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Social Impacts of Climate Change in Chile

A Municipal Level Analysis of the Effects of Recent and Future Climate Change on Human Development and Inequality

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Abstract

This paper uses municipality level data to estimate the general relationship between climate, income, and life expectancy in Chile. The analysis finds that incomes are negatively related to temperature, while life expectancy is not significantly related to average temperatures. Both incomes and life expectancy are greater in areas with either very little rain or a lot of rain. The authors use the estimated relationships to simulate the effects of both past (1958–08) and future (2008–58) climate change. The findings indicate that past climate change has been favorable for the central, and most populous, part of Chile, and it has contributed to reduced poverty and reduced inequality of health outcomes.

Whereas temperatures in the past have shown a downward trend for most of the Chilean population, climate models suggest that they will increase in the future, and that there will be a reduction in precipitation in the central part of Chile. The analysis simulates the likely effects of these projected climate changes over the next 50 years. The findings suggest that expected future climate will tend to reduce incomes across the whole country, with an average reduction of about 7 percent, all other things equal.

This paper—a product of the Social Development Division, Sustainable Development Department—is part of a larger effort in the department to reduce poverty and vulnerability to climate change. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at dverner@worldbank.org.

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Social Impacts of Climate Change in Chile: A municipal level analysis of the effects of recent and future climate change on human development and inequality[*]

by

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1. Introduction

The Chilean territory stretches from the tropics to Antarctica and from the middle of the Pacific Ocean (Easter Island) to the Andean peaks almost 7 kilometers above sea level. This makes for tremendous climatic variation within a single country, and in this paper we will exploit some of this spatial variation to investigate how climate and climate change might affect human development in Chile.

Climate is affecting people and their activities in many complex and intertwined ways. Some activities, such as agriculture and tourism, are more sensitive to climatic conditions than others (e.g. accounting and teaching), and some population groups, such as people with poor health and those who work outdoors, are more sensitive to climate stresses than other groups. Not only does climate change affect each individual differently, but climate change in one place can have indirect effects on people on the other side of the globe, even if they don't experience any climate change themselves.[1]

Despite these multi-dimensional complexities, and without understanding all the underlying mechanisms and links, it is possible to assess the likely net effects of climate change on different population groups. In order to assess how climate change is likely to affect a particular population, two things are necessary: First we have to understand how climate is currently affecting them, and second we have to understand how climate is changing.

A simple way to gauge how climate affects human development is to compare human development across regions with different climates. For example, Horowitz (2006) uses a cross-section of 156 countries to estimate the relationship between temperature and income level. The overall relationship found is very strongly negative, with a 2°F increase in global temperatures implying a 13 percent drop in income. This is very dramatic, but the relationship is thought to be mostly historical and thus not very relevant for the prediction of the effects of future climate change. In order to control for historical factors, the paper includes colonial mortality rates as an explanatory variable, and finds a much more limited, but still highly significant, contemporaneous effect of temperature on incomes. The contemporaneous relationship estimated implies that a 2°F increase in global temperatures would cause approximately a 3.5 percent drop in world GDP.

In order to further control for historical differences, Horowitz (2006) uses more homogeneous sub-samples, such as only OECD countries or only countries from the Former Soviet Union, and the negative relationship still holds. However, for directions for further research, he recommends empirical studies of income and temperature variations within large, heterogeneous countries, which would provide much more thorough control for historical differences.

This is exactly what we will do in the present paper. Using data from 333 municipalities (*comuna*s) in Chile, we will estimate short-run relationships between climate variables

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[1] For example, an extensive drought in Central America might damage its coffee-production and the reduced supply of coffee would increase the world price of coffee, which could benefit coffee-producers in other parts of the world.

(average temperature and precipitation) and income, as well as between climate variables and life expectancy. While it is always dangerous to make inferences about changes in time from cross-section estimates, these relationships can at least be used to gauge the likely direction and magnitude of effects of climate change in Chile.

Two different types of climate change will be assessed. First, the documented recent climate change in each of the 333 municipalities, as estimated from average monthly temperature series from 1948 to 2008 for all the Chilean meteorological stations that have contributed systematically to the Monthly Climatic Data for the World (MCDW) publication of the US National Climatic Data Center. Second, we will use the predictions of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC4) climate models to simulate the likely effects of projected future climate change in Chile.

The rest of the paper is organized as follows. Section 2 describes the data sources and provides descriptions of the key variables. Section 3 estimates the cross-municipality relationships between climate and human development, controlling for other key variables that also affect development. Section 4 analyzes past climate change for 7 meteorological stations across Chile, and estimates average trends for each municipality. Section 5 uses the findings from sections 3 and 4 to simulate the effects of past climate change on incomes in each of the 333 municipalities in Chile. Section 6 summarizes the climate changes that are expected for Chile during the next 50 years, and section 7 simulates the likely effects of these changes on incomes. Section 8 concludes.

2. The data

The data used for this paper consist of both cross-section data and time series data. The municipal level cross-section data-base, which is used to estimate the relationship between climate and development in Chile, is constructed using data from different sources. Table 1 lists the variables, their definitions, and the sources of the information.

Table 1: Variables in the Chilean municipal level data base

Variable	Definition	Unit	Source
Total population	The number of inhabitants in the *comuna*.	-	2002 Census
Urbanization rate	The share of the population who lives in urban areas, where urban is defined as human settlements that has more than 2000 inhabitants *or* that has between 1,001 and 2,000 inhabitants with more than 50% of the population economically active in secondary or tertiary activities.	-	2002 Census
Years of education	Average number of years of education of the population aged 15 or more.	Years	2002 Census
Life expectancy	Life expectancy at birth for each *comuna* in 1998. This variable was derived from the health index of UNDP's Human Development Index.	Years	UNDP Chile (2000)
Per-capita income	Average household income per capita in each *comuna*, as estimated from the CASEN 2006 survey, which is representative at the *comuna*-level except for a few sparsely populated *comunas*. Pesos were converted into USD using the exchange rate 530.28 pesos/dollar.	USD/month	CASEN 2006
Latitude	Latitude of the main city in the *comuna*.	Degrees south of equator	Google Earth, GeoMaker
Longitude	Longitude of the main city in the *comuna*.	Degrees west of the Prime Meridian	Google Earth, GeoMaker
Elevation	Elevation of the main city in the *comuna*.	Kilometers above sea level	Google Earth, GeoMaker
Normal average annual temperature	The average annual temperature in the main city of the *comuna* as measured over a reference period (typically 1951-1990).	ºC	Chilean Meteorological Department and www.worldclimate.com
Normal annual precipitation	The average annual precipitation in the main city of the *comuna* as measured over a reference period (usually 1951-1990).	Meters	Chilean Meteorological Department and www.worldclimate.com

As we did not have meteorological data for each and every municipality in Chile, this information was estimated. Since average annual temperature in any particular location depends principally on distance from the equator and elevation above sea-level, we estimated a simple model (see Table 2) using information on average annual temperature, latitude, and altitude for all the Chilean stations for which we could obtain "normal" temperature data (from www.worldclimate.org). In order to get sufficient variation in the elevation variable, we included 4 stations located close to Chile (Catamarca, Mendoza, Arequipa, and Oruro).

Table 2: Model used to estimate temperature in Chilean municipalities with missing data

Variable	Coefficient	t-value	P-value
Elevation	-2.1518	-4.48	0.0000
Latitude	-0.3883	-8.87	0.0000
Constant	27.2469	17.25	0.0000
No. of observations	27		
R^2	0.7669		

The model indicates that, for every kilometer of elevation, the temperature drops 2.15 degrees Celsius, and for every latitudinal degree further south, the temperature drops 0.39 degrees. This information was used to estimate temperature in all the remaining municipalities, using the altitude and latitude of the municipality capital.

Precipitation does not present such simple regularities, so in order to estimate precipitation for the municipalities where this information was missing; we extended the findings from particular stations to the macro-region to which they belong. For example, for the northernmost macro-region, Tarapacá, we have precipitation data from two stations (Arica and Iquique), so we average the precipitation for these two stations and use this average for the remaining municipalities in the macro-region. This is a reasonable process, as Chile is a long, narrow country divided into 13 relatively homogeneous macro-regions from north to south. The three northernmost macro-regions (Tarapacá, Antofagasta, and Atacama) have desert climates with hardly any rain, but rain increases towards the south to a maximum in the macro-region Aisén, and then it falls again as we move further south.

As can be seen from Table 3, the variation in precipitation within each macro-region is quite small compared to the variation between macro-regions. One exception is the Aisén region, which is crossed by a mountain range, and precipitation is substantially larger on the western side of the range. Therefore all municipalities on the western side will be assigned the same precipitation as Aisén, whereas the municipalities on the eastern side will be assigned the same precipitation as Coihaique.

For one macro-region, O'Higgins, we did not have even one meteorological station, so we assumed that precipitation there was the average between the region immediately north of it (Metropolitan Region) and the region immediately south of it (Maule).

Table 3: Rules used to infer precipitation in municipalities for which precipitation data was not available in Chile

Macro-region	Available meteorological stations	Average annual precipitation for station (mm)	Average annual precipitation for macro-region (mm)
1. Tarapacá	- Arica	0.9	1.5
	- Iquique	2.1	
2. Antofagasta	- Antofagasta	3.5	3.5
3. Atacama	- Caldera	29.3	32.3
	- Copiapo	11.4	
	- Vallenar	56.1	
4. Coquimbo	- La Serena	119.0	119.0
5. Valparaíso	- Quintero	329.0	350.8
	- Valparaíso	372.5	
0. Metropolitan Region	- Santiago	312.5	325.4
	- Pudahual	338.2	
6. O'Higgins			523.6
7. Maule	- Curicó	721.7	721.7
8. Bío Bío	- Concepción	1276.4	1276.4
9. Araucanía	- Temuco	1152.7	1152.7
10. Los Lagos	- Valdivia	2445.3	1800.0
	- Osorno	1436.9	
	- Puerto Montt	1972.8	
	- Quellón	1344.8	
11. Aisén	- Aisén	2826.1	2826.1 (West)
	- Coihaique	596.1	596.1 (East)
12. Magallanes	- Punta Arenas	397.4	397.4

Source: Authors' estimation based on data from www.worldclimate.org .
Note: Island stations excluded due to dramatically different precipitation patterns than in mainland Chile.

In order to assess the climate change trends in the different parts of Chile, we obtained monthly temperature and precipitation data from 1948 to 2008 from the Monthly Climatic Data for the World (MCDW) publication of the US National Climatic Data Center.[2] Section 4 below contains a more detailed description and analysis of this data.

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[2] This data is available for free at http://www7.ncdc.noaa.gov/IPS/mcdw/mcdw.html (although in a very inconvenient format).

3. Modeling climate and human development

In this section, we will estimate the contemporary relationship between climate and human development in Chile. Two dimensions of human development will be analyzed: income and health, because these are the ones that most directly could be affected by climate change. Education, another human development indicator, is treated as an explanatory variable instead of a dependent variable.

As several researchers have pointed out, the relationship between temperature and development is likely to be hump-shaped, as both too cold and too hot climates may be detrimental for human development (Mendelsohn, Nordhaus and Shaw, 1994; Quiggin and Horowitz, 1999; Masters and McMillan, 2001, Tol, 2005). In order to allow for this possibility we include both average annual temperature and its square in the regression. The same argument also holds for precipitation and possibly also urbanization rates, which is why we also include precipitation and urbanization rates squared.

Thus, the regressions in this section will take the following form:

$$\ln y_i = \alpha + \beta_1 \cdot temp_i + \beta_2 \cdot temp_i^2 + \beta_3 \cdot rain_i + \beta_4 \cdot rain_i^2 + \beta_5 \cdot edu_i + \beta_6 \cdot urb_i + urb_i^2 + \varepsilon_i$$

where y_i is a measure of the income level in municipality i, $temp_i$ and $rain_i$ are normal average annual temperature and normal accumulated annual precipitation in municipality i, edu_i is a measure of the education level (average years of schooling), urb_i is the urbanization rate of the municipality, and ε_i is the error term for municipality i. The life expectancy regression will take the same form as the income regressions, except that we will not apply the natural logarithm to the dependent variable. All regressions are weighted OLS regressions, where the weights consist of the population size in each municipality. The regression findings for both income and life expectancy are reported in Table 4.

Table 4: Estimated short-term relations between climate and income/life expectancy in Chile

Explanatory variables	**(1)** (log per capita income)	**(2)** (life expectancy)
	9.4701	58.0242
Constant	(248.77)	(18.04)
	-0.0592	1.0571
Temperature	(-7.37)	(2.27)
	-	-0.0560
Temperature^2		(-3.12)
	-0.3153	-4.9969
Precipitation	(-4.30)	(-5.57)
	0.1195	1.5325
Precipitation^2	(3.68)	(3.87)
	0.3504	0.9710
Education level	(30.11)	(7.44)
	-	-2.5520
Urbanization rate		(-2.81)
	-0.6291	-
Urbanization rate^2	(-10.52)	
Number of obs.	324	333
R^2	0.823	0.364

Source: Authors' estimation based on assumptions explained in the text.

Note: Numbers in parenthesis are t-values. When t-values are numerically larger than 2, we will consider the coefficient to be statistically significant, corresponding to a confidence level of 95%.

The findings at the bottom of the table show that just these four explanatory variables (temperature, precipitation, education, and urbanization rates) explain more than 82 percent of the variation in incomes between the municipalities in Chile. This is a very good fit, which suggests that we have included the most important explanatory variables, and that including addition variables would make little difference. The same four variables only explain about 36 percent of the variation in life expectancy, which is less impressive but still good for a cross-section model.

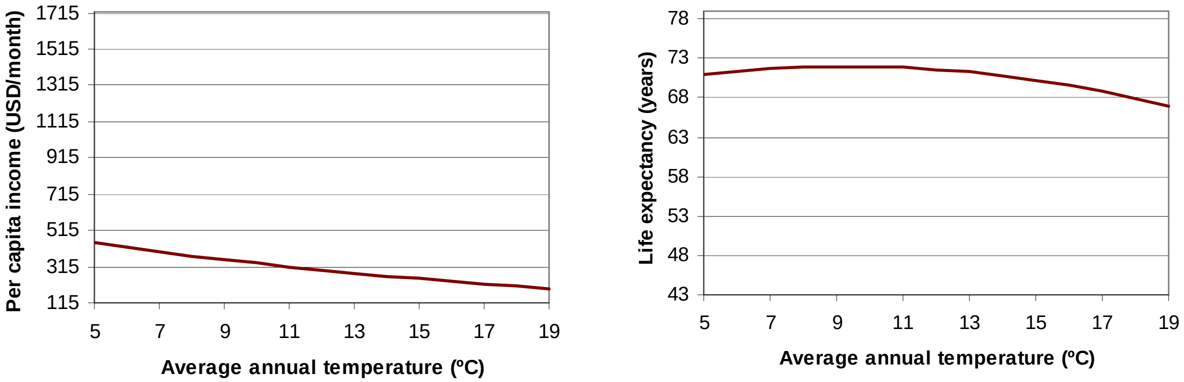
Education is by far the most important variable, explaining about 73 percent of the variation in incomes and about 26 percent of the variation in life expectancy. The remaining variables are also all statistically significant, but sometimes linearly and other times non-linearly. As it is difficult to judge the relationships directly by looking at the estimated coefficients, we have plotted the estimated relationships in Figure 1. The axes are scaled to represent the actual range of temperatures, precipitation, incomes, and life expectancies experienced in different Chilean municipalities, so that the magnitude of climate impacts can be seen in the appropriate perspective.

Panel (a) shows a negative relationship between average annual temperature and per capita income, with inhabitants of the warmest regions earning less than half the income of inhabitants from the coolest regions.

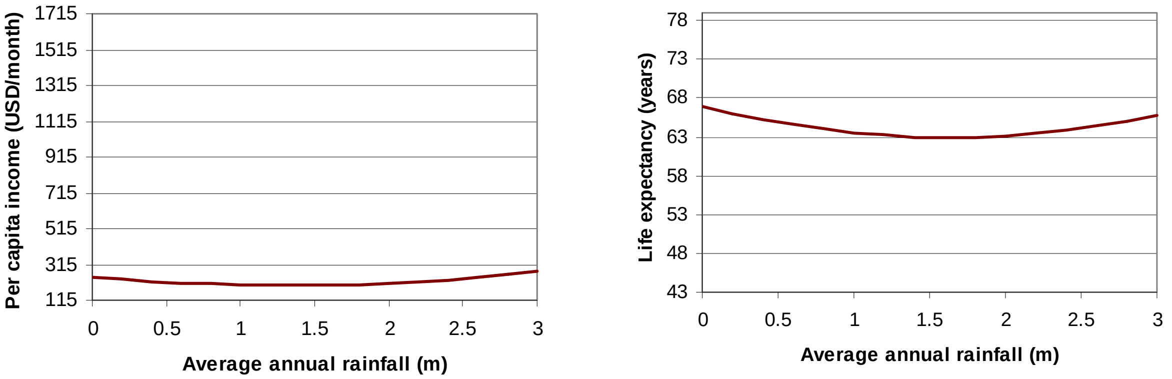
Panel (b) shows that life expectancy in the short run (when holding other factors constant) is almost 5.1 years shorter in the warmest regions compared to the regions with the most optimal temperatures. However, the relationship between temperature and life expectancy is not very tight. Indeed, the wide confidence interval on the estimated relationship suggests that there is no statistically significant relationship between temperature and life expectancy.

Figure 1: Estimated short-term relations between temperature/precipitation and income/life expectancy in Chile

(a) Temperature and Income **(b) Temperature and life expectancy**



(c) Precipitation and Income **(d) Precipitation and life expectancy**



Source: Graphical representation of the estimation findings from Table 3.
Note: The thick red line represents the point estimate from Table 3, whereas the thin black lines delimit the 95% confidence intervals as estimated using Stata's lincom command.

Panel (c) and (d) suggest that people in Chile do better with either very little rain or with a lot of rain. For intermediate amounts of rain, both incomes and life expectancy are lower. This is somewhat counter-intuitive, but the findings are robust.

4. Recent climate change in Chile

In this section we will analyze climate data for Chile from May 1948 to March 2008 to test whether there are any significant trends, and whether these trends differ between regions.

We will use the Monthly Climatic Data for the World database collected by the National Climatic Data Center (NCDC) in the US. This project started in May 1948 with 100 selected stations spread across the World, including five in Chile. Since then, many more stations have been included in the data base, but only seven stations in Chile have contributed systematically throughout the period, with only inconsequential gaps. These are listed in Table 5, ordered from north to south.

Table 5: Meteorological stations in Chile with almost complete monthly data, 1948-2008

Station	Latitude	Longitude	Elevation (m)
Arica	18°21'S	70°20'W	55
Antofagasta	23°26'S	70°27'W	140
La Serena	29°55'S	71°12'W	146
Isla Juan Fernandez	33°37'S	78°49'W	30
Valdivia	39°38'S	73°05'W	43
Puerto Montt	41°26'S	73°06'W	110
Punta Arenas	53°00'S	70°51'W	90

Source: NCDC’s Monthly Climatic Data for the World.

The original data was organized in 61 printed volumes with 12 issues in each (one for each month of the year), totaling 719 months. All data has been quality-checked and was published by the NCDC about three months after the raw data had been collected. From each of these monthly issues, we extracted average monthly temperature and total monthly precipitation for the seven Chilean stations listed above, in order to create time series for each station.

Once the temperature and precipitation series had been constructed and checked for unrealistic values (there was only one, which was eliminated), we proceeded to calculate “normal” temperatures and “normal” precipitation for each station-month for the reference period 1960-90.

Table 6 shows the average “normal” values for temperature and precipitation for each month for each of these stations. It is seen that the climate differs dramatically from region to region, with Arica and Antofagasta being located in tropical desert climates with almost no rain, while Valdivia and Puerto Montt are located in temperate, wet climates. There is also a sub-tropical island, Isla Juan Fernandez, with mild temperatures and moderate amounts of rain, and Punta Arenas with very cold winters, due to the location far south.

Table 6: Average temperature (ºC) and precipitation (mm) for 1960-90, by station in Chile

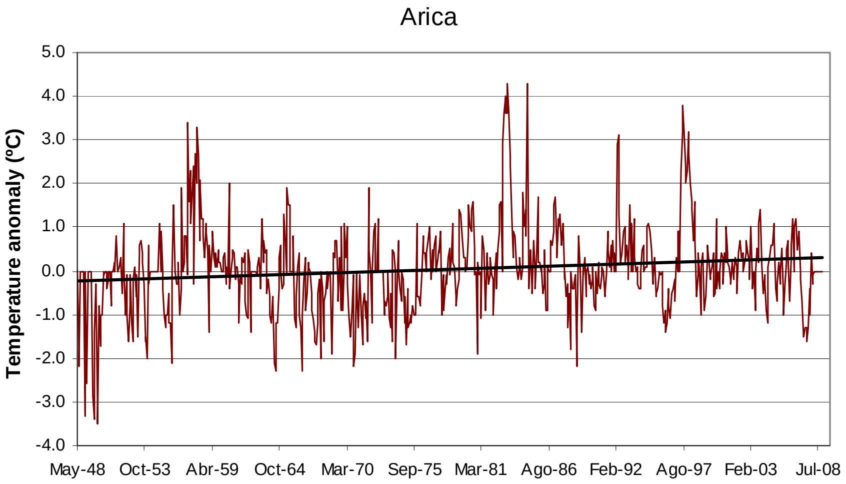
	Arica		**Antofagasta**		**La Serena**		**Isla Juan Fernandez**		**Valdivia**		**Puerto Montt**		**Punta Arenas**	
	Temp.	**Prec.**	**Temp.**	**Prec.**	**Temp.**	**Prec.**	**Temp.**	**Prec.**	**Temp.**	**Prec.**	**Temp.**	**Prec.**	**Temp.**	**Prec.**
January	22.1	0.0	20.2	0.0	17.1	0.0	18.7	32.4	16.3	57.6	14.4	88.2	10.5	36.5
February	22.2	0.2	20.1	0.0	16.9	0.0	18.7	30.8	15.5	51.4	14.2	82.2	10.2	28.1
March	21.5	0.0	18.9	0.0	15.6	0.3	17.9	61.9	13.6	70.1	12.2	97.5	8.4	29.7
April	19.5	0.0	16.9	0.0	13.6	1.1	16.7	84.5	10.8	136.4	10.1	134.2	6.0	42.7
May	17.7	0.0	15.4	0.0	12.3	6.7	15.6	147.4	9.2	296.9	8.5	210.5	3.8	41.9
June	16.5	0.2	13.9	0.2	11.1	17.3	13.7	168.0	7.3	266.5	6.8	206.0	1.8	26.9
July	15.7	0.3	13.4	0.3	10.7	35.8	13.0	178.6	7.2	316.0	6.7	238.8	1.3	35.1
August	15.6	0.1	13.7	0.9	10.9	17.5	12.5	106.2	7.7	250.8	6.7	200.8	2.2	36.1
September	16.3	2.2	14.6	0.2	11.6	6.1	12.5	79.4	8.7	154.8	8.0	148.8	4.0	23.8
October	17.5	0.0	15.6	0.0	12.8	1.6	13.4	47.3	10.9	122.4	9.5	151.8	6.4	24.5
November	18.9	0.1	17.1	0.0	14.0	0.3	15.0	38.8	13.1	69.6	11.6	104.1	8.2	30.9
December	20.7	0.0	18.6	0.0	16.2	0.0	16.9	35.7	15.2	69.3	13.4	100.9	9.8	30.1

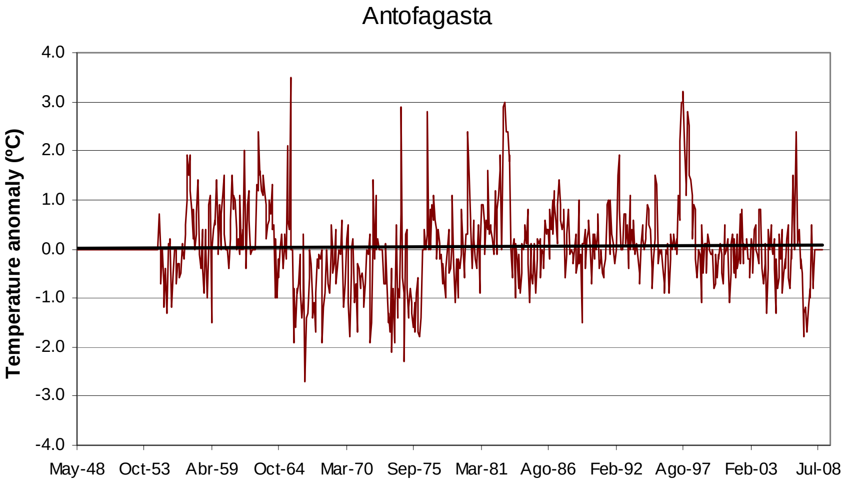
Source: Authors' estimation based on data from the NCDC's Monthly Climatic Data for the World.

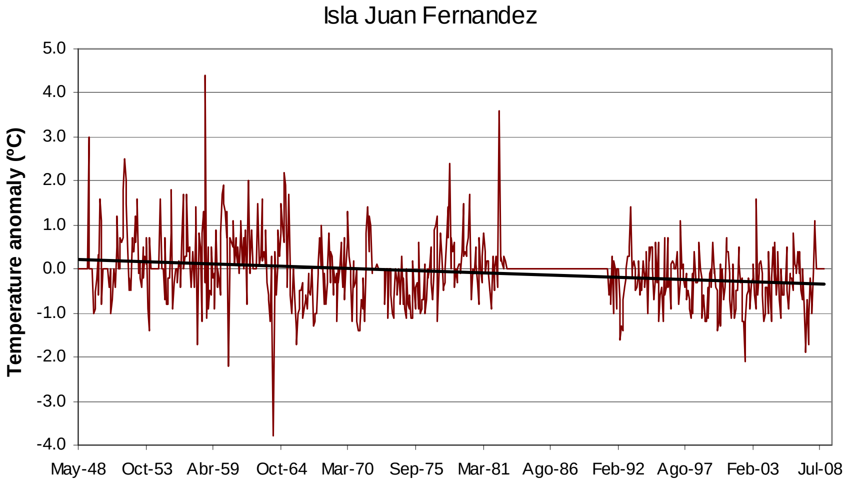
4.1. Temperature trends

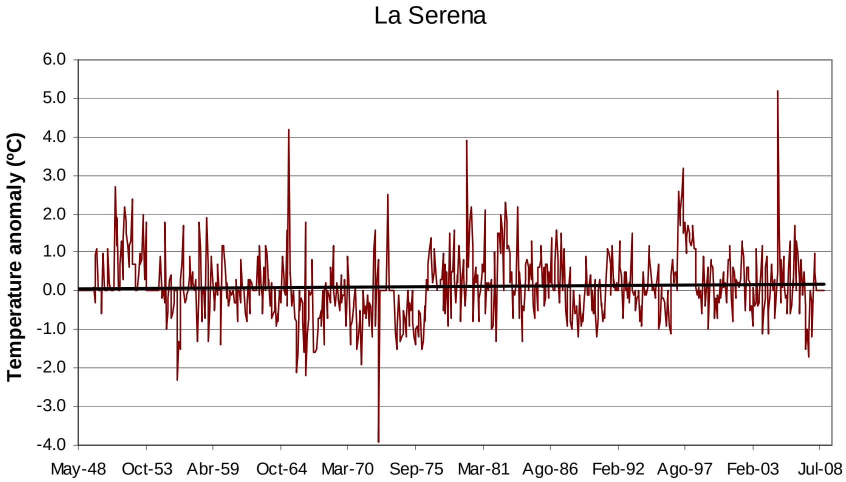
Using the "normal" values for each station and each month, we calculate monthly anomalies for each station for the whole period (actual temperature minus normal temperature for that month). Anomalies are easier to analyze than the raw temperature and precipitation data, since the seasonal variation is eliminated through the subtraction of normal monthly temperatures. Figure 2 plots the temperature anomalies for each station.

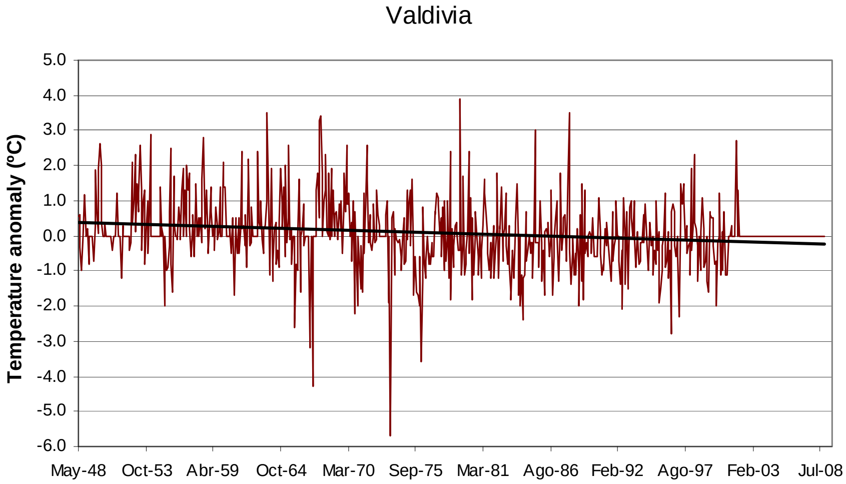
Figure 2: Monthly temperature anomalies for seven meteorological stations in Chile, 1948-2008






Isla Juan Fernandez
Temperature anomaly (ºC)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
May-48
Oct-53
Abr-59
Oct-64
Mar-70
Sep-75
Mar-81
Ago-86
Feb-92
Ago-97
Feb-03
Jul-08


La Serena
Temperature anomaly (ºC)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
May-48
Oct-53
Abr-59
Oct-64
Mar-70
Sep-75
Mar-81
Ago-86
Feb-92
Ago-97
Feb-03
Jul-08


Valdivia
Temperature anomaly (ºC)
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
May-48
Oct-53
Abr-59
Oct-64
Mar-70
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Feb-03
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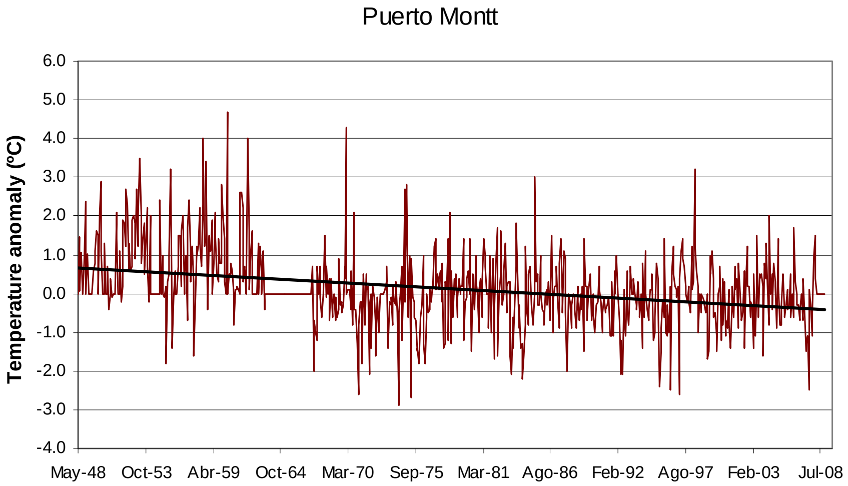
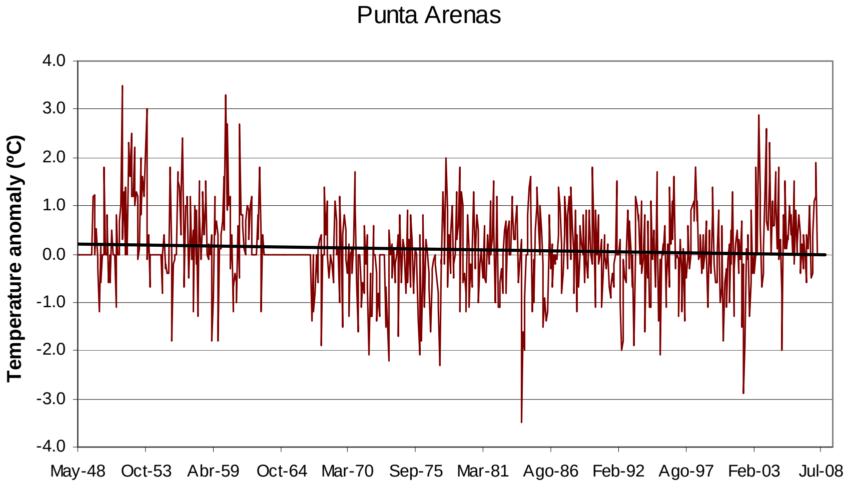




Source: Authors' estimation based on data from the NCDC's Monthly Climatic Data for the World.

Once we have the series of temperature anomalies, it is straightforward to test whether there is a significant trend. This is done simply by regressing the anomaly on a trend-variable, which has been scaled so that the coefficient can be directly interpreted as temperature change per decade in degrees Celsius. We use a confidence level of 95 percent to decide whether the trend is statistically significant, which means that the P-value should be less than 0.05 for the trend to be significant.

Table 7 shows the estimated trends for each of the seven stations in Chile. Of these, two stations show significant warming since the middle of the previous century; two show no significant change; and three show significant cooling.

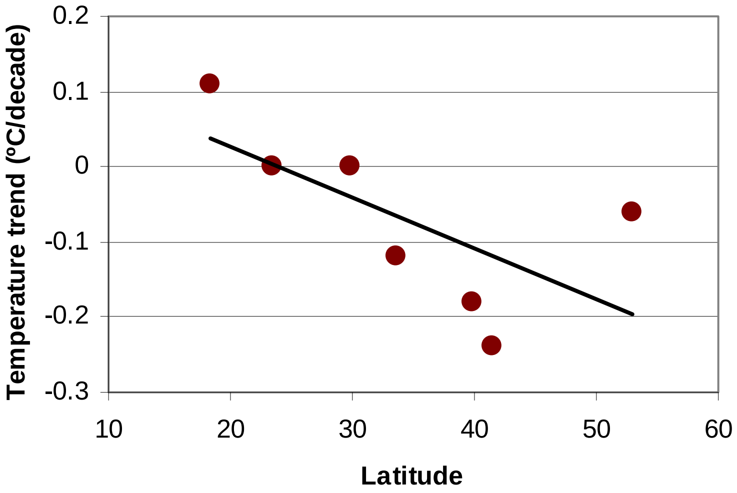
Table 7: Estimated temperature trend (ºC/decade) for seven stations in Chile

Station	Trend	t-value	P-value	# of obs.
Arica	0.11	4.40	0.000	648
Antofagasta	0.01	0.49	0.628	599
La Serena	0.02	0.73	0.465	624
Isla Juan Fernandez	-0.12	-6.14	0.000	531
Valdivia	-0.18	-5.66	0.000	547
Puerto Montt	-0.24	-9.98	0.000	605
Punta Arenas	-0.06	-2.54	0.011	549

Source: Authors' estimation based on data from the NCDC's Monthly Climatic Data for the World.

There seems to be a clear tendency for northern stations to be warming, southern stations to be cooling, and intermediate stations to experience no change (see Figure 3). This general pattern is confirmed by the latest IPCC report (see Trenberth et al. 2007, Figure 3.9 based on Smith and Reynolds, 2005)[3].

Figure 3: Estimated temperature trend (ºC/decade) versus latitude in Chile



Source: Authors' estimation based on data from the NCDC's Monthly Climatic Data for the World.

We will use this simple relationship to estimate the average temperature change experienced in each of the municipalities in Chile over the last 50 years. According to a simple regression, the trend is reduced by 0.067 ºC/decade for each 10 degrees we move south. This means that at the latitude of Antofagasta (23°26'S), there is no trend in temperatures, but for each 10 degrees further south, the 50-year change is reduced by

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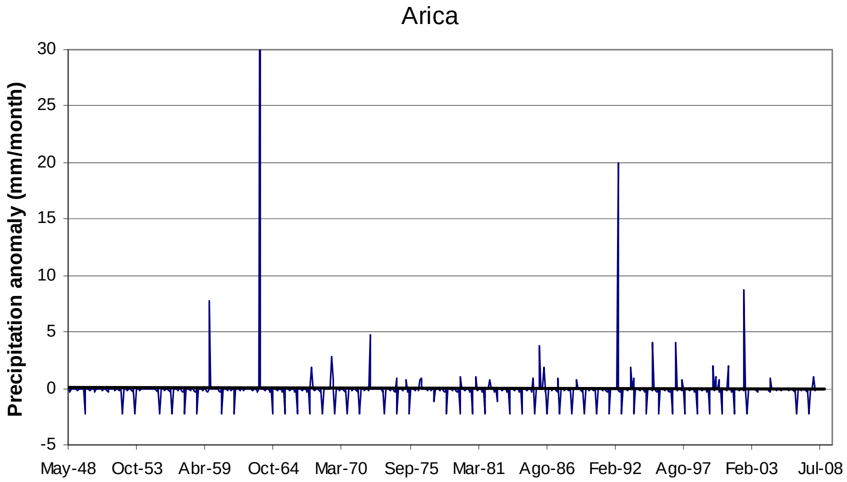
[3] Falvey and Garreaud (2009) partly confirm this, but their interpretation of the data is different. They suggest cooling along the coast and warming in the mountains. However, they only use data from 1979 to 2006, and such a short period is vulnerable to spurious trends produced by natural multi-decadal cycles.

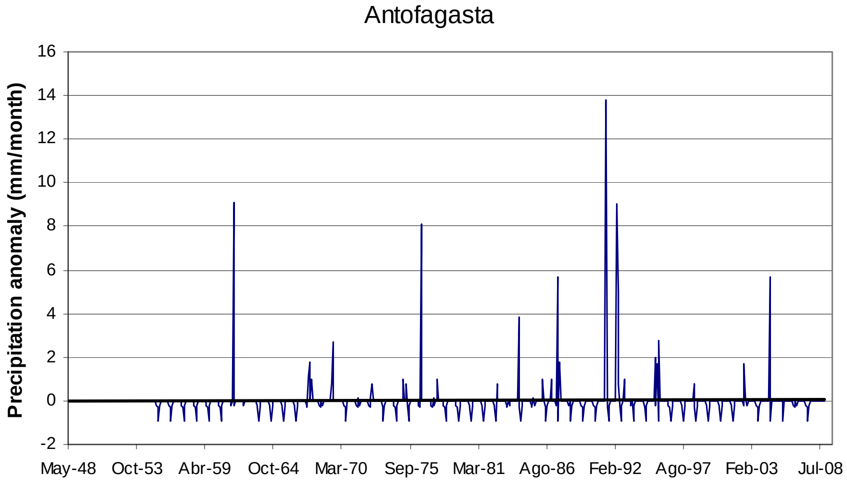
0.336ºC. Just south of Punta Arenas the change in temperatures over the last 50 years would be about -1ºC. At the most northern place in Chile, the temperature change over the last 50 years would be about +0.17ºC.

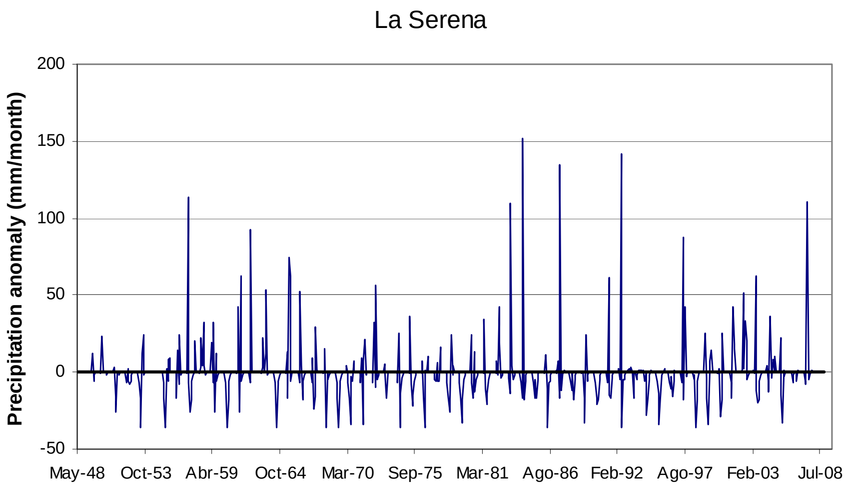
4.2. Precipitation trends

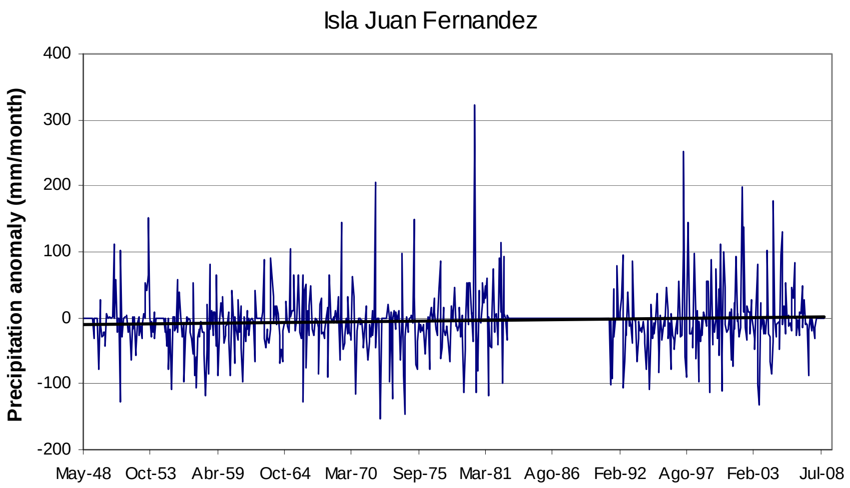
Figure 4 plots precipitation anomalies for the same seven meteorological stations in Chile.

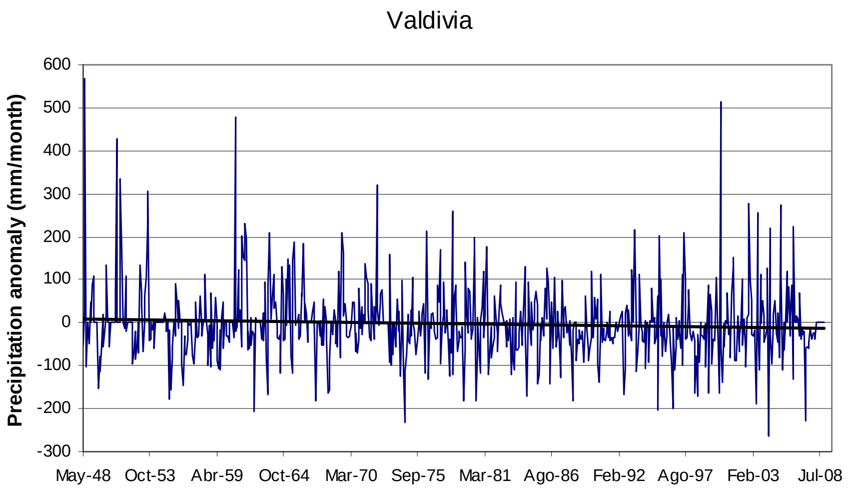
Figure 4: Monthly precipitation anomalies (mm/month) for 7 meteorological stations in Chile, 1948-2008



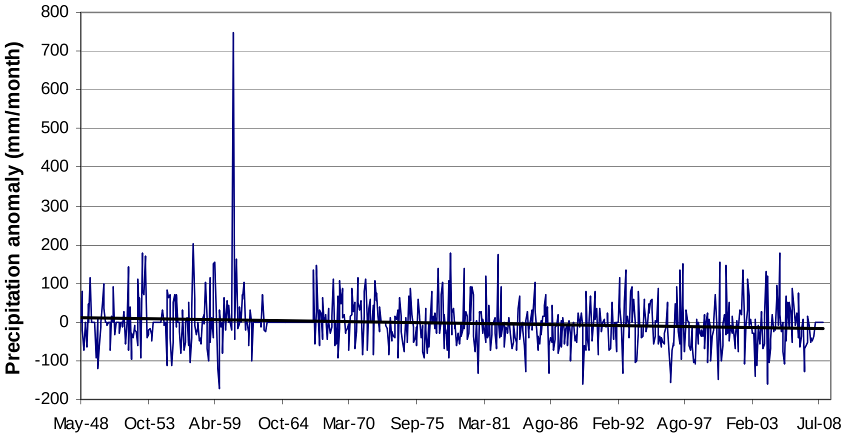



La Serena
Precipitation anomaly (mm/month)
200
150
100
50
0
-50
May-48
Oct-53
Abr-59
Oct-64
Mar-70
Sep-75
Mar-81
Ago-86
Feb-92
Ago-97
Feb-03
Jul-08

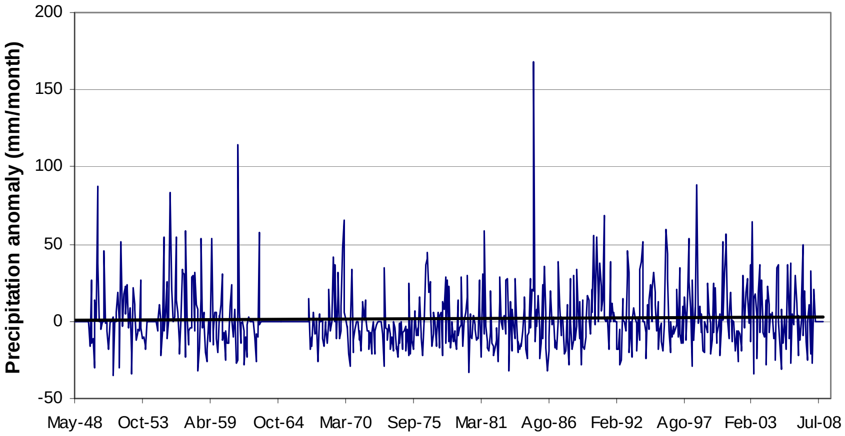

Isla Juan Fernandez
Precipitation anomaly (mm/month)
400
300
200
100
0
-100
-200
May-48
Oct-53
Abr-59
Oct-64
Mar-70
Sep-75
Mar-81
Ago-86
Feb-92
Ago-97
Feb-03
Jul-08


Valdivia
Precipitation anomaly (mm/month)
600
500
400
300
200
100
0
-100
-200
-300
May-48
Oct-53
Abr-59
Oct-64
Mar-70
Sep-75
Mar-81
Ago-86
Feb-92
Ago-97
Feb-03
Jul-08

Puerto Montt



Punta Arenas



Source: Authors' estimation based on data from the NCDC's Monthly Climatic Data for the World.

A trend analysis, like the one performed on temperatures above, reveals two mid-latitude stations with a significant negative precipitation trend, while the remaining five stations show no significant trend (see Table 8). This is consistent with the findings in the latest IPCC report (see Magrin et al. 2007, Figure 13.1).

Table 8: Estimated precipitation trend (mm/decade) for seven stations in Chile

Station	Trend	t-value	P-value	# of obs.
Arica	-0.02	-0.28	0.782	632
Antofagasta	0.02	0.75	0.451	585
La Serena	0.05	0.10	0.923	618
Isla Juan Fernandez	2.26	1.75	0.080	537
Valdivia	-5.01	-2.24	0.026	621
Puerto Montt	-5.26	-3.18	0.002	601
Punta Arenas	0.31	0.58	0.565	595

Source: Authors' estimation based on data from the NCDC's Monthly Climatic Data for the World.

The regions that have seen significant reductions in precipitation over the last 60 years, are the ones that initially (and still) received the largest amounts of precipitation, and the significant reductions are limited to the season with the heaviest rains (May to August). Valdivia, for example, used to receive about 280 mm of rain per month during the rainy season, but this amount has been going down by about 5 mm per decade over the last half century, or about 10 percent over 50 years.

For the purposes of the simulations in the following section, we will assume a 10 percent reduction in precipitation over the last 50 years for all municipalities located between 35ºS and 45ºS.

5. Simulating the impact of recent climate change

Since life expectancy was not found to depend significantly on temperature, and since precipitation changes are limited to a small region in the middle of the country with already abundant precipitation, we will limit the simulation analysis to the impact of climate change on average incomes.

To find the impacts of recent climate change we will compare the following two scenarios: 1) Climate Change, which is the factual scenario, and 2) No Climate Change, which is the counterfactual scenario. The Climate Change temperatures are the actual temperatures in each municipality, whereas the No Climate Change temperatures are the actual temperatures minus the temperature changes experienced over the last 50 years, according to the analysis in the previous section. Similarly, Climate Change precipitation are the actual precipitation levels, while No Climate change precipitation is 10% higher in all municipalities located between 35ºS and 45ºS, as indicated by the analysis in the previous section.

The ratio of Climate Change Income to No Climate Change Income can be written as:

$$\Delta_{CC} Y_i = \frac{Y_{i,CC}}{Y_{i,NCC}} = \frac{\exp\left\{\hat{\beta}_1 \cdot t_{i,CC} + \hat{\beta}_2 \cdot t_{i,CC}^2 + \hat{\beta}_3 \cdot r_{i,CC} + \hat{\beta}_4 \cdot r_{i,CC}^2\right\}}{\exp\left\{\hat{\beta}_1 \cdot t_{i,NCC} + \hat{\beta}_2 \cdot t_{i,NCC}^2 + \hat{\beta}_3 \cdot r_{i,NCC} + \hat{\beta}_4 \cdot r_{i,NCC}^2\right\}}$$

After estimating this ratio for each municipality, it is easy to calculate the percentage change in income levels that can be attributed to climate change.

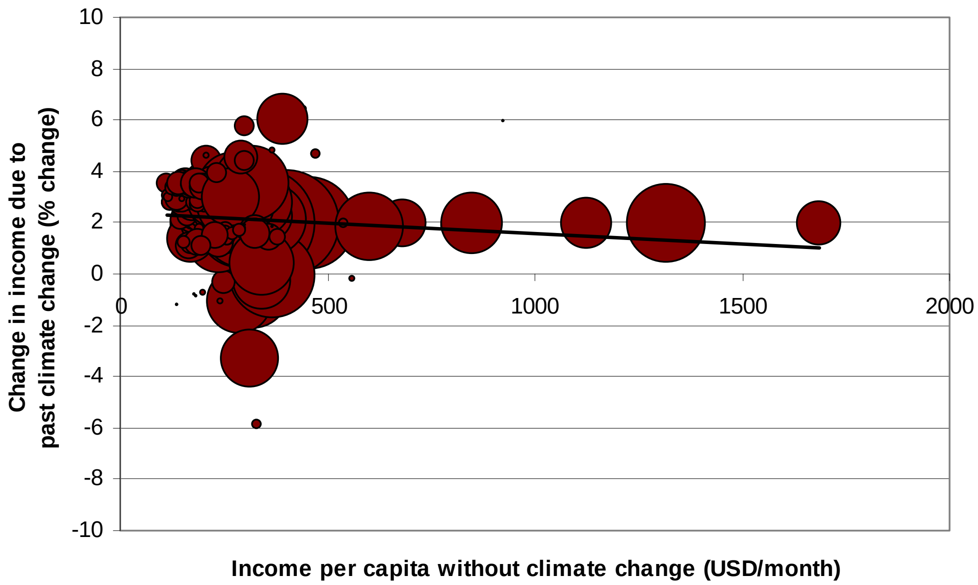
At the national level, the simulation indicates that incomes have increased by about 2 percent due to recent climate change. This is mostly due to the cooling of all but the most northern regions, since colder climates have been shown above to be more favorable for income generation in Chile. Figure 5 plots the estimated change in income at the municipal level against the income level each municipality would have had in the absence of recent climate change.

Table 9: Effects of recent climate change on income (% change), by region in Chile

Region	Effects of temperature changes	Effects of changes in precipitation	**Total effect of recent climate change**
1. Tarapacá	-0.9	0.0	**-0.9**
2. Antofagasta	-0.1	0.0	**-0.1**
3. Atacama	0.7	0.0	**0.7**
4. Coquimbo	1.3	0.0	**1.3**
5. Valparaíso	1.8	0.0	**1.8**
0. Metropolitan Region	1.9	0.0	**1.9**
6. O'Higgins	2.1	0.0	**2.1**
7. Maule	2.4	0.8	**3.2**
8. Bío Bío	2.7	0.1	**2.8**
9. Araucanía	3.0	0.5	**3.5**
10. Los Lagos	3.5	-2.5	**0.9**
11. Aisén	4.4	-0.8	**3.6**
12. Magallanes	6.0	0.0	**6.0**
Total	**2.1**	**-0.1**	**2.0**

Source: Authors' estimations.

Figure 5: Estimated change in incomes due to past climate change versus initial income level, municipal level in Chile



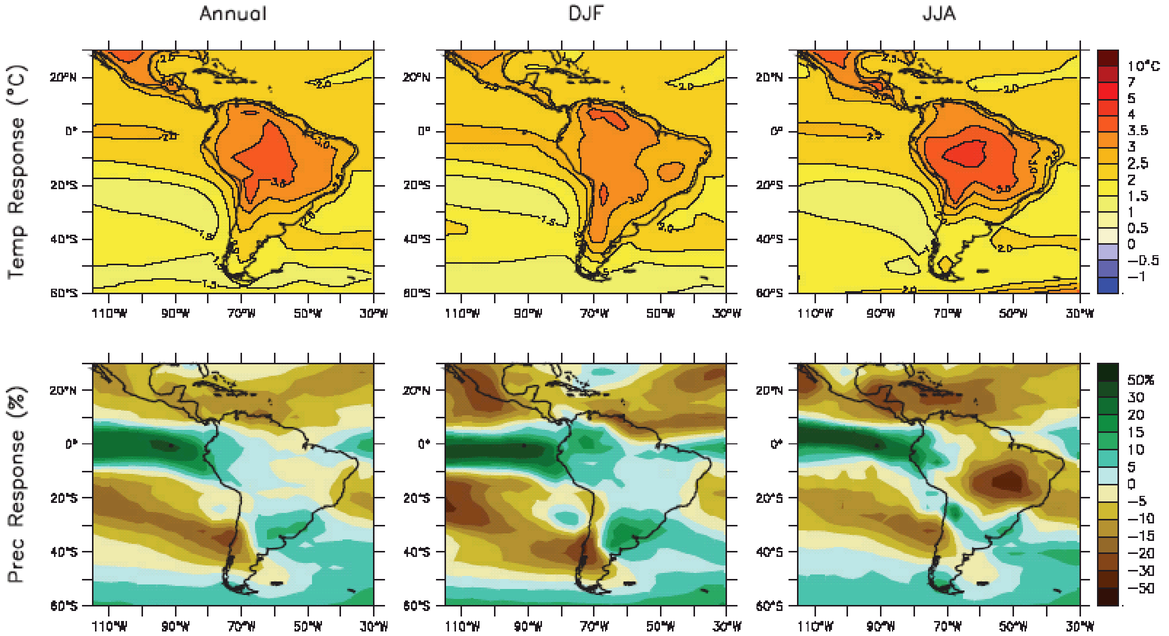
There is a slight, statistically insignificant, negative relationship, indicating that recent climate change has not had any significant effect on the income distribution, but that it has contributed slightly towards poverty reduction in all but the most northern municipalities.

6. Expected future climate change in Chile

Having quantified the impacts of climate change during the last 50 years, we now turn to an assessment of the likely impacts of possible climate change during the next 50 years. For that purpose we will use the regional climate projections made by Working Group 1 for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, which provides a comprehensive analysis based on a coordinated set of 21 Atmosphere-Ocean General Circulation Models (Christensen et al 2007). The use of several different models allows an assessment of the level of confidence with which predictions can be made.

According to the model simulations reported in Christensen et al (2007), temperatures are going to increase faster in the northern part of Chile than in the southern part (see Figure 6). This thus corresponds well to the pattern observed in the past.

Figure 6: Temperature and precipitation changes predicted by the climate models used by IPCC 4, 1990-2090 in Latin America and the Caribbean



Source: Christensen et al 2007, Figure 11.15.

Since temperatures are projected to increase almost linearly over this century, it is reasonable to assume that temperature increases over the next 50 years will range from 1.5ºC in the northernmost part of Chile to 0.75ºC in the southernmost part, so we will gradually (linearly) increase the amount of warming from 0.75ºC at 54.95ºS to 1.5ºC at 17.65ºS.

Most of the models used for these projections suggest that there will be a reduction in precipitation in central Chile due to a pole ward shift of the South Pacific and South Atlantic subtropical anticyclones (Christensen et al (2007, p. 896). The magnitude of reductions that can be expected in central Chile over the next 50 years appears to be around 10 percent, which is very similar to what has happened over the last 50 years, but now starting from a slightly lower base in the central region.

7. Simulating the impact of expected future change

The simulated effects of future climate change on incomes are presented in Table 10. The overall reduction in incomes we might expect due to the climate change over the next 50 years is around 7 percent. The negative effects are stronger in the north, which is expected to experience more warming than the southern regions, but all regions are projected to experience a significant negative impact from climate change (holding all else constant).

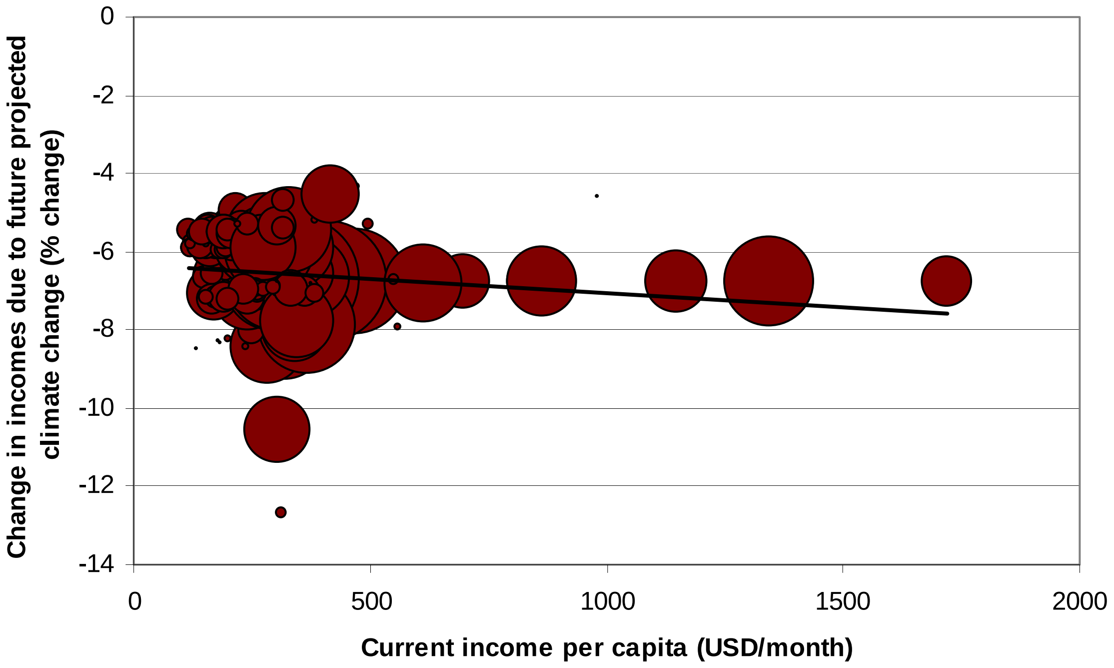
Table 10: Effects of future climate change on income (% change), by region in Chile

Region	Effects of temperature changes	Effects of changes in precipitation	**Total effect of future climate change**
1. Tarapacá	-8.3	0.0	**-8.3**
2. Antofagasta	-7.9	0.0	**-7.9**
3. Atacama	-7.4	0.0	**-7.4**
4. Coquimbo	-7.1	0.0	**-7.1**
5. Valparaíso	-6.8	0.0	**-6.8**
0. Metropolitan Region	-6.8	0.0	**-6.8**
6. O'Higgins	-6.6	0.0	**-6.6**
7. Maule	-6.5	0.8	**-5.7**
8. Bío Bío	-6.4	0.5	**-5.9**
9. Araucanía	-6.2	0.7	**-5.5**
10. Los Lagos	-5.9	-1.6	**-7.5**
11. Aisén	-5.4	-0.6	**-6.0**
12. Magallanes	-4.6	0.0	**-4.6**
Total	**-6.7**	**0.0**	**-6.7**

Source: Authors' estimations.

Figure 7 plots the estimated change in incomes for each municipality against the current level of incomes. There is a very weak, barely statistically significant, negative relationship (ρ = -0.12), which indicates that while future climate change is likely to have a negative effect on incomes, it is not going to contribute to increased inequality between municipalities.

Figure 7: Estimated change in incomes due to future climate change versus current income, municipal level in Chile



8. Conclusions

In this paper we first used a municipality level cross-section database to estimate the general relationship between climate and income in Chile. We found that incomes are negatively related to temperature, while life expectancy is not significantly related to average temperatures. Both income and life expectancy were higher for either very low levels of rain or high levels of rain, whereas intermediate levels of rain were less favorable.

These estimated relationships were then used to simulate the effects of both past (1958-2008) and future (2008-58) climate change. Past changes in climates were analyzed using historical data from seven meteorological stations spread across the territory, and estimating average trends for each station. It was found that trends varied systematically across the country, with northern regions having warmed over the last half century, southern regions having cooled, and central regions having experienced little or no change in temperatures. The central region did experience significant reductions in precipitation (about 10%), whereas the regions to the north and to the south experienced no changes.

The consequences of these past climatic changes were then simulated using the estimated cross-section models. The findings indicate that past climate change (reductions in temperatures and reductions in precipitation) has been favorable for the central part of Chile, where the majority of the population is concentrated, whereas the sparsely populated northern regions have suffered from warming.

Whereas temperatures in the past have shown a downward trend for most of the Chilean population, most climate models suggest that they should increase in the future, and that they will increase faster in the northern part of Chile than in the South. The models also indicate that the reductions in precipitation observed in the central part of Chile over the last 50 years will continue during the next 50 years, amounting to a further 10 percent drop over the next 50 years.

The paper simulated the likely effects of these projected climate changes, and found that expected future climate change would reduce incomes across the whole country, with an average reduction of about 7 percent.

Some qualifications to these findings are in order. First, the simulations have been carried out by varying only temperature and precipitation, but holding all other factors constant. Holding everything else constant is of course not realistic. Education levels are likely to increase and the structure of the economy is likely to keep changing towards activities that are less sensitive to the climate. If the high growth rates experienced over the last 25 years (5.2% per year) continue, incomes in 2058 would be 1,261 percent higher than now if there were no climate change, and 1,177 percent higher if climate changes as projected by the IPCC models. In either case, people will be considerably richer than they are now, and their ways of living may be so different, that the climate-income relationships of today are no longer relevant.

Another factor which is assumes to be constant, but which is almost certainly going to increase, is the atmospheric CO_2 concentration. It seems likely that atmospheric CO_2 concentration will increase from the current level of 387 ppm to somewhere between 500 and 600 ppm 50 years from now, depending on how effective Kyoto and Post-Kyoto policies are at reducing emissions. The resulting CO_2 fertilization effect may increase crop productivity significantly, as indicated by almost all studies of CO_2-fertilization (e.g. Allen et al 1987; Baker et al 1989; Poorter 1993; Rozema et al 1993; Wittwer 1995; Torbert et al 2004). Ignoring this beneficial effect may imply that the estimates presented in the present paper are too pessimistic.

Second, people do not necessarily have to stick around as temperatures increase, as the simulations in the present paper have assumed. Internal migration could potentially reduce the costs of climate change, if people can move towards regions with more suitable climates. Chile has climates for every taste, and the fact that the population currently is concentrated in the central region with moderate climates, whereas the extremes are sparsely populated, suggests that people have been taking advantage of this possibility in the past. Currently, however, adaptation through migration is somewhat hindered by the public housing policy. Soto and Torche (2004) show that the very effective public housing subsidies in Chile have the unfortunate side effect of tying people to their geographical location and inhibiting migration.

Third, this paper compares equilibrium situations before and after climate change, but ignores transition costs. Since climate changes in Chile are quite slow, especially compared to the natural variation from month to month and from place to place, such transition costs are likely small, but they may include additional investments in new reservoirs and irrigation systems, as hydroelectric facilities and water supplies are affected by changes in the water flow from melting glaciers.

Finally, it should be warned that the impacts found for Chile cannot be generalized to apply to other countries. The impacts of climate change differ from country to country depending on the spatial distribution of the population, the types of activities they are engaged in, and the particular patterns of climate change.

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