PLOS SUSTAINABILITY AND TRANSFORMATION

RESEARCH ARTICLE

Climate change's impact on real estate prices in Chile

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Citation: Hernández K, Luna F, Madeira C (2022) Climate change's impact on real estate prices in Chile. PLOS Sustain Transform 1(11): e0000035. https://doi.org/10.1371/journal.pstr.0000035

Editor: Wei-Ta Fang, National Taiwan Normal University, TAIWAN

Received: January 7, 2022

Accepted: October 7, 2022

Published: November 22, 2022

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Data Availability Statement: The TerraClimateData for Chile (and other countries, as well) is publicly available at https://www.climatologylab.org/terraclimate.html. See the reference: Abatzoglou, J., S. Dobrowski, S. Parks and K. Hegewisch (2018), "Terraclimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958-2015," Scientific Data, 5, 170191. The Chilean Real Estate Properties Registry (in Spanish, Catastro de Bienes Raíces) is not publicly available, but it is widely accessed by researchers in Chile with statistical confidentiality agreements with the Chilean Internal Revenue Service (in Spanish, Servicio de Impuestos

Abstract

Climate change should deteriorate the value of real estate, but studies are lacking for developing economies which may suffer the worst weather changes. We match an administrative register of all the real estate properties' transactions in Chile between 2002 and 2020 with a high spatial resolution dataset of local temperatures and precipitation. Even after controlling for a wide set of home characteristics or fixed-effects for each property, we find that fluctuations in temperatures had an impact on the prices of residential homes and agricultural properties.

Author summary

This work assesses the impact of climate change on real estate prices in Chile, analyzing two key climate change dimensions: change in temperature and change in precipitation. Chile presents a particular setting since it has a high climatic amplitude, allowing us to exploit the impact of temperature and rainfall on real estate prices for both low and high temperatures and more humid or dry regions. Our results show that hotter maximum temperatures during the Summer, Fall, and Winter seasons lowered the prices of residential homes. This result is consistent with the desire of households to avoid extremely hot days. Agriculture properties suffer an adverse effect from higher maximum and minimum Winter temperatures while experiencing a positive impact from higher minimum temperatures in the Summer, Fall, and Spring seasons, evidencing a preference from owners to avoid low temperatures except in Winter. Finally, from a prospective point of view, ex expects that maximum temperatures will have a negligible effect on Agricultural property prices in 2050. However, for the Residential Homes' prices, the higher maximum temperatures in 2050 could represent a substantial negative effect between -10.0% and -12.3% for the different possible scenarios.

Introduction

Climate change is predicted to affect negatively the economic growth of almost all the countries across the world during the 21st century [1, 2]. Climate change should also deteriorate

Internos): https://www.sii.cl/sobre_el_sii/estadisticas_y_estudios_del_sii.html. All the codes (Stata, Python and R) used in this article are publicly available in the repository Mendeley Data (https://data.mendeley.com/datasets/zn4xv8j9sc/1): Madeira, Carlos (2022), "Codes for replication of the article "Climate change's impact on real estate prices in Chile"", Mendeley Data, V1, doi: 10.17632/zn4xv8j9sc.1.

Funding: The authors received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist.

more the value of long term assets such as real estate [3, 4] and increase mortgage interest rates or securitization for the riskier homes [5–7]. Studies for the UK [4] and the United States have found a negative effect of global warming (as measured by natural disasters, flood risk or the risk of exposure to sea level rise) on housing prices [3, 4], although with heterogeneous reactions according to the beliefs of owners about climate change [8, 9] or their sophistication [10]. However, climate change impact studies on real estate are lacking for developing countries, despite these countries being predicted to suffer the worst economic effects due to their warm weather, oceanic location, geography proximity to the Equator and a larger relevance of the agriculture and fishing sectors [11, 12].

There is mounting evidence that the climate (i.e., long-term patterns of average of temperature, is being warmed and changed by human behavior). According to the 2021 International Panel on Climate Change [13], averaged over the next 20 years, global temperature is expected to reach or exceed 1.5˚C of warming. Every day, climate influences human activity, therefore households spend considerable amounts on housing, energy, clothing, and travel to protect themselves from extreme climates and to enjoy comfortable moderation. Geographically, climate affects the desirability of different locations and the quality of life they offer [14]. Given the undeniable influence climate has on economic decisions and welfare, is relevant to estimate the relationship between housing prices and changes in temperature, which is assumed to be related with quality of life and get insights about the future urban mobility occasioned by climate change. Thus, knowledge of the current and projected future global climate conditions is fundamental for the determination of vulnerabilities and the development of climate change adaptation strategies [15].

This work estimates the impact of climate change on real estate prices in Chile, analyzing two key climate change dimensions: change in temperature and change in precipitation [13]. Chile is an especially interesting case, because it is an example of a developing country that is estimated to suffer less from some aspects of climate change such as heatwaves due to its dry weather and its distance in latitude from the Equator [16]. Furthermore, it is a country that has been recently hit by mass political unrest [17], with some of its major concerns being the pension system and economic inequality, two aspects that may be worsened by climate change [18, 19]. Also, Chile has a high climatic amplitude which constitutes and interesting setting to study, since it allows us to exploit the impact of temperature and rainfall on the price of real estate for extreme climates, both low and high temperatures as well as more humid or dry regions.

For this purpose we match an administrative register of all the real estate properties' transactions in Chile between 2002 and 2020 with the TerraClimate dataset of local temperatures and precipitation. An exhaustive dataset for the real estate properties' transactions and characteristics is obtained from the Chilean Real Estate Properties Registry (in Spanish, *Catastro de Bienes Raíces*, hence on CBR). TerraClimate is a dataset of monthly climate and climatic water balance for global terrestrial surfaces, presenting a high spatial resolution of local temperatures and precipitation.

We then estimate two hedonic models for the effect of seasonal weather temperatures and precipitation on residential home and agricultural property prices. The first hedonic model considers fixed-effects for county, quality of the construction, plus the size and age of the property and its oldest appraisal value. The second hedonic model considers fixed-effects for each property plus controls for the size and age of the property. All the models consider the total precipitation, maximum and minimum temperatures for each property's local geocode in every season (Summer, Fall, Winter, Spring). We then apply these models to obtain an estimate of the impact of climate change on the Chilean real estate prices for the horizon of 2050.

There are other weather effects from climate change besides temperature and precipitation fluctuations, which this work does not study. Our model of housing prices is limited to temperature and precipitation, because these are the variables that are most consistently measured across different counties and over a long period of time, while other climate risks such as floods or fires are less consistently measured by weather databases [59]. Furthermore, most climate forecasts for the future are limited to temperature paths, since the frequency of other types of natural disasters is difficult to predict, especially for the distant future [13], therefore most counterfactual analysis in climate change economics are limited to temperature. Finally, it is worth noticing that most of the economic growth and development analysis of the impact of climate change is limited to either temperature-precipitation variables [20–24].

This works contributes to filling the gap in knowledge of the impact of climate change on real estate prices, especially for a developing country, since other works are focused mainly on the United States or other developed countries. Also, as far as we know, this is the first work to establish a relationship between two key climate change characteristics (temperature and precipitation) with house prices. Prior work focused on extreme and isolated events such as wildfires [25] and sea level rises [3, 4, 8, 9], but little is known of the impact of increases of temperature, which will be the most likely scenario in the future according to the IPCC 2021. Finally, this work complements the analysis of climate change risks for Chile. Previous works have shown a substantial uncertainty of the economic effects of climate change in Chile, with past estimates for the costs of climate change in terms of GDP ranging between a loss of 11% and a gain of 32% [26]. Recent work has shown that the Agriculture-Silviculture, Fishing and Energy-Gas-Water sectors in Chile could be more susceptible towards negative climate change shocks [16]. This work further complements the literature by showing that residential homes and real estate properties are also susceptible to weather shocks.

This work is organized as follows. Section 2 describes the matched dataset of the Chilean Real Estate Properties Registry with the TerraClimate weather measurements. We then summarize the econometric methodology of the hedonic models of real estate prices. Section 3 presents the econometric results of the estimated hedonic models. Section 4 concludes with a summary of the main results.

1 Climate change in Chile: Literature review

This section presents a brief literature review of the climate change literature in Chile. Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity [13]. According to the IPCC (2021) emissions of greenhouse gases from human activities are responsible for approximately 1.1 C of warming since 1850-1900, and finds that averaged over the next 20 years, global temperature is expected to reach or exceed 1.5˚C of warming. Moreover, according to IPCC (2021) climate change is affecting rainfall patterns. In high latitudes, precipitation is likely to increase, while it is projected to decrease over large parts of the subtropics. Changes to monsoon precipitation are expected, which will vary by region.

Chile's climate encompasses a wide range of conditions across a large geographic scale that spans almost 40 degrees latitude. Based on the Köppen-Geiger climate classification system, the climates of continental Chile are essentially arid (B), temperate (C) and polar (E) [27]. The north has a drier climate with relatively high temperatures, while the south has a cooler and more humid climate. Temperatures become gradually cooler from north to south [28]. The north weather corresponds to a cold desert climate with dry summer, where the temperature frequently exceeds 35˚C. The dryness of these regions is always limited to the plains; however, a cloudy coastal desert climate is observed towards the coast. The north center region

experiences cold semi-arid climate with dry summers. A cold semi-arid climate with dry summer is observed in the valleys and the mountains are characterized by a tundra climate with dry summers. The center-south regions experience Mediterranean climate. The south regions the classification corresponds to a marine west coast climate, while the most austral region experience tundra climate, with average temperatures below 0 C and a mean annual precipitation of 3500 mm [27, 29].

Climate change is expected to change the magnitude, frequency, intensity, and exposure to physical risks in Chile, especially due to changes in temperature and precipitation. Temperatures are expected to rise 1.4˚C-1.7˚C by mid-century and 3˚C-3.5˚C by the end of the century across all emission scenarios. The annual probability of heat waves in Chile could also increase by 8% by the 2040s and 20% by the 2090s. Precipitation is projected to decrease by 1.5 mm to 9.3 mm per month by the 2050s, to 5.5 mm to 11 mm by the 2090s [30].

The Central Chile Megadrought (2010-2021) is one of the longest drought events recorded over the last millennia, with a mean rainfall deficit of 20-40% [31]. A very emblematic case that has caused terrible water scarcity problems is the Petorca basin drought, experiencing the driest period over the last 700 years of streamflow reconstruction, where consumptive withdrawals reach up to 18% of the mean annual precipitation [32]. The Biobio basin in central south Chile has also suffered from drought periods that have affected agriculture in the area in the past two decades [33].

During the Megadrought in Central Chile, the number, area, simultaneity, and duration of large fires increased significantly compared with the previous 10-year period [34]. The fires of the 2016-2017 summer burned an area that was 14 times the mean for the period 1985-2016 and the highest on record till then [35]. This megafire was one of the severest ever recorded, burning in three weeks an area close to 350,000 hectares in south-central Chile [36] and was also associated with the prolonged drought and increase of heatwaves [37].

There's also been a significant increase of heatwaves in the Central macrozone [38] and an extreme sea level rise of 15-20 cm in Chile [39], with rainfall decreasing rapidly. Furthermore, droughts in the Central Chilean Andes increase the freezing resistance of high-Andean plant species, implying that warmer growing seasons due to climate change may threaten plant survival [40].

Water availability could change dramatically at some regions in Chile due to this changes in temperature and precipitation, which leaves the water system particularly vulnerable [41]. Adaptation studies for the city of Santiago show that water supply performance without climate change adaptations is worse under climate scenarios with lower water availability, which are likely to be associated with higher GHG emissions scenarios such as RCP 8.5 [42].

We also review the past studies for the impact of climate change on agricultural activity, which are summarized in Table 1. Agricultural activity is relevant, because of its high exposure to the weather and outdoors labor, therefore being subject to climate change. The OECD 2015 [1] estimates a positive impact of 0.30% of GDP for Agriculture and 0.40% of GDP for the aggregated Agriculture, fisheries and forestry sector, with the positive impact coming from stronger international demand for the Chilean products and from higher yields in rice, fruits and vegetables, sugar-cane and beet. However, these agricultural impact results are highly model dependent, with González and Velasco 2008 [34], Vergara et al. 2013 [11] and Bárcena et al. 2019 [12] showing negative estimates of climate change for the Chilean agriculture sector. The study of González and Velasco 2008, however, estimates that a warming of the globe by 2.5 degrees Celsius could result in a significant fall of 6.21% in the agricultural land value.

Furthermore, an extensive study of crops in Chile by Meza et al. 2021 [43] classified climate risks for agriculture and cattle production in terms of 6 categories: Opportunity (positive impact), No risk, Low risk, Moderate risk, High risk, Very high risk. Under this classification,

Table 1. Review of estimates for the climate change impact in Chile's Agriculture sector (relative to no climate change scenario).

Authors	Time horizon	Outcome	Estimated impact for Chile
Simulations of the impact on agriculture, health, energy, outdoors labor, flood damages			
OECD 2015	2060	Agricultural GDP	+0.30% in GDP
OECD 2015	2060	Agricultural GDP	+0.25% in GDP (global factors)
OECD 2015	2060	Agricultural GDP	+0.05% in GDP (domestic factors)
OECD 2015	2060	Agriculture, fisheries, forestry	+0.40% in GDP
OECD 2015	2050	Change in crop yields	+31% (rice), +9% (fruits and vegetables), +8% (sugar-cane and beet), -7% (other grains), -13% (wheat), -15% (plant fibres), -28% (oil seeds).
Vergara et al. 2013	2020	Change in crop yields	-8% (Coarse grains), 18% (Wheat)
Vergara et al. 2013	2050	Change in crop yields	-17% (Coarse grains), 19% (Wheat)
González and Velasco 2008	2100	Agricultural land value	-6.21% (+2.5˚C, -10% precipitation)
Bárcena et al. 2019	2080	Agricultural GDP	-27% (crop method)
Bárcena et al. 2019	2080	Agricultural GDP	-22% (Ricardian method)
Bárcena et al. 2019	2080	Agricultural GDP	-13% (with fertilization)
Bárcena et al. 2019	2080	Agricultural GDP	-24% (without fertilization)

https://doi.org/10.1371/journal.pstr.0000035.t001

they found No risk or Opportunity in most Chilean areas in terms of meat cattle raising, milk cattle raising, ovines, and productivity of the prairies. The same authors found that most areas in Chile show No risk or Low risk for the productivity of almonds, potatoes under irrigation, potatoes without irrigation, wheat under irrigation and wheat without irrigation. However, some areas—particularly, those in the central region of the country—show productivity risks for some crops, including cherry trees (Moderate risk), beans (Moderate and High risk in some areas), corn (Moderate, High, and Very High risk in some areas), red apples (Moderate, High, and Very High risk in some areas), and nuts (Moderate, High, and Very High risk in some areas).

2 Data description and econometric methodology

Our main dataset is the Chilean Real Estate Properties Registry (in Spanish, *Catastro de Bienes Raíces*, hence on CBR). This administrative dataset from the Chilean tax authorities includes all the real estate properties in Chile, whether for the purposes of Agriculture, Retail/Commerce, Offices, Residential, Storage/Cellar, Parking Space, or Empty Site/Undeveloped Terrain. For the purposes of our climate change analysis, we will focus only on the Agriculture and Residential properties. The CBR dataset contains the following information on each property in Chile: address, county, date (day, month, year) and price in real monetary units of the transaction, taxable value in real monetary units (implemented by tax authorities to prevent owners from under-reporting the properties' true transaction values), year and quality of the construction (with 7 categories for quality), property surface of the land area (in square meters), and property surface of the construction (in square meters). We use the available property transactions data between 2002 and 2020.

We then obtain latitude and longitude geocoding references for each address of the CBR data using the geospatial API of Google Maps and HERE developers, which have geographic coordinates with a detailed spatial resolution between 240 to 460 meters. Both APIs provided highly similar results and we used the average latitude-longitude location obtained from Google Maps and HERE. With the detailed georeferences for all the CBR properties, we match

each property to a grid square with a 1/24˚degree latitude x 1/24˚degree longitude (roughly, 4 square kilometers) from the TerraClimate weather dataset, which is publicly available from the Climatology Lab of the University of Idaho [44].

TerraClimate is a dataset of high-spatial resolution that provides gridded (1/24˚, ∼4-km) monthly climate and climatic water balance for global terrestrial surfaces since 1958 until the current year. TerraClimate uses climatically aided interpolation, combining high-spatial resolution climatological normals from the WorldClim dataset, with coarser resolution time varying (i.e., monthly) data from other sources to produce a monthly dataset of precipitation, maximum and minimum temperature, wind speed, vapor pressure, and solar radiation. TerraClimate datasets showed noted improvement in overall mean absolute error and increased spatial realism relative to coarser resolution gridded datasets. The data covers the terrestrial area of the globe with a grid size of 1/24˚degree latitude x 1/24˚degree longitude, which is approximately 4 square kilometers at the equator. The grid squares intersect the area of Chile. Using the TerraClimate dataset we obtain for each property-grid the maximum temperature, minimum temperature, and total precipitation accumulation for the period between 2002 and 2020 with a monthly frequency.

We preferred the TerraClimate dataset over other alternatives such as the Berkeley Earth Surface Temperature (BEST) and the University of Delaware Climate Dataset (UDEL) due to its higher resolution, since the Berkeley Earth and the University of Delaware are only available, respectively, with a 1˚x1˚ and 0.5˚x0.5˚ resolution grids. This implies that TerraClimate has a resolution that is 12 and 24 times higher than such alternatives. However, alternative datasets can be better in other aspects relative to TerraClimate. For instance, the Berkeley Earth is available with a daily frequency instead of just at the monthly level. Furthermore, the Berkeley Earth and University of Delaware datasets are available since the years 1750 and 1900, respectively, therefore such datasets provide a longer time frame of analysis that would not be possible in TerraClimate. Since our real estate registry is available only since 2002, we opted for the TerraClimate weather dataset and our focus on real estate properties (which are not traded daily, unlike bonds or stock market assets) as a more appropriate choice due to its higher resolution.

Using this matched CBR-TerraClimate dataset, we then estimate a hedonic models for house and agricultural properties' transaction prices and its relationship with the standard properties characteristics [45, 46] and augmented with measures of climate risks [3, 8].

We estimate this hedonic model for each property i in year t (located in geocode $g(i)$ and county $c(i)$) at time t:

$$\ln(P_{i,t}) = \alpha_{c(i)} + \beta_1 Age_{i,t} + \beta_2 \ln(S_{i,t}) + \beta_3 X_i + \gamma C_{g(i),t} + \boldsymbol{\varepsilon}_{i,t} \quad (1)$$

$$\ln(P_{i,t}) = \alpha_i + \beta_1 Age_{i,t} + \beta_2 \ln(S_{i,t}) + \gamma C_{g(i),t} + \boldsymbol{\varepsilon}_{i,t} \quad (2)$$

with $Age_{i,t}$ denoting dummies for the number of years of each construction (0-4 years of age, 5-10 years, . . ., until 80 years of age or more), $S_{i,t}$ denoting the surface area of the property in square meters, X_i denoting fixed characteristics of the property such as quality of construction fixed-effects or the first observed appraisal value for property i ($\ln(P_{i,t=0})$, in log), $C_{g(i),t}$ denoting climate weather variables for the geocode $g(i)$ at time t, and $\boldsymbol{\varepsilon}_{i,t}$ is an unobservable idiosyncratic factor that affects the property prices but which is unobserved by the econometrician. The vector $C_{g(i),t}$ includes the total precipitation and the minimum-maximum temperatures observed for all the season (summer, fall, winter, spring). The average for the monthly minimum and maximum daily temperatures and total precipitation for each geocode g are obtained from the Terra Climate dataset. The regressions include two different lags for the

year of the temperature seasons, with a first set of regressions applying a lag of two years and a second set of regressions applying a lag of three years. For the case of the precipitation, all the regressions use the lag of one year. The reason why we found optimal to use a longer lag for temperature is because the effects of temperature may require a longer trend of abnormal temperatures before making a difference for the perceived quality of living, while the precipitation may affect the agricultural productivity almost immediately.

There are many issues of whether a regression is linear or not in the covariates. Let us define the vector of covariates $Z_{i,t} \equiv \{\alpha_i, \alpha_{c(i)}, Age_{i,t}, \ln(S_{i,t}), X_i, C_{g(i),t}\}$. Since the true model for an endogenous variable $Y_{i,t}$ is unknown (in this case the endogenous variables is the log price of the house), it makes sense that very likely the true model has additional covariates in the $Z_{i,t}$ term such as quadratic or cubic terms of $Z_{i,t}$, therefore there could be reason to add $Z_{i,t}^2, Z_{i,t}^3$ and other variables to the regression model. Another way of estimating a non-linear model would be to consider a Kernel estimator, which would give local estimates $E\left[Y_{i,t} \mid Z_{i,t}\right] = \frac{1}{nh}\sum_{i=1}^{n} w_i K\left(\frac{x - Z_{i,t}}{h}\right)$, with h being optimized bandwidth and $K(.)$ being a function such as the normal density or Epanechnikov function. However, it is also true that models with more variables and non-linear models are harder to interpret. Non-linear models such as Kernel estimators are computationally hard to estimate with large datasets (our dataset includes millions of real estate properties) and with several variables that must be optimized. Models with quadratic and cubic terms can also suffer from a lack of precision due to many variables. However, even if the true model is non-linear, our regression coefficients still satisfy the property of being the best linear predictor of the variable $Y_{i,t}$ [47], satisfying the condition $\beta^* = \arg\min E[(Y_{i,t} - Z_{i,t}\beta)^2]$. It is worth noting that all the standard-errors in our regressions are clustered by county and year, therefore the analysis takes into account the heterogeneity of the data adequately.

These models consider as alternatives fixed-effects at the level of each county (Eq 1) and at the level of each home (Eq 2). Both fixed-effects and random-effects models seek to account for unobserved heterogeneity in the individual units (whether counties or homes, in the case of our application) that is fixed over time. The advantage of using fixed-effects instead of random-effects is that the fixed-effects account for any sort of correlation that is constant between the individual units and the unobserved idiosyncratic terms or the independent variables [48, 49]. The random-effects models account for unobserved heterogeneity of the individual units, but fail to account for correlation between these individual units and the unobserved idiosyncratic terms [49, 50]. Furthermore, the random-effects models assume a specific parametric distribution for the unobserved heterogeneity across individual units. This makes the random-effects estimator a specific case of the fixed-effects estimator, therefore most empirical applications prefer fixed-effects unless there is a small number of observations. For the cases in which the researchers are interested in the random-effects models, a Hausman test can show whether the data rejects the null hypothesis that the random-effects model is valid [48, 49]. An advantage of the random-effects models occurs in non-linear models, such as multi-category choice models, where it is harder to estimate fixed-effects consistently due to the incidental parameters problem [49] and with random-effects being useful to interpret the utility preference parameters of the model [50].

In the case of our empirical application of house prices and climate change, it is possible that counties or properties that are more exposed to the weather (such as temperature or precipitation fluctuations) could also be located in areas with worse economic opportunities and therefore worse expectations for future price appreciation. Since it is hard to account for all the possible variables in which different counties or real estate properties can differ among themselves, then it is relevant that the models estimated in this article use fixed-effects instead of random-effects

[51]. Finally, it is relevant to note that many of the economic analysis of real estate markets use fixed-effects to account for differences among geographical areas (this is the case, for instance, of the Case-Shiller indexes, as seen in Shiller 2007 [51] and Case et al. 2012 [52]).

3 Results

3.1 Linear regressions with quality and age characteristics

Now Table 2 summarizes the results for the hedonic model with county fixed-effects, that is the model in Eq 1), for Residential housing and Agricultural properties. For Residential housing, once we control for the first observed appraisal value of the property ($\ln(P_{i,t=0})$), the results

Table 2. Linear regressions (OLS) with fixed-effects for the county and quality of construction.

	Temperature lag: $k = 2$		Temperature lag: $k = 3$	
	Residential Homes	**Agriculture**	**Residential Homes**	**Agriculture**
$\ln(Area_{i,t})$	0.0386***	-0.00583	0.0426***	-0.00722
	(0.00645)	(0.00519)	(0.00662)	(0.00689)
$\ln(P_{i,t=0})$	0.939***	0.967***	0.935***	0.965***
	(0.00897)	(0.0121)	(0.00929)	(0.0125)
Precipitation Summer_{t-1}	-0.000287	-0.000203	-0.000182	-0.000154
	(0.000209)	(0.000194)	(0.000187)	(0.000149)
Precipitation Fall_{t-1}	-0.000196	-0.000185*	-0.000203	-0.000167
	(0.000119)	(9.47e-05)	(0.000131)	(9.81e-05)
Precipitation Winter_{t-1}	-0.000161	-6.72e-05	-0.000177	-7.69e-05
	(0.000148)	(0.000116)	(0.000139)	(0.000110)
Precipitation Spring_{t-1}	0.000340	8.73e-05	0.000301	0.000114
	(0.000262)	(0.000153)	(0.000262)	(0.000192)
Max Temp. Summer_{t-k}	0.00767	0.00502	-0.000622	-0.00283
	(0.00854)	(0.00505)	(0.00643)	(0.00502)
Max Temp. Fall_{t-k}	-0.0116	-0.00394	-0.00201	0.00515
	(0.0106)	(0.00928)	(0.0107)	(0.00984)
Max Temp. Winter_{t-k}	-0.000663	-0.00594	0.000803	0.000741
	(0.0105)	(0.00778)	(0.0108)	(0.00997)
Max Temp. Spring_{t-k}	-0.00217	-0.00318	0.00330	-9.40e-05
	(0.00678)	(0.00440)	(0.00699)	(0.00448)
Min Temp. Summer_{t-k}	0.0184	0.0174**	0.0216**	0.0147*
	(0.0114)	(0.00806)	(0.00938)	(0.00788)
Min Temp. Fall_{t-k}	0.0154	0.00947	0.0173	0.00512
	(0.0125)	(0.00940)	(0.0105)	(0.00829)
Min Temp. Winter_{t-k}	-0.00907	-0.00997	-0.0129	-0.00562
	(0.0123)	(0.00777)	(0.0109)	(0.00748)
Min Temp. Spring_{t-k}	-0.0136	-0.00769	-0.0233**	-0.0149
	(0.00946)	(0.00681)	(0.00996)	(0.00903)
Constant	0.163	0.209**	0.156	0.210**
	(0.0938)	(0.0847)	(0.0924)	(0.0931)
Observations	2,489,439	153,573	2,357,867	144,062
R-squared	0.933	0.965	0.929	0.963

Notes: Other controls (residential housing): fixed-effects for county and construction county, age dummies.
Other controls (agricultural properties): fixed-effects for county. Standard-errors clustered by county and year in (),
***,**,* denote 1%, 5% and 10% statistical significance.

https://doi.org/10.1371/journal.pstr.0000035.t002

show that precipitation does not have a statistically significant effect on housing prices. For temperatures, the regression with a three year-lag shows that the minimum Summer temperature could have a positive effect on housing prices, while the minimum Spring temperature could have a negative effect on housing prices. This result makes some sense, since households would prefer cooler temperatures during the Summer but a somewhat warmer Spring weather. The surface area in square meters is positively associated to residential housing prices, whatever the lag, showing that richer households prefer larger homes. For Agriculture properties, a higher precipitation in the Fall season implies a lower property price that is significant at the 10% level, but this result is no longer significant with the 3-year lag specification for temperature. In a similar way as for Residential Housing, a higher minimum Summer temperature decreases the Agricultural property prices, showing a preference of the owners for cooler Summers.

3.2 Linear regressions with property fixed-effects

The regressions in Table 2 only controlled for the first observed price, county fixed-effects and the quality of construction of each property. However, since each property is unique, it can be relevant to control for a fixed-effect for each property. This would allow us to control for whether in general lower priced properties are concentrated in warmer areas rather than being affected by a trend in temperatures from global warming. Table 3 summarizes the results obtained with the fixed-effects model that was suggested in Eq 2). The results now show that higher precipitation in all seasons is associated with lower Residential Homes and Agriculture Property prices, if one assumes the 3-year lag temperature model specification. However, under the two-lag specification the Summer and the Spring precipitation effects are statistically insignificant, respectively, for the Residential Homes and Agriculture Properties.

For Residential Homes, under the two year lag specification, we observe a negative effect on prices from higher maximum Summer, Fall and Winter temperatures, which is consistent with the desire of households to avoid extremely hot days. A higher minimum temperature for the Summer, Fall and Spring seasons has the opposite effect of increasing home prices, showing that households also wish to avoid extremely low temperatures. Results are somewhat similar for the three-year lag specification, which also shows a negative effect of the maximum Summer temperature, but a positive effect for the minimum Summer and Fall temperatures. The model with the two-year lag specification, however, provides a better fit to the data, as shown by its higher R-squared.

Agriculture properties suffer a negative effect from higher maximum and minimum Winter temperatures, while experiencing a positive effect from higher minimum temperatures in the Summer, Fall and Spring seasons, which shows in general a preference from owners to avoid extremely low temperatures except in Winter. Under the three-year lag specification, the results show a positive effect from higher maximum temperatures in the Fall and higher minimum temperatures in the Summer, while higher maximum temperatures in the Summer and Spring and higher minimum temperatures in the Winter have a negative effect on the property prices.

In summary, the results of Table 3 suggest that climate change is likely to impact both Residential Home and Agriculture Property prices through its effect on precipitation and global temperature warming.

3.3 Calibrated projections of the climate change impact

Now we use the estimated coefficients from the fixed-effects model with two year lags ($k = 2$) in Table 3 to implement a calibrated exercise using the global temperature projections of the

Table 3. Linear regressions (OLS) with fixed-effects for each property.

	Temperature lag: $k = 2$		Temperature lag: $k = 3$	
	Residential Homes	**Agriculture**	**Residential Homes**	**Agriculture**
$\ln(Area_{i,t})$	0.409***	-0.0857**	0.405***	-0.123***
	(0.0304)	(0.0339)	(0.0311)	(0.0357)
Precipitation Summer$_{t-1}$	4.58e-05	-0.00705***	0.000716***	-0.00573***
	(0.000217)	(0.00109)	(0.000227)	(0.00118)
Precipitation Fall$_{t-1}$	-0.000319***	-0.00408***	-0.000264***	-0.00311***
	(6.49e-05)	(0.000347)	(5.76e-05)	(0.000340)
Precipitation Winter$_{t-1}$	-0.000296***	-0.00301***	-0.000305***	-0.00328***
	(7.31e-05)	(0.000385)	(7.09e-05)	(0.000371)
Precipitation Spring$_{t-1}$	0.00105***	-0.000169	0.000840***	-0.00176**
	(0.000146)	(0.000907)	(0.000162)	(0.000865)
Max Temp. Summer$_{t-k}$	-0.0253***	-0.0372	-0.0353***	-0.0748**
	(0.00414)	(0.0326)	(0.00426)	(0.0353)
Max Temp. Fall$_{t-k}$	-0.0289***	-0.00758	-0.000560	0.114***
	(0.00265)	(0.0259)	(0.00278)	(0.0268)
Max Temp. Winter$_{t-k}$	-0.0165***	-0.112***	0.00326	0.0181
	(0.00400)	(0.0317)	(0.00375)	(0.0322)
Max Temp. Spring$_{t-k}$	-0.00623	-0.0362	0.00726**	-0.0429*
	(0.00420)	(0.0238)	(0.00335)	(0.0234)
Min Temp. Summer$_{t-k}$	0.0489***	0.423***	0.0648***	0.372***
	(0.00463)	(0.0331)	(0.00557)	(0.0353)
Min Temp. Fall$_{t-k}$	0.0651***	0.104***	0.0462***	0.0599
	(0.00359)	(0.0323)	(0.00409)	(0.0391)
Min Temp. Winter$_{t-k}$	0.00372	-0.0793**	-0.0163***	-0.0544*
	(0.00413)	(0.0333)	(0.00383)	(0.0310)
Min Temp. Spring$_{t-k}$	0.0110**	0.147***	-0.0143***	0.0333
	(0.00453)	(0.0304)	(0.00498)	(0.0341)
Constant	4.249***	4.169***	3.743***	3.091***
	(0.175)	(0.875)	(0.180)	(0.865)
Observations	430,161	14,170	409,924	13,445
R-squared	0.112	0.062	0.106	0.066
Number of properties	213,605	6,986	211,766	6,858

Notes: Other controls: Residential housing regressions also control for age dummies. Standard-errors clustered by county and year in (),
***,**,* denote 1%, 5% and 10% statistical significance.

https://doi.org/10.1371/journal.pstr.0000035.t003

IPCC (2021) [13] to project how a uniform temperature increase throughout the entire year may affect housing prices. Climate studies consider several scenarios given by the Shared Socioeconomic Pathways (SSP), published recently by the IPCC (2021), which represent an update of the older Representative Concentration Pathways (RCP) scenarios, with the SSP1-2.6 being the more optimist scenario, while the SSP2-4.5, SSP3-6.0, SSP4-7.0 and SSP5-8.5 denote increasingly pessimistic scenarios similar to the previous RCP paths. Table 4 considers the impact of the scenarios SSP2-4.5 (which is considered by many academics as the more likely scenario given the current policy compromises) and the worst scenario of "business as usual" of SSP5-8.5 (which considers that countries will not implement mitigation measures to attenuate climate change).

Table 4. Impact of the climate change using the fixed-effects models with a temperature lag of two years as a percentage (%) of the property log-prices: Impact for all seasons and each season separately, with the sum of the maximum and minimum temperature coefficients.

Total impact of each season	All the estimated coefficients		Only statistically significant coefficients	
	Residential Homes	Agriculture	Residential Homes	Agriculture
Sum of the estimated model coefficients (Fixed-effects model, k = 2, Table 3)				
All seasons: max+min	5.2	42.5	5.4	31.4
All seasons: max	-7.7	1.4	-7.1	-0.4
All seasons: min	12.9	4rent1.1	12.5	31.8
Summer: max+min	2.4	29.7	2.4	29.7
Fall: max+min	3.6	17.4	3.6	11.4
Winter: max+min	-1.3	-3.6	1.1	-5.4
Spring: max+min	0.5	-1.0	-1.7	-4.3
Change in prices in 2050 relative to a scenario with no additional climate change, according to the path SSP 4.5: +1.3°C				
All seasons: max+min	6.7	55.3	7.1	40.8
All seasons: max	-10.0	1.9	-9.2	-0.5
All seasons: min	16.7	53.4	16.3	41.3
Summer: max+min	3.1	38.6	3.1	38.6
Fall: max+min	4.7	22.6	4.7	14.8
Winter: max+min	-1.7	-4.7	1.4	-7.1
Spring: max+min	0.6	-1.2	-2.1	-5.6
Change in prices in 2050 relative to a scenario with no additional climate change, according to the path SSP 8.5: +1.6°C				
All seasons: max+min	8.3	68.0	8.7	50.2
All seasons: max	-12.3	2.3	-11.3	-0.6
All seasons: min	20.6	65.7	20.0	50.8
Summer: max+min	3.8	47.6	3.8	47.6
Fall: max+min	5.8	27.8	5.8	18.2
Winter: max+min	-2.0	-5.8	1.8	-8.7
Spring: max+min	0.8	-1.5	-2.6	-6.9

https://doi.org/10.1371/journal.pstr.0000035.t004

We start by summing up the coefficients obtained by summing the coefficients of different seasons (s = 1, 2, 3, 4, denoting Summer, Fall, Winter and Spring) and whether the maximum and minimum temperatures are considered. Let us define the sum of the coefficients for all seasons for, respectively, the maximum, minimum and sum of maximum and minimum temperatures ($\gamma^{\max}$, $\gamma^{\min}$, γ^{all}) as:

$$\gamma^{\max} = \sum_{s=1}^{4} \gamma_s^{\max} \tag{3}$$

$$\gamma^{\min} = \sum_{s=1}^{4} \gamma_s^{\min} \tag{4}$$

$$\gamma^{all} = \gamma^{\min} + \gamma^{\max} \tag{5}$$

This allows us to analyze separately the overall impact of climate change and the isolated impact from maximum and minimum temperatures only. Furthermore, we consider also the separate impact of each season separately:

$$\gamma^{\text{Summer}} = \gamma_{s=1}^{\min} + \gamma_{s=1}^{\max} \tag{6}$$

$$\gamma^{\text{Fall}} = \gamma_{s=2}^{\min} + \gamma_{s=2}^{\max} \tag{7}$$

$$\gamma^{\text{Winter}} = \gamma_{s=3}^{\min} + \gamma_{s=3}^{\max} \tag{8}$$

$$\gamma^{\text{Spring}} = \gamma_{s=4}^{\min} + \gamma_{s=4}^{\max} \tag{9}$$

The quantitative exercise considers the impact on the property prices in year t of a given global temperature change in climate change, T_t^{SSP-x}, for each $SSP-x$ path (with x = 2.6, 4.5, 6.0, 8.5): $I_t^c = \gamma^c(T_t^{SSP-x} - T_{2020})$, with c = max, min, all, Summer, Fall, Winter, Spring. For simplicity, we only show the results for the horizon of the year 2050 (t = 2050) relative to the baseline of the year 2020.

Table 4 summarizes the impact of the estimated fixed-effects model (with a two year lag for temperatures, k = 2) from Table 3, which presents both the sum of all the model coefficients and the sum of the statistically significant coefficients for both minimum and maximum temperatures for all seasons of the year and each season separately. We find that higher maximum temperatures have a negative impact on residential homes of 7.7% for each additional Celsius degree, with a negative estimated impact of 7.1% if we just include the statistically significant coefficients. However, the negative impact of maximum temperatures on Agricultural properties is negligible, being just -0.4% if we consider just the statistically significant coefficients. In terms of each season, I find that higher temperatures in the Winter affect both Residential Homes and Agricultural properties' prices negatively by 1.3% and 3.6% (if considering all the model coefficients), respectively. Agricultural properties are also negatively affected by 1% for each additional Celsius degree during the Spring season. If one considers just the statistically significant coefficients, then the Residential Homes are only affected negatively during the Spring by 1.7% and for the sum of the maximum temperatures in all seasons by 7.1%, while the Agriculture properties are negatively affected both during the Winter and Spring seasons by 5.4% and 4.3% with each additional Celsius degree of higher temperature.

Table 4 also shows the impact on real estate property prices of the median estimated paths for the average scenarios SSP2-4.5 and SSP5-8.5 for the year 2050, relative to a scenario in which the climate remains similar to the year 2020. If one considers just the maximum temperatures, then there would be a very small effect on the Agricultural property prices (a small positive effect with all coefficients or a small negative effect with only the statistically significant coefficients). However, for the Residential Homes' prices, the higher maximum temperatures in 2050 could represent a substantial negative effect of -10.0% and -12.3% for the SSP2-4.5 and SSP5-8.5 paths, respectively. Even if one considers just the statistically significant coefficients, then the effect of the maximum temperatures in 2050 on Residential Homes' prices would be -9.2% and -11.3% for the SSP2-4.5 and SSP5-8.5 paths, respectively.

3.4 Discussion

Our results show that there exists a negative relationship between real estate prices and temperature. These findings are consistent with the hypothesis that higher temperatures affect negatively the quality of life of the household. Albouy et al. 2016 [14] find that Americans most prefer daily average temperatures near 65 degrees Fahrenheit (18˚C), agreeing with standard degree-day models that predict little need for heating or cooling at this temperature, and that households pay more to avoid a degree of excess heat than a degree of excess cold. In this line, Gounopoulos et al. 2021 [53] also show that higher temperatures affect negatively the quality of life in the United States. Then, we can establish a direct link between higher temperatures

and lower quality of life due to the works of Absalon and Ślesak 2012 [54], and Mendes et al. 2017 [55]. Ultimately, to complete the channel that allows us to establish the relationship between temperatures and house prices, McDonald 2012 [56] and Streimikiene 2015 [57] show that quality of life is an important determinant of house pricing.

Regarding the positive impacts of higher minimum temperatures in the Summer, Fall, and Spring seasons and precipitation on agricultural properties prices, our findings are consistent with those in Deschenes and Greenstone 2007 [58], Mendelsohn et al. 1994 [59], who find that climate may have a long-term positive impact on agricultural land due to increases of annual profits due to higher expected yield. Finally, our results on the effects of extreme temperatures on housing prices are consistent with the results showing that hotter summers and colder winters increase residential electricity consumption, particularly during the summer [60]. This could be one mechanism on why households prefer to live in areas with more stable temperatures, which supports the analysis in this article. Furthermore, climate shocks are associated with a higher probability change of intergroup conflict and interpersonal violence [61], which provides another channel through which weather changes can affect real estate prices.

Finally, when considering the impact under the different prospective scenarios, we find that for the Residential Home's prices, the higher maximum temperatures in 2050 could represent a decrease in 9.2% and 11.3% for the SSP2-4.5 and SSP5-8.5 paths, respectively. However, one possible caveat of this estimation is that we are holding technology and preferences constant and are therefore our estimates are best interpreted as a benchmark case. This assumption is common to most estimates of climate change damages [14].

4 Conclusions

This work uses a matched dataset of the administrative register of all the real estate properties' transactions in Chile between 2002 and 2020 with a high spatial resolution of local temperatures and precipitation from TerraClimate. We then estimate two hedonic models for the effect of seasonal weather temperatures and precipitation on residential home and agricultural property prices. The first hedonic model considers fixed-effects for county, quality of the construction, plus the size and age of the property and its oldest appraisal value. However, since each property is unique, it can be relevant to control for a fixed-effect for each property. This allows us to control for whether in general lower priced properties are concentrated in warmer areas rather than being affected by a trend in temperatures from global warming. Therefore the second hedonic model considers fixed-effects for each property plus controls for the size and age of the property in each year.

The first model shows negligible effects of weather variables on the prices of residential homes and agricultural properties. Controlling for fixed-effects for each property, we find that hotter maximum temperatures during the Summer, Fall and Winter seasons had a negative impact on the prices of residential homes. This result is consistent with the desire of households to avoid extremely hot days. Agriculture properties suffer a negative effect from higher maximum and minimum Winter temperatures, while experiencing a positive effect from higher minimum temperatures in the Summer, Fall and Spring seasons, which shows in general a preference from owners to avoid low temperatures except in Winter.

We then use the fixed-effects model to estimate the impact on real estate property prices of the median estimated paths for the scenarios SSP2-4.5 (which represents the most likely future scenario, according to most climate experts) and SSP5-8.5 (which represents the worst climate scenario) for the year 2050, relative to a scenario in which the climate remains similar to the year 2020. If one considers just the maximum temperatures, then there would be a small effect on the Agricultural property prices. However, for the Residential Homes' prices, the higher

maximum temperatures in 2050 could represent a substantial negative effect of -10.0% and -12.3% for the SSP2-4.5 and SSP5-8.5 paths, respectively.

These results can lead to a policy implication related to financial systemic the first one, with regulators and central banks increasingly worried about potential systemic risks from climate change, it is crucial to answer whether loan market participants and banks are aware of and price climate change risk [5]. Most residential real estate is purchased with a mortgage, and then, climate risk will also affect the valuations of these mortgages. Consistent with this characteristic of the housing market, recent research has shown that climate changes episodes lead to increased mortgage default [62, 63] and areas affected by natural disasters attract less affluent and less creditworthy home-buyers [64]. Similarly, Ouazad and Kahn 2021 [65] show that, in the aftermath of natural disasters, lenders are more likely to approve mortgages that can be securitized, thereby transferring climate risk and increasing real estate's exposure to weather risks above the optimal.

Regulations that improve air quality may become more important in warmer temperatures since poor air quality has more adverse effects as temperatures rise [53], and hence, affecting negatively the quality of life of households. Existing literature links environmental policies to various dimensions of quality of life, raising the possibility that it may be a source of adaptation to climate change. However, whether environmental regulations attenuate or exacerbate the effects of temperature shocks on quality of life is a question that exceeds the scope of this paper.

Future research should consider non-linear effects of climate change on real estate markets, as well as spillovers to other sectors of the economy [16, 66].

Acknowledgments

All errors are our own. The results and perspectives expressed in this work do not necessarily represent the Central Bank of Chile.

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