Growth and Convergence of Residential Water Consumption

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Introduction

Hypotheses

- Per household water consumption across localities is growing and converging to a long run level that is higher than the current level.
- The main factor explaining convergence is the increase in income of poor localities, which have enabled them to consume more water.

- Water Demand is linearly increasing for residential and non-residential uses, while Water Supply is seriously affected by the drought and climate change.
- If our hypotheses holds, we should expect an increase in the growth rate of total water consumption during the following century, making the water availability an urgent problem, since Water Demand would increase exponentially.

Literature Review

Sala-i-Martin (1996). There is economic convergence when several economies showing different levels of income converge (or diverge) in the long run to similar levels of income.

There are two concepts of convergence:

- β-convergence. 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.

- 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.

Literature Review

In the field of water demand...

- ...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.

Portnov & Meir (2007) find β-convergence of residential water consumption in Israel, and concluded that convergence stems from two main factors:

1. The saturation of water consumption in wealthy localities.
2. The rising standards of living in poor localities, enabling them to consume more water for household use.

Data

The **database** is a monthly panel of 530 Chilean localities from January 2010 to December 2015 (72 months).

- Consumption and water prices data are collected from the regulatory agency SISS.
- Socioeconomic and demographic data are collected from the CASEN survey, a national household survey, available for 2009, 2011 and 2013.
- Climate data are collected from the DMC and DGA, assembled by the Center of Cllimate Science and Resilience.

Per household consumption is calculated by dividing total consumption by the total number of households in each locality.

Therefore, we have a measure that can be interpreted as the per household water consumption of a *representative household* of the locality.

Figure: Per household consumption (ln(m3)) over time.

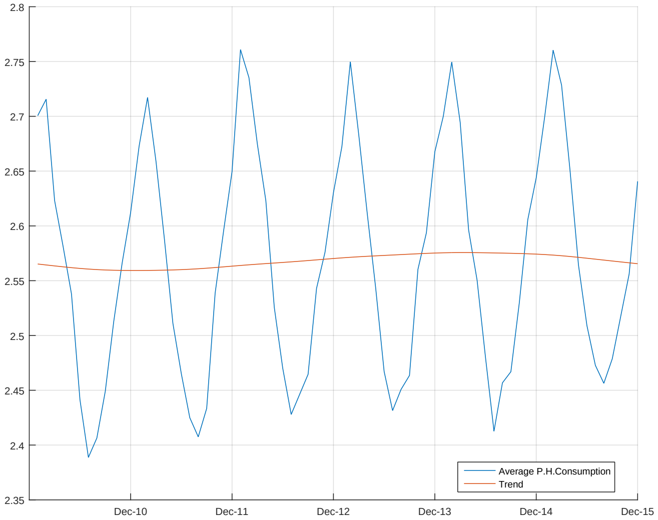
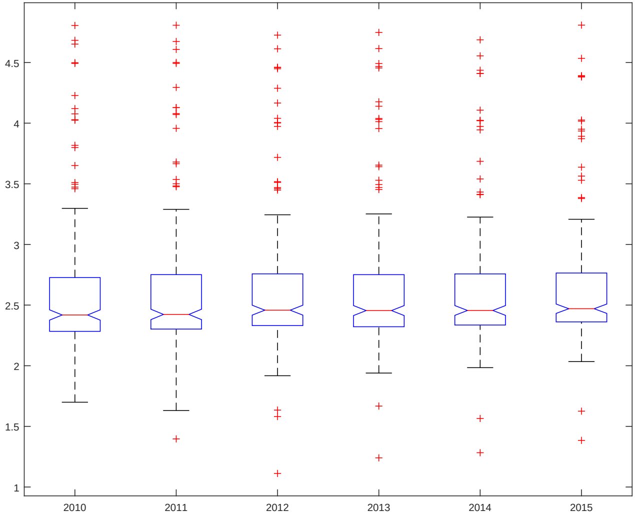
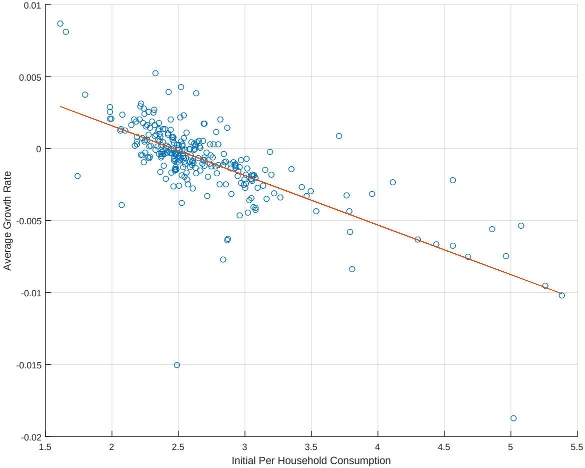


Figure: Box plot: per household consumption (ln(m3)) per year.



Empirical Results

We find a strong negative correlation (-0.72) between the average growth rate and the initial level of income.



Empirical Results

We can estimate the speed of convergence β by regressing the average growth rate of a set of localities between times t_0 and $t_0 + T$ on the initial level of income, using the following nonlinear **growth equation**:

$$\frac{1}{T}\log\left(\frac{y_{it_0+T}}{y_{it_0}}\right) = \alpha + \left(\frac{1-\exp(-\beta T)}{T}\right)\log(y_{it_0}) + u_{it_0+T} \tag{1}$$

If β is positive, then we have evidence of β-convergence.

For estimation we considered only the localities for which we had the whole 6 years of observations (72 months), and we worked with the monthly growth rate.

Empirical Results

Table: Growth Equation

	Av. Growth Rate
Constant (alpha)	0.0085***
	(0.0000)
Initial consumption (beta)	0.0040***
	(0.0000)
N	269
R2	0.5186

Empirical Results

Table: Mean and Dispersion of per household consumption

Year	Mean	Std.Dev.
2010	2.5589	0.4888
2011	2.5651	0.4871
2012	2.5833	0.4714
2013	2.5840	0.4671
2014	2.5837	0.4531
2015	2.5944	0.4379

The dispersion of per household consumption is decreasing over time, so there is σ-convergence: the per household consumption distribution is less unequal.

However, the convergence is heading towards a higher level of consumption, which is undesirable from the point of view of sustainable development.

Figure: Dispersion of per household consumption (standard deviation) over time.

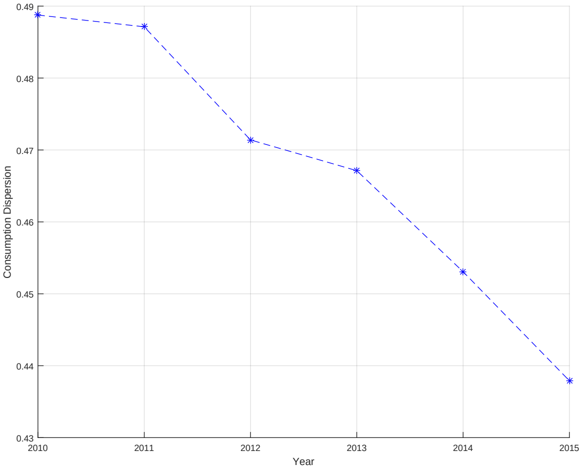
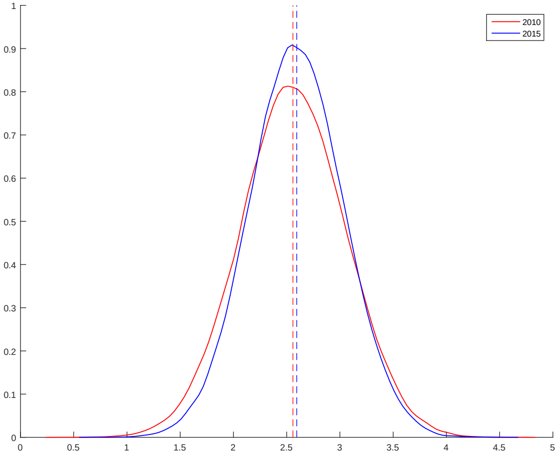


Figure: Per household consumption distribution: 2010 vs 2015



Why is there convergence?

We estimate a water demand equation to analyze which variables can mainly explain the convergence of per household consumption over time.

For robustness of the results, we estimate three models of the form $Q_d = f(P, Z)$, which relates water consumption to price (P) and other factors (Z) such as income, household and dwelling characteristics, and climate variables.

These equations depend on different assumptions for both, the coefficients and standard error estimations.

Models

Pooled OLS estimator, Clustered robust errors by locality:

$$y_{it} = \alpha + X_{it}'\beta + u_{it} \tag{2}$$

Between estimator, OLS standard errors:

$$\bar{y}_i = \alpha + \bar{X}_i'\beta + (\alpha_i - \alpha + \bar{u}_i) \tag{3}$$

Within estimator, AR(1) errors:

$$\begin{aligned} y_{it} &= \alpha_i + X_{it}'\beta + u_{it} \\ u_{it} &= \rho u_{it-1} + \varepsilon_{it} \end{aligned} \tag{4}$$

Variables

Dependent Variable

Per household consumption by locality (ln) (siss)

Independent Variables

- Average price of water (ln)
- Per capita income (ln)
- Number of people in the household
- Number of people in the household aged below 15
- Number of bedrooms in the dwelling
- Number of bathrooms in the dwelling
- Monthly accumulated rainfall
- Monthly average temperature
- Interaction between rainfall and temperature
- Monthly dummies

About the endogeneity of water prices

When there are block prices, prices are endogenously determined by the quantity demanded, therefore there is a simultaneous-equations problem.

However, we consider the simultaneity problem as not relevant in our case, since only the 2% of the observations are associated with consumption in the second block of prices.

We repeated the estimations dropping those observations, and we obtained similar results.

Table: Water demand estimations

	OLS	BE	FE
Average Price	-0.3296***	-0.4792***	-0.0321***
	(0.0000)	(0.0000)	(0.0000)
PC Income	0.1751***	0.3444***	0.1999***
	(0.0020)	(0.0010)	(0.0000)
N People	0.2869***	0.3281***	0.0426***
	(0.0020)	(0.0100)	(0.0030)
People below 15	-0.3290**	-0.4881**	0.0436
	(0.0140)	(0.0380)	(0.1070)
N Bedrooms	0.1175***	0.1573	0.0163
	(0.0080)	(0.1800)	(0.2040)
N Bathrooms	0.3166***	0.1322	0.0354
	(0.0010)	(0.3570)	(0.1550)
Acc. Rainfall	0.0002	-0.0065**	0.0002***
	(0.1570)	(0.0500)	(0.0000)
Av. Temperat	0.0210***	0.0013	0.0040***
	(0.0000)	(0.9340)	(0.0000)
Rainfall*Tempet	0.0000	0.0006*	0.0000***
	(0.1350)	(0.0840)	(0.0000)
Constant	0.7712	0.3628	-0.0354***
	(0.3570)	(0.7840)	(0.0090)
N	21,230	21,230	20,792
R2	0.4013	0.0261	0.2385
R2-within		0.0003	0.4001
R2-between		0.4253	0.3037

Table: OLS regression with standardized variables

	OLS
Tarifa Promedio	-0.3195***
	(0.0000)
Ingreso PC	0.1448***
	(0.0020)
N Personas	0.1987***
	(0.0020)
Menores de 15	-0.1236**
	(0.0140)
N Dormitorios	0.0696***
	(0.0080)
N Baños	0.1954***
	(0.0010)
Precipitaciones	0.0371
	(0.1570)
T Media	0.1852***
	(0.0000)
Precip*T Media	-0.0408
	(0.1350)
Constante	-0.3496***
	(0.0000)
N	21,230
R2	0.4013

Results

Per household consumption depends on two types of forces, one of them decreasing per household consumption and the other decreasing it.

Among the factors decreasing per household consumption during the period, the increase in prices has been the most important followed by the decrease in the number of people in the household.

Among the factors increasing consumption growth rate, income related factors have been the most important.

Table: Regressors: average annual growth rate. Cluster 1 groups low income localities; Cluster 2 groups medium income localities; Cluster 3 groups high income localities.

Variable	Mean	Cluster 1	Cluster 2	Cluster 3
Av. Consumption	0.6%	0.8%	0.2%	-1.9%
Average Price	3.9%	3.9%	3.6%	4.2%
PC Income	3.5%	3.6%	4.2%	-1.6%
N People	-1.5%	-1.4%	-1.4%	-2.8%
People below 15	-4.0%	-3.8%	-5.2%	-1.3%
N Bedrooms	0.7%	0.8%	0.3%	0.1%
N Bathrooms	0.5%	0.4%	0.9%	0.1%
Acc. Rainfall	-0.1%	-0.3%	1.7%	-5.8%
Av. Temperat	0.1%	0.0%	0.7%	-1.4%

Conclusions

First, we find evidence of absolute β-convergence and σ-convergence in per household water consumption:

- Consumption of localities with smaller initial levels of consumption tends to grow faster than localities of higher initial level of consumption.
- Per household consumption distribution has been becoming less unequal.

Second, the main reason of convergence appears to be the increase in income of poor localities, which have enabled them to consume more water.

Conclusions

However, the convergence is heading towards a higher level of consumption, which is undesirable from the point of view of sustainable development.

It is desirable to have σ-convergence to achieve social justice, but the convergence should be to a smaller level of consumption.

Therefore, this evidence justifies the implementation of programs promoting efficient consumption at a household level, with the aim of moderating the increase in per household consumption over time (as a climate change adaptation measure), and these programs must be focused in households with high levels of consumption.