equation (3) using the Arellano-Bond estimator. In the first equation, we do not use control variables, thus, the fixed-effects are the only variables controlling for the different steady states. In the second equation, we use the determinants of water demand as variables determining the different steady states. However, only accumulated rainfall was significant, which it could mean that the most important variables determining the different steady states are omitted of the model, but their effects are at least partially being captured by the fixed effects. The estimated speeds of convergence, 0.0529 and 0.0944, imply a "half-life" of about 13 and 7 years, respectively. Portnov and Meir (2007) found a speed of conditional β-convergence equal to 0.1550 for residential water consumption in Israel.

Table 9. Estimates of conditional β-convergence

	(1)	(2)
L.ln(consumption)	0.9471***	0.9056***
	(0.0000)	(0.0000)
L.ln(income)		0.0281
		(0.2210)
L.ln(price)		-0.2549
		(0.1620)
L.npeople		-0.0292
		(0.1050)
L.nyoungsters		0.0244
		(0.4020)
L.nbedrooms		0.0074
		(0.6060)
L.nbathrooms		-0.0170
		(0.5450)
L.temperature		-0.0017
		(0.1260)
L.rainfall		0.0000**
		(0.0250)
constant	-0.0035	-0.0038
	(0.5110)	(0.6110)
N	1376	1262
Beta	-0.0529	-0.0944

p-values in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The different magnitudes in the estimates of absolute and conditional convergence, could be explained by some localities converging faster to their own steady states (some localities are closer to their steady states than others). If we estimate the speed of conditional convergence using OLS (table 9, column 2), β would be -0.0432, while the Arellano-Bond estimator gives a value of 0.0944, two times greater. Caselli, Esquivel and Lefort (1996) obtained a greater difference, since they estimated a speed of income convergence equal to 0.10, while the previous research estimated a β equal to 0.02 using OLS.

Table 10 shows the results of the analysis of the sources of convergence. The first row is the estimate of equation (5), while the following rows show the results of the *kth* version of equation (6). A negative sign in a coefficient means that the corresponding variable is a source of convergence, while a positive sign indicates a source of divergence. The "percentage" (%) column show the contribution of each variable to the total beta coefficient.

The most noticeable result is that the 89% of the speed of convergence cannot be explained by the determinants of water consumption. However, three variables are identified as a significant source of convergence: npeople, nbathrooms and rainfall. In the case of nbathrooms, they have the greater increase in localities of positive growth of consumption. The number of bathrooms is the variable most correlated to income (see appendix 3), and could be reflecting that income is related to water consumption only when a higher income is related to a larger dwelling (it is a long run effect of income on water consumption). Accumulated rainfall had the greater decrease in localities with positive growth of consumption, so the increase in water consumption could have been related with a need for more watering. The case of npeople is unclear, since decreased the most in localities with positive growth. We think that the decrease in npeople affected the consumption of localities with negative growth, while other factors were more important in localities with positive growth of consumption.

Table 10. Causes of convergence in water consumption

Source	Beta	%	P	R2
	-0.0321***	100.00	(0.000)	0.3548
Income	0.0005	-1.56	(0.104)	0.0085
Price	0.0002	-0.64	(0.653)	0.0006
Npeople	-0.0008**	2.61	(0.038)	0.0138
nyoungsters	0.0001	-0.24	(0.441)	0.0019
nbedrooms	0.0000	0.13	(0.390)	0.0024
nbathrooms	-0.0016***	4.93	(0.005)	0.0250
temperature	0.0000	0.14	(0.474)	0.0016
Rainfall	-0.0019***	6.03	(0.005)	0.0252
Residual	-0.0284***	88.60	(0.000)	0.3088

p-values in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Despite that a great percentage of convergence could not be explained by this analysis, we find some significant variables explaining convergence in water consumption. The unexplained sources of convergence could be related to long-run effects of water determinants, for example, the change in the demographics of people of the characteristics of the dwellings may not be so important in a 6 years period, but they do be important in longer periods. On the other hand, the factors explaining convergence in localities with positive and negative growth could be different.

Table 11 and 12 show the results of the analysis of the sources of convergence in localities with negative and positive growth of water consumption, respectively. It should be noted that the speed of convergence is faster in localities with positive growth of water consumption.

Table 11 (localities with negative growth of water consumption) show that income and nbathrooms are significant causes of convergence. We believe that these variables capture the effect of income on water consumption, which is negative, since greater levels of income, through its correlation with education, are capturing the effect of water conservation measures taken by the households (Worthington and Hoffman 2008). Temperature is also a source of convergence; it has decreased during the period of analysis in these localities, leading to less water consumption.

Table 11. Causes of convergence in localities with negative growth of water consumption

Source	**Beta**	**%**	**P**	**R2**
	-0.0131***	100.00	(0.000)	0.2207
income	-0.0001**	1.10	(0.021)	0.0580
price	-0.0003	2.08	(0.100)	0.0297
npeople	-0.0008***	6.01	(0.004)	0.0042
nyoungsters	0.0000	-0.25	(0.701)	0.0016
nbedrooms	0.0004	-3.19	(0.137)	0.0243
nbathrooms	-0.0010**	7.51	(0.035)	0.0486
temperature	-0.0007**	5.38	(0.045)	0.0440
rainfall	0.0000	-0.13	(0.824)	0.0006
residual	-0.0107***	81.50	(0.000)	0.1558

p-values in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 12 (localities with positive growth of water consumption) show that the only relevant variable explaining convergence is rainfall, that has decreased during the period of analysis, so the increase in water consumption may be explained by a need for more watering.

Table 12. Causes of convergence in localities with positive growth of water consumption

Source	**Beta**	**%**	**P**	**R2**
	-0.0297***	100.00	(0.000)	0.2263
income	-0.0001	0.26	(0.873)	0.0001
price	-0.0009	3.09	(0.365)	0.0037
npeople	-0.0001	0.49	(0.408)	0.0031
nyoungsters	-0.0001	0.40	(0.722)	0.0006
nbedrooms	-0.0003	0.91	(0.524)	0.0013
nbathrooms	-0.0010	3.27	(0.153)	0.0093
temperature	0.0002	-0.78	(0.284)	0.0052
rainfall	-0.0019**	6.43	(0.011)	0.0293
residual	-0.0255***	85.93	(0.000)	0.1912

p-values in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Portnov & Meir (2007) find β-convergence of residential water consumption in Israel, and they attributed the cause of convergence to the increase in income of poor localities, which enable them to consume more water. By contrast, we find that the increase of income, along with the reduction in the number of people per household, explains the convergence process in localities showing a reduction in water consumption, while the decrease in rainfall is the cause of convergence is localities with increasing levels of water consumption, a factor that could be related to climate change.

6. Simulation of the process of convergence

In this section, we perform a simulation of the process of convergence, using the estimates of table 1, column 1, which imply that consumption is converging to a value of 16.33 m^3/month in the long run. Figure 3 shows how consumption (ln) converges to its long run level or steady state (during the period 2010-2045).

Figure 3. Simulation: consumption (ln) distribution by year (2010-2045)

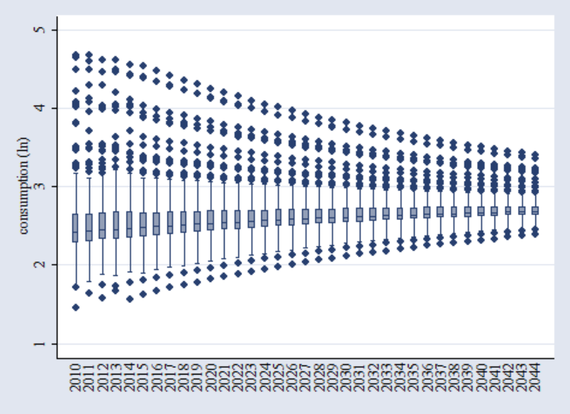


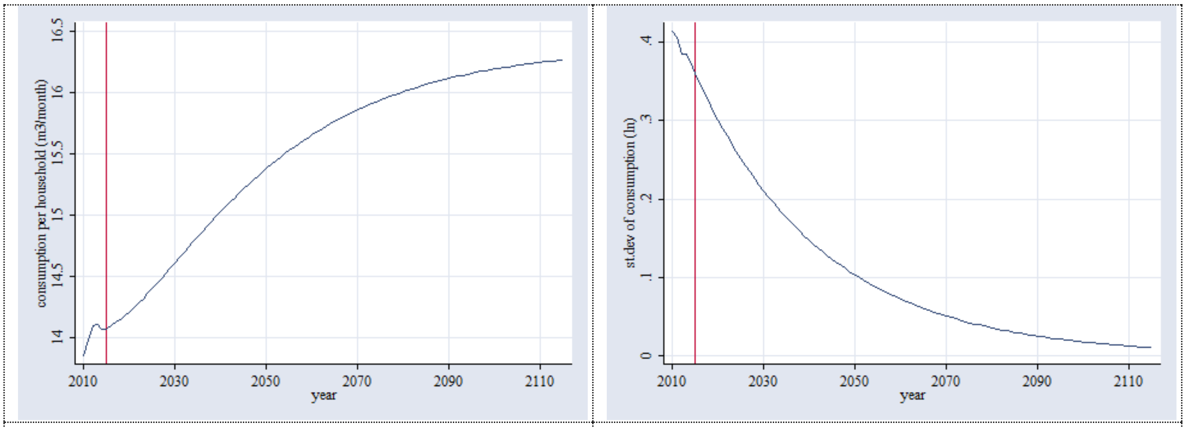
Table 11 and Figure 4 show the mean and standard deviation (SD) of consumption (ln) by year, during the period 2010-2110. There is an increase in average consumption and a decrease in standard deviation, as predicted by the model; and it can be seen that the convergence process is very slow.

Table 13. Simulation: mean and SD of consumption every 5 years (2010-2115)

Year	Mean	SD	Year	Mean	SD
2010	13.8538	10.8653	2065	15.7602	1.0146
2015	14.0688	9.1087	2070	15.8548	0.8421
2020	14.2078	6.8357	2075	15.9355	0.7000
2025	14.3970	5.2740	2080	16.0042	0.5824
2030	14.6098	4.1554	2085	16.0625	0.4850
2035	14.8233	3.3243	2090	16.1118	0.4042
2040	15.0257	2.6890	2095	16.1534	0.3370
2045	15.2108	2.1927	2100	16.1884	0.2811
2050	15.3766	1.7985	2105	16.2179	0.2346
2055	15.5228	1.4817	2110	16.2427	0.1958
2060	15.6502	1.2246	2115	16.2635	0.1634

A positive aspect of water consumption convergence is that water demand will grow at a decreasing rate, and the future consumption level could be predicted. However, water demand is increasing, which is undesirable from the point of view of sustainable development. The rapid increase of the coming years will pressure the capability of water utilities for supplying water, and it will cause a rapid increase in water prices that could affect the consumption of poor households.

Figure 4. Simulation: consumption (ln) distribution by year (2010-2115)



(a) Mean by year

(b) SD by year

7. Conclusions

We find evidence of absolute β-convergence in per household water consumption, given that there is a negative relationship between the growth rate and the initial level of water consumption, which means that localities with small initial levels of consumption tends to grow faster than localities of higher initial level of consumption. The speed of convergence is around 3% by year. We also find evidence of σ-convergence, which means that the dispersion of per household consumption distribution is decreasing over time, so water consumption distribution has been becoming less unequal. However, the convergence is heading towards a higher level of consumption, which is undesirable from the point of view of sustainable development.

On the other hand, we find that some localities are increasing their consumption level while others are decreasing it. We find that the increase of income, along with the reduction in the number of people per household, explains the convergence process in localities showing a reduction in water consumption, while the decrease in rainfall is the cause of convergence is localities with increasing levels of water consumption, a factor that could be related to climate change.

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Appendix 1. Comparison of statitics of localities with positive and negative total growth

The following tables compares the levels and growth rates of water demand determinants in localities with positive and negative total growth during the period 2010-2015.

price

C. Growth	Mean 2010	Mean 2015	Change %
Total	943.68	988.09	4.7%
Negative	836.34	877.84	5.0%
Positive	987.06	1032.64	4.6%

income

C. Growth	Mean 2010	Mean 2015	Change %
Total	234,949	270,608	15.2%
Negative	317,899	357,601	12.5%
Positive	201,769	235,810	16.9%

npeople

C. Growth	Mean 2010	Mean 2015	Change %
Total	3.42	3.19	-6.9%
Negative	3.46	3.25	-5.9%
Positive	3.41	3.16	-7.2%

nyoungsters

C. Growth	Mean 2010	Mean 2015	Change %
Total	0.75	0.66	-11.9%
Negative	0.75	0.66	-12.0%
Positive	0.75	0.66	-11.9%

nbedrooms

C. Growth	Mean 2010	Mean 2015	Change %
Total	2.69	2.80	4.1%
Negative	2.76	2.87	3.9%
Positive	2.66	2.78	4.2%

nbathroooms

C. Growth	Mean 2010	Mean 2015	Change %
Total	1.05	1.14	8.9%
Negative	1.20	1.30	7.9%
Positive	0.98	1.08	9.4%

rainfall			
C. Growth	**Mean 2010**	**Mean 2015**	**Change %**
Total	581.76	482.84	-17.0%
Negative	434.90	386.75	-11.1%
Positive	641.10	521.67	-18.6%

temperature			
C. Growth	**Mean 2010**	**Mean 2015**	**Change %**
Total	13.42	12.99	-3.1%
Negative	14.04	13.66	-2.8%
Positive	13.15	12.73	-3.3%

Appendix 2. Estimation of a demand equation

The table shows the estimates of a demand equation with the following functional form:

$$\ln\left(C_{i,t}\right) = \alpha + \beta_1 \ln\left(income_{i,t}\right) + \beta_2 \ln\left(price_{i,t}\right) + W_{i,t-\tau}\delta + \eta_i + \xi_t + \epsilon_{i,t}$$

Where the natural logarithm of consumption, $C_{i,t}$, depends on a constant, α, the natural logarithm of income and price, and a set of control variables, $W_{i,t}$, plus individual and time effects, η_i and ξ_t, respectively. The Hausman (1978) specification test rejects the random-effects model, so we estimate fixed-effects using three different estimators: (1) OLS with dummy variables (using fixed-effects and clustered standard errors by natural regions), (2) the between estimator, and (3) the within estimator (using clustered standard errors by locality). We ignore the issue of endogeneity in the estimation, since only affect a small proportions of households in the sample (and the correct estimation of elasticities is not the objective of the paper). However, the issue is partially solved by the use of fixed-effects.

	OLS	**BE**	**FE**
income	0.1904**	0.2187**	-0.0331*
	(0.0360)	(0.0100)	(0.0600)
price	-0.3828***	-0.4040***	-0.1992**
	(0.0010)	(0.0000)	(0.0180)
npeople	0.2853*	0.3471***	-0.0074
	(0.0770)	(0.0040)	(0.6420)
nyoungsters	0.2603*	0.2806	0.0174
	(0.0600)	(0.1820)	(0.5790)
nbedrooms	0.1989***	0.2806***	-0.0176
	(0.0020)	(0.0010)	(0.1740)
nbathrooms	0.2362***	0.2058*	0.0169
	(0.0040)	(0.0840)	(0.5620)
temperature	0.0256***	0.0151	0.0017
	(0.0060)	(0.1090)	(0.1810)
rainfall	0.0000	0.0000	0.0000***
	(0.3410)	(0.1380)	(0.0090)
constant	0.3788	0.0924	4.3017***
	(0.8130)	(0.9330)	(0.0000)
N	1914	1914	1914
R2-within		0.0029	0.1247
R2-between		0.6093	0.2703
R2-overall	0.5755	0.5589	0.2612

p-values in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Fercovic, Foster & Melo (2015) estimate a residential demand function at the municipal level in Chile using panel data for the period 1998-2010, finding a price-elasticity of -0.14 and an income-elasticity of 0.20 They also find a significant effect of temperature over water consumption, and projected a small increase (about 1% greater) in per household consumption toward the end of the century (because of climate change).

Appendix 3. Correlations matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. consumption	1.00								
2. income	0.41	1.00							
3. price	-0.32	-0.12	1.00						
4. npeople	0.38	-0.11	-0.25	1.00					
5. nyoungsters	0.27	-0.18	-0.06	0.80	1.00				
6. nbedrooms	0.36	0.38	-0.03	0.25	0.06	1.00			
7. nbathrooms	0.48	0.86	-0.22	0.06	-0.07	0.47	1.00		
8. temperature	0.31	0.17	-0.40	0.28	0.16	0.06	0.30	1.00	
9. rainfall	-0.26	-0.18	0.29	-0.24	-0.17	-0.01	-0.29	-0.57	1.00