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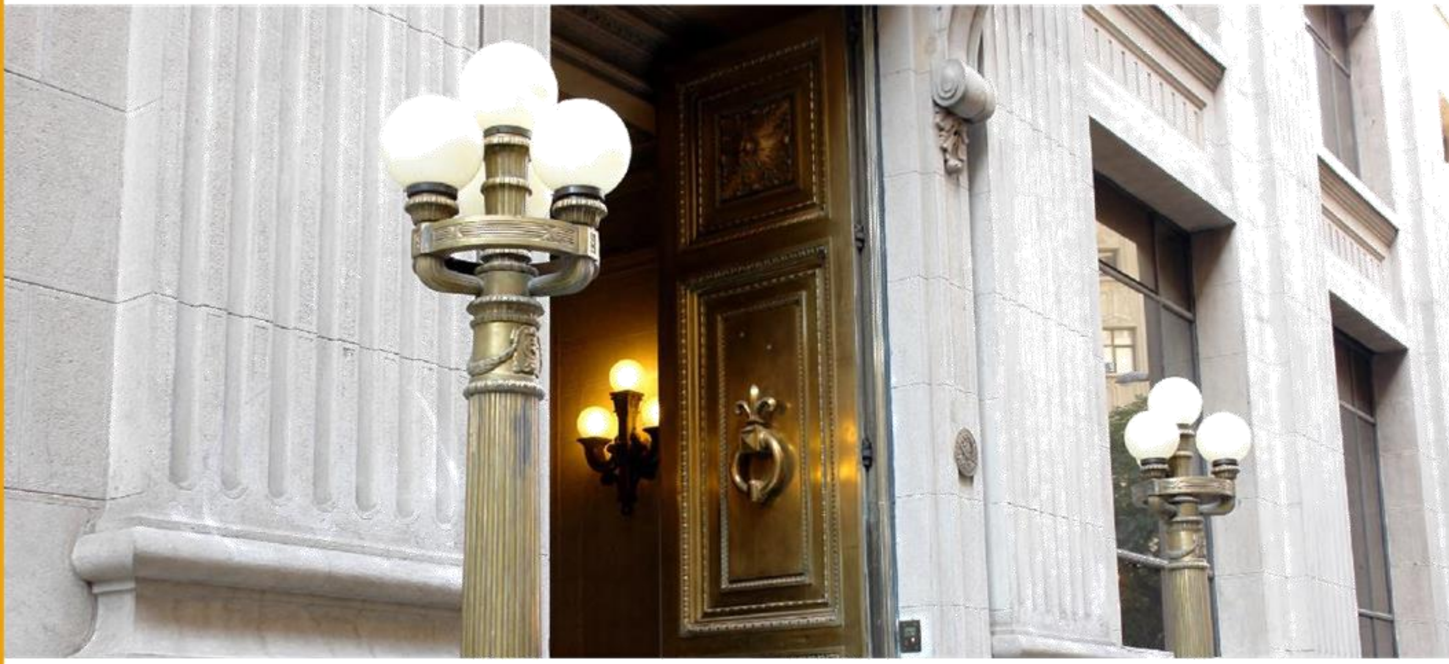

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The impact of climate change on economic output in Chile: past and future

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Abstract

We study the impact of some weather variables (precipitation and temperatures) on GDP by using a region-industry panel data for Chile over the period 1985-2017. We find no effect of precipitation changes on GDP, but the results confirm a negative impact of higher summer temperatures on Agriculture-Silviculture and Fishing. An increase of one Celsius degree in January implies a 3% and 12% GDP reduction in Agriculture and Fishing, respectively, plus a negative effect on Construction, Electricity, Gas, and Water. Substantial uncertainty can be argued around these results due to the unavailability of region-industry GDP at a quarterly or monthly frequency and the assumption of fixed-coefficients over time.

Stress test exercises for 2050 and 2100 that use all the industry coefficients estimated from our model or from an USA model imply a small effect of climate change on the overall Chilean GDP relative to a scenario without further climate change. However, these results should be taken with caution due to the overall fitness of the model. Indeed, under some parameter settings of the model, our stress test implies that the Chilean GDP would fall between -14.8% and -9% in 2050 and between -29.6% and -16.8% in 2100 relative to a scenario without further climate change.

We also review several studies for the future impact of climate change during the 21st century. Some studies suggest that Chile is likely to suffer mild effects in terms of GDP growth, labor productivity and mortality costs. However, the studies of Kahn et al. (2019), Kalkuhl and Wenz (2020) and Swiss Re (2021) predict that Chile may suffer significant GDP costs due to the adaptation difficulties in a warmer weather. Furthermore, several studies find that Chile is facing non-GDP related problems from climate change, such as air pollution, drought, water stress, migration and changes in land classification.

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Resumen

Este estudio analiza el impacto de algunas variables de clima (precipitación y temperaturas) en el PIB de Chile utilizando datos panel por región-industria desde el año 1985 hasta 2017. Los resultados muestran que fluctuaciones de precipitación no han tenido un impacto en el PIB, pero existe un efecto negativo de temperaturas elevadas durante el verano en las industrias de Agricultura-Silvicultura y Pescas. Un punto Celsius de temperatura adicional en el mes de enero reduce el PIB de Agricultura-Silvicultura y Pescas en 3% y 12%, respectivamente, y además implica un efecto negativo en las industrias de Construcción, Electricidad, Gas y Agua. Existe mucha incertidumbre en relación a la interpretación de los resultados por la no disponibilidad de datos de PIB a nivel mensual o trimestral para cada región-industria y también por el presupuesto de coeficientes fijos al largo del tiempo.

Ejercicios cuantitativos para 2050 y 2100 – basados en todos los coeficientes del modelo estimado para Chile o del modelo estimado para EEUU – muestran un efecto pequeño del cambio climático en el PIB de Chile en relación a un escenario sin cambio climático adicional. Sin embargo, estos resultados deben ser interpretados con cautela dado que el modelo explica solo una pequeña fracción de las fluctuaciones del producto de cada industria. De hecho, considerando algunas configuraciones de parámetros de nuestro modelo, el *stress test* implica que el PIB de Chile bajaría entre -14.8% y -9% en 2050 y entre -29.6% y -16.8% en 2100, relativamente a un escenario sin cambio climático adicional.

También revisamos diversos estudios en relación al impacto futuro del cambio climático al largo del siglo 21. Algunos estudios sugieren que Chile experimentará efectos moderados o pequeños en términos de crecimiento de PIB, productividad laboral y costos de mortalidad. Sin embargo, los estudios de Kahn et al. (2019), Kalkuhl y Wenz (2020) y Swiss Re (2021) predicen que Chile podrá sufrir costos de PIB significativos y dificultades en la adaptación a un clima más caluroso. Además, muchos estudios encuentran que Chile enfrentará problemas de cambio climático no directamente relacionados al PIB, tales como polución del aire, sequía, escasez de agua, migración y cambios en la clasificación de los ecosistemas.

1 Introduction

Climate change is predicted to affect negatively the economic growth of almost all the countries across the world (OECD 2015, Kahn et al. 2019, IMF 2021). Nordhaus and Moffat (2017), in a large revision of different studies, gives an estimate of -2.04% and -8.06% on the impact of world GDP for a 3 °C and 6 °C global temperature increase, respectively, with substantial uncertainty around the central estimates. A wide range of climate studies give estimates of the impact of climate change as lowering the world GDP level in 2100 between -2% and -10% (Harris et al. 2017). Since the negative consequences fall disproportionately on the poorest countries due to their proximity to the earth's Equator, the impact on the average world GDP per capita could be as high as -20% (Stern 2007). It is estimated that the Latin America region will suffer substantially from global warming in the 21st century, with some Caribbean countries being strongly affected due to their oceanic location and dependence on the agriculture and fishing sectors (Fernandes et al. 2012, Vergara et al. 2019, Bárcena et al. 2019). Due to its worst impact on the poorest countries and the poorest households, climate change will be a significant threat to economic growth and reducing income inequality in Latin American countries (Bárcena et al. 2019, Cavallo and Hoffmann 2020).

This study provides a view of the economic impact of climate change in Chile over the past 35 years, plus a review of different estimates for the future. Using annual frequency GDP data for 12 economic sectors across 15 regions of Chile over the period 1985 to 2017, we find that temperature and rain precipitation fluctuations had little impact on economic activity, except for the Agriculture-Silviculture and Fishing sectors. Furthermore, our work provides an extensive review of the estimates of economic costs for Chile of the future climate change dynamics.

Using data from the University of Delaware, we summarize changes in weather precipitation and temperature in Chile over the last 30 years, using both surface and GDP weights for each region, with surface weights being a better measure of the impact of climate change on habitats and GDP weights a better measure of its impact for economic activity. The results show that yearly precipitation in Chile over the last 30 years decreased slightly with surface weights, but it decreased substantially when applying regional GDP weights. Our measurement also shows a strong increase in mean yearly temperature of 0.37 Celsius degrees over the last 30 years with GDP weights, although barely no change in mean temperature with surface weights (which is explained by a strong decrease in temperature in the North region over the last 30 years, although the rest of Chile saw its temperatures increase). These weather changes in temperature are reflected across all regions of Chile, except for the North.

We then apply a methodology similar to Colacito, Hoffmann and Phan (2019), who estimated the impact of climate change on different industries at the state-level for the USA over a 55 year period from 1957 to 2012, finding that higher summer temperatures affected negatively the economic output of at least half of the industries, especially finance, insurance and real estate. Using annual GDP growth data across 12 industries for each of the 15 Chilean regions over the last 35 years, we find a statistically significant impact of climate change during the Summer season for the Agriculture and Fishing sectors. Each Celsius degree of temperature increase in the months of January implies a GDP reduction of 3% and 12% for the Agriculture and Fishing sectors, respectively. However, many industries have either been unaffected or could even be getting a positive impact from the temperature increases implied by climate change. Furthermore, some impacts of the temperature increase can be positive for the economic output outside of the Summer months. For instance, Agriculture is positively affected by the temperature increases during the month of November. If we consider the point estimates for all the model coefficients across every month (whether the coefficients are statistically significant or not), then each additional Celsius degree of temperature decreases GDP by -8.8% in Fishing, -1.9% in Mining and -0.7% in the Home property sector, but it shows a positive impact on the output of other sectors, including Agriculture. If one considers just the statistically significant coefficients, then each Celsius degree of temperature decreases GDP by -3% in Agriculture, -8.8% in Fishing, -2.2% in Manufacturing, -3.9% in Energy-Gas-Water, -0.3% in Construction and -0.7% in Commerce, but it still has a positive impact on several other sectors such as Mining, Finance and Personal Services. Unfortunately, extreme weather is often associated with a single month or even shorter periods, therefore the unavailability of regional-industry GDP data at a quarterly or monthly frequency makes statistical identification harder and casts some uncertainty on the interpretation of our findings.

Our estimates for the impact of the global climate change on the Chilean GDP growth rate in 2017 change between +0.1% and -0.2%, depending on whether we consider all the model's coefficients (+0.1%), just the statistically significant coefficients (-0.1%) or just the negative statistically significant coefficients (-0.2%). Therefore the positive or negative impact of climate change on the current GDP growth are still limited to a low value, especially because the most affected sectors (Agriculture and Fishing) represent just 4% of the national GDP.

Over time, the fraction of GDP represented by the sectors economically affected by climate change falls, with Agriculture and Fishing almost disappearing in terms of their weight on the GDP, and this limits the negative impact of climate change on GDP even as global temperatures become worse. At the same time the sectors least affected by climate change increase their weight in terms of the national GDP. Applying the model to forecast the future impact of climate change on GDP according to different scenarios for the global temperature path until 2050 or 2100, we find that the analysis is highly dependent on whether to include or not the model coefficients that are not statistically significant. The scenarios used are the same RCP and SSP paths[1] specified by the United Nations (IPCC 2014, 2021) and widely used in all the climate change literature and the most recent studies of macro-financial stress tests with climate change factors (NGFS 2021). Using all the model's coefficients we estimate that climate change has a positive impact on the level of GDP in 2050 and 2100, whatever is the path scenario for the global temperatures. Since most of the model's coefficients are statistically insignificant, we then consider model forecasts using only statistically significant coefficients. Using only the statistically significant coefficients, the model forecasts a fall in the Chilean GDP level between -2.3% and -1.7% for a global temperature increase between 1 °C and 1.4 °C, but with a small increase of 0.4% for an increase of 2 °C (which is the global temperature forecast in 2050 for the RCP 8.5). Finally, applying only the coefficients with a negative value and that are statistically significant, we obtain a decline in GDP between -14.8% and -9% in 2050 and between -29.6% and -16.8%, depending on the path of the global temperatures. A robustness exercise that applies only the statistically significant industry coefficients estimated for the USA (Colacito, Hoffmann and Phan 2019) implies that the Chilean GDP would fall between -12.9% and -6.8% in 2050 and between -42.3% and -15.5% in 2100 due to climate change. The

[1] Climate studies consider several scenarios given by Representative Concentration Pathways (RCP) published by the IPCC (2014), with RCP 2.6 being denoted as the best possible scenario in which climate change is completely controlled, RCP 4.5 being a scenario in which the global temperature rise is likely to fall below 2.0°C, and RCP 8.5 being considered the worst scenario in which no country implements policies or mitigators for climate change. In the same way, the Shared Socioeconomic Pathways (SSP), published recently by the IPCC (2021), denote an update of the RCP scenarios, with equivalent notation with SSP1-2.6 being the more optimist scenario, while SSP2-4.5, SSP3-6.0, SSP4-7.0 and SSP5-8.5 denote increasingly pessimistic scenarios similar to the previous RCP paths.

stress test exercises are robust to using either the 2014 or the 2021 scenarios of the IPCC.

These results imply a low impact of climate change in Chile over the past 35 years. This is consistent with the previous literature showing that Chile so far has received little impact from climate change in terms of overall climate change costs (HSBC 2018), GDP costs (German Watch 2019), temperature fluctuations (Collins et al. 2013, Kahn et al. 2019), water availability (Gerten et al. 2011) or labor hours lost to high temperatures (Watts et al. 2018, 2019). Furthermore, studies such as Dell et al. 2012 have found little effect so far of climate change in high income economies such as Chile, with negative effects being significant only for poorer nations.

Most past studies of climate change at the multinational level give estimates for Chile with either a low negative (OCDE 2015, McKinsey 2020, Cruz and Rossi-Hansberg 2020) or even a positive economic impact (Burke et al. 2015a, Krusell and Smith 2018, Carleton et al. 2020). This happens due to Chile's distance from the Equator, therefore a small or moderate temperature increase could result in higher economic activity (Burke et al. 2015a) and lower mortality costs (Carleton et al. 2020). Also, Chile is estimated to have a low sensitivity of the local weather to fluctuations in global temperature (Collins et al. 2013, Harris et al. 2017, Krusell and Smith 2018). Kahn et al. 2019, however, estimates a strong negative economic growth effect of climate change for Chile, because their model assumes that the new higher temperatures are outside of the historical norm for Chile and will require adaptation costs. Chile may also face increasing costs in terms of its ecosystem preservation (Vergara et al. 2013, OECD 2015, McKinsey 2020, Albagli 2021) and with higher water stress (Gerten et al. 2011, McKinsey 2020). It may also face stronger human migration from neighboring countries that will be more negatively affected by climate change (OECD 2015, Cruz and Rossi-Hansberg 2020), although current evidence on the effect of climate fluctuations on migration patterns is still very limited (OECD 2015).

This work is related to the research on the economic costs of climate change, with a particular emphasis on GDP (Stern 2007, Burke et al. 2015a) and physical risks. Besides its impact on GDP growth (Nordhaus and Moffat 2017, Colacito, Hoffmann and Phan 2019, Kahn et al. 2019), other socioeconomic effects include higher mortality (Deschenes and Moretti 2009, Carleton et al. 2020), worse health (Watts et al. 2019), a widening of economic inequality, higher conflict, domestic violence and criminality (Burke et al. 2015b), with a worse impact on poorer countries (Dell et al. 2012, Watts et al. 2019). Finally, climate change issues are gaining more relevance in Chile, as pension funds prefer investments with higher Environmental, Social and Governance (ESG) factors (Hoffmann et al. 2020) and lower reliance on fossil fuels which are heavily used in Latin America (Di Bella et al. 2015, IRENA 2015). Furthermore, macroeconomic implications for central banks, fiscal policy and financial regulation are also being discussed (Batten 2018, Harnish 2019, NGFS 2021). Other works deal more with transition risks (BIS 2021), which are not analyzed in this paper.

This article is organized as follows. Section 2 details the data used and the econometric methodology. Section 3 comments on the empirical findings over the 1985-2017 period, while Section 4 reviews the economic estimates of the future impact of climate change for the 21st century. Finally, Section 5 summarizes the conclusions and implications for policy.

2 Data

2.1 Regional-industry GDP data

We use region-industry level GDP series for Chile over the period 1985-2017 from the National Accounts data publicly available from the Central Bank of Chile. There are 12 industries shown in Table 1. Prior to 2007, Chile was divided into 13 regions. In 2007, region I split into regions I and XV and region X split into regions X and XIV, resulting in 15 regions. Region XIII is particularly important, being the Metropolitan Region of the capital Santiago, which represents around 40% of the national GDP and population.

For the years 1985-2007, we created a 15 region and 12 industry panel series assuming that each of the divided regions I and X shares of industry-level GDP is constant between 1985-2008. We allocate the industry-level GDP of regions I and X across their future sub-divided regions according to their share of the combined region's GDP for each industry in the year 2008:

1) $GDP_{r,i,t} = GDP_{A(r),i,t}\dfrac{GDP_{r,i,2008}}{GDP_{A(r),i,2008}}$, for $t \leq 2007$,

with t representing the year, i the industry, r being the region classification after 2008 and $A(r)$ being the region classification before 2008. In particular, $A(r) = I + XV$ for $r = I, XV$

Table 1: Economic sectors available from the National Accounts data

Industry Code	Industry Name
1	Agriculture and Forestry
2	Fishing
3	Mining
4	Manufacturing
5	Electricity, Gas, and Water
6	Construction
7	Commerce, Restaurants, and Hotels
8	Transport and Communications
9	Financial Services
10	Home Ownership
11	Personal Services
12	Public Administration

and $A(r) = X + XIV$ for $r = X, XIV$. This adjustment is possible because the original region classification for the period 1985-2007 was exactly the same as the recent 2008-2017 classification for regions II, III, IV, V, VI, VII, VIII, IX, XI, XII and XIII. However, the original regions I and X in the period 1985-2007 are exactly equivalent to the sum of regions I and XV and the sum of regions X and XIV, respectively, for the period 2008-2017. In the appendix at the end of the article, we also show results with a set of 13 regions over the entire period 1985 to 2017.

The data is reported in four separate series 1985-1996, 1996-2003, 2003-2008, and 2008-2017 with base years 1986, 1996, 2003, and 2013 respectively. We harmonize the data as follows. To join adjacent series, we use the common year that is available in the series of both base years to create an adjustment factor for each region-industry observation as the ratio of GDP measured in the more recent base year to the GDP measured in the previous base year: $Adj_{r,i,b=t_0} = GDP_{r,i,t^*,b=t_1}/GDP_{r,i,t^*,b=t_o}$, with r denoting the region, i the industry, t_1 being the most recent base year and t_0 the previous base year. t^* is the first period in the new base year t_1 series and the last period for the old base year t_0 series. We multiply each observation in the earlier dataset of base year t_0 by the adjustment factor: $Adj_{r,i,b=t_0}$. This procedure was applied first to link the most recent 2008-2017 series to the previous series 2003-2008, then to the series 1996-2003 and the series 1985-1996, to finally obtain the combined series 1985-2017. Therefore the adjusted GDP series used in the article is:

Table 2: Fraction (%) of the value of each industry in national GDP (1985-2017)

Industry Code and Name	Fraction of the GDP (in %)
1. Agriculture and Forestry	3.5
2. Fishing	0.5
3. Mining	15.1
4. Manufacturing	12.7
5. Electricity, Gas, and Water (EGA)	4.0
6. Construction	6.8
7. Commerce, Restaurants, and Hotels	10.9
8. Transport and Communications	8.2
9. Financial Services	14.9
10. Home Ownership and property	8.2
11. Personal Services	11.5
12. Public Administration	5.2

2.1) $GDP^{adj}_{r,i,t} = GDP_{r,i,t}$ for $t \in [2008, 2017]$,

2.2) $GDP^{adj}_{r,i,t} = GDP_{r,i,t} Adj_{r,i,b=2003}$ for $t \in [2003, 2007]$,

2.3) $GDP^{adj}_{r,i,t} = GDP_{r,i,t} Adj_{r,i,b=2003} Adj_{r,i,b=1996}$ for $t \in [1996, 2002]$,

2.4) $GDP^{adj}_{r,i,t} = GDP_{r,i,t} Adj_{r,i,b=2003} Adj_{r,i,b=1996} Adj_{r,i,b=1985}$ for $t \in [1985, 1995]$.

We create datasets of both nominal and real GDP where the real GDP is adjusted using the UF or the value of real monetary unit which is indexed to the CPI. Dividing the nominal GDP series by the UF value results in a real series for Chile. The average UF data for each year is also publicly available from the Central Bank of Chile, based on daily UF values published by the Chilean Bureau of Official Statistics (INE, *Instituto Nacional de Estadísticas* in Spanish). The UF money index is commonly used by companies and individuals in Chile for all kinds of long term contracts, including loans, real estate purchases, rent and wages. This option is made, because there are no price series in Chile that are valid for different industries in order to obtain real quantities per industry.

In some years, industry GDP is negative for specific regions. This occurs in regions where few firms are operating in that sector. For example, negative values for industry-region GDP can occur in years in which a firm has costs exceeding revenue on its balance sheet. We replace negative values with 0 when calculating the growth rate of industry-region level GDP, therefore growth rates can be either -100% or missing when one of the years has a zero output value. Using weighted

Table 3: Fraction (%) of the value of each industry for the GDP of each region (1985-2017)

Industry / region	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
1. Agriculture and Forestry	0.1	0.0	1.8	7.0	3.0	11.7	12.7	7.4	14.5	7.7	3.7	1.9	0.9	13.3	5.3
2. Fishing	1.4	0.2	0.6	0.4	0.2	0.0	0.1	1.2	0.3	5.9	16.6	1.0	0.0	1.0	2.4
3. Mining	37.1	63.2	50.5	30.1	15.7	30.7	1.7	0.1	0.0	0.0	3.7	19.5	2.2	0.0	2.7
4. Manufacturing	7.5	5.8	1.8	2.9	16.6	10.4	13.3	22.8	11.4	20.9	7.5	25.3	12.3	25.7	12.6
5. Electricity, Gas, and Water (EGA)	1.7	2.6	5.4	2.2	3.3	5.2	17.5	9.3	1.7	4.1	1.2	1.9	2.6	4.3	1.6
6. Construction	7.5	6.7	9.2	7.8	7.5	7.1	8.2	7.1	8.6	8.0	8.1	5.8	6.2	5.2	6.4
7. Commerce, Restaurants, and Hotels	8.9	2.7	3.9	7.4	6.7	6.4	6.3	6.3	8.4	7.9	7.4	6.0	17.4	8.0	8.0
8. Transport and Communications	7.6	4.6	5.0	6.9	12.9	5.1	7.6	8.8	8.1	9.0	8.6	7.0	8.7	7.6	16.0
9. Financial Services	8.8	8.9	12.9	9.5	8.6	8.0	6.5	7.5	7.5	8.2	8.6	9.1	23.3	7.0	8.4
10. Home Ownership	4.1	1.9	4.2	7.9	10.3	6.5	10.1	9.3	10.6	7.7	6.1	6.2	9.8	8.2	8.9
11. Personal Services	7.0	3.7	5.8	11.5	11.8	11.0	14.3	14.0	19.7	15.2	12.8	8.1	12.7	15.6	17.2
12. Public Administration	4.8	1.4	4.0	5.9	5.9	3.6	6.7	6.3	9.7	8.5	17.4	9.9	4.7	8.8	16.7

regressions for the value of each region-industry is also an adequate way to solve this, because those observations are attributed a zero weight. Table A1 in the appendix shows that the results are robust to using weighted regressions. Furthermore, since 2008 the Central Bank of Chile computes the share of financial services costs for each region-industry. Before 2008 the financial services costs are reported for each region, but are not disaggregated to the industry level, implying that the output of each industry is slightly over-estimated before 2008.

Table 2 shows the average value of each industry in terms of the national GDP over the period 1985 to 2017. The largest economic sectors are Mining (15.1%), Financial Services (14.9%), Manufacturing (12.7%), Personal Services (11.5%) and Commerce (10.9%), with shares between 10.9% and 15.1% of the national GDP over the last 35 years.

This representation is quite different at the regional level, with large disparities across regions. For example, Mining represents a share close to 0% of the regions VIII, IX, X and XIV, plus a share between 1.7% and 3.7% for the regions VIII, XI, XIII and XV. However, Mining represents more than 50% of the GDP in regions II and III, and also has a share between 15.7% and 37.1% of the value in regions I, IV, V and XII. Therefore Mining is the largest economic sector in Chile, but its resources are unequally distributed across regions. The capital region (XIII, Metropolitan Region of Santiago) represents more than 40% of the national GDP and population, being particularly important. For the capital region XIII the top industries are Financial Services (23.3%), Commerce

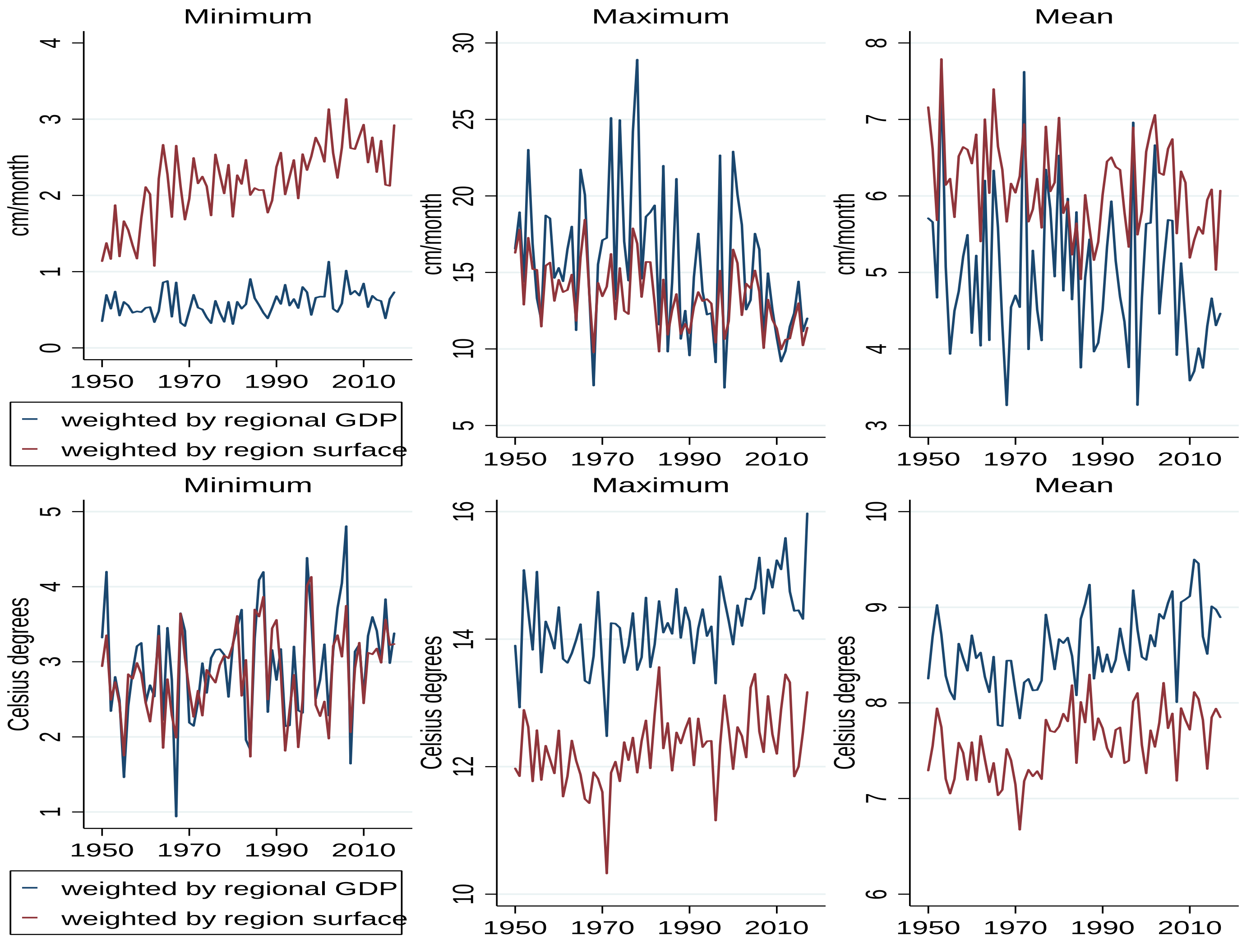
(17.4%), Personal Services (12.7%) and Manufacturing (12.3%). Therefore it is interesting to observe that both Financial Services and Commerce are much more prevalent in the capital region than at the national level, while Mining has almost no value for the capital even if it represents the largest economic sector in the nation.

2.2 Weather Data

We use weather data available from the University of Delaware Air Temperature and Precipitation dataset that provides gridded mean monthly surface air temperature (in Celsius degrees) and total monthly precipitation (in centimeters per month) data from 1900-2017. The data covers the terrestrial area of the globe with a grid size of 0.5 degree latitude x 0.5 degree longitude, which is approximately 56km x 56km at the equator. The grid squares intersect the area of Chile. We use geospatial software (QGIS) to aggregate the weather data to the regional level. First, we determine the fraction of each grid that falls within the borders of each region. Then, for each region, we create the regional weather series as a weighted average of the weather series of each grid where the weight is equal to the share of the grid that intersects the region. In this way, a grid square that has $\frac{1}{2}$ of its area intersecting a region receives $\frac{1}{2}$ the weight of a grid square that completely intersects the region.

Figure 1 shows the yearly precipitation and temperature from the University of Delaware data for Chile between 1950 and 2017, reporting the minimum, maximum and mean monthly values over the 12 months of the year. The national-wide temperature and precipitation are reported as weighted averages of the regions by surface area or by the GDP of each region. Both measures differ, since some regions can be large in surface area (square kilometers), but small in terms of GDP and economic activity (or in terms of population). Calculating average precipitation weighted by each region's GDP can help obtain more accurate measures for the temperature and precipitation that affect economic activities such as agriculture, transports and services. Surface weights on the other hand may be a better proxy for the impact of weather changes on natural habitats and biodiversity. Minimum and mean precipitation is larger for the weighted surface measure, because larger regions have higher precipitation. Maximum and mean temperatures are lower by weighted surface, since the larger regions are cooler. Both the weighted GDP and weighted surface measures

Figure 1: The evolution of the yearly precipitation and temperature (weighted by the regional GDP in 2017 or by the surface area of each region) during the period 1950-2017. Minimum, Maximum and Mean values are from January to December of each year.



at the national level show that - despite large fluctuations in some years - the mean precipitation has been falling in Chile over time, while mean temperatures have increased substantially.

To summarize the regional heterogeneity in a more succinct way, we create 4 macrozones, with macrozone 1 "North Chile" corresponding to regions I, II, III, IV and XV, macrozone 2 "Central Chile" corresponding to regions V, VI, VII, VIII, macrozone 3 "South Chile" corresponding to regions IX, X, XI, XII and XIV, and macrozone 4 "Metropolitan Region" corresponding to region XIII (which concentrates around 45% of the population and GDP of the nation). Figure 2 shows the yearly precipitation and temperature for each macrozone between 1950 and 2017. For simplicity we report only the weighted values by surface area. Figure 2 shows that mean precipitation has been falling in the Central, South and Metropolitan macrozones, while mean temperatures have been increasing across all the macrozones. Figure 4 in the appendix 6.3 shows a similar qualitative pattern in the temperature and precipitation values weighted by GDP for each macrozone.

Table 4 summarizes how much the distribution of the precipitation and temperature in Chile and its macrozones changed between 1950 until 1985 and between 1985 until 2017. Since there are substantial fluctuations between individual years, we implement a comparison by decades between 1950-1959, 1980-1989 and the last 7 years between 2010-2017. The results in Table 4 show that the mean precipitation weighted by surface are decreased substantially between 1950-1959 and 1980-1989 and also decreased slightly between 1980-1980 and 2010-2017. The results are similar for mean precipitation weighted by regional GDP, but with a sharper fall in mean precipitation between 2010-2017. Maximum precipitation in Chile also decreased substantially between 1950-1959 and 1980-1989 and again between 1980-1980 and 2010-2017, whether with surface or GDP region weights. The results also show a substantial decrease in maximum and mean precipitation across all macrozones (with either surface or GDP weight), except for the North, although minimum precipitation changed only slightly (except for the South).

In terms of temperature changes, Table 4 shows a substantial increase in mean temperature between 1950-1959 and 1980-1989 with regional surface weights, although barely no change afterwards. However, with regional GDP weights there was an increase in mean temperature of 0.20 Celsius between 1950-1959 and 1980-1989 and an even stronger increase of 0.37 Celsius between 1980-1989 and 2010-2017. The maximum temperature for Chile also increased substantially between 1980-1989 and 2010-2017 with increases of 0.13 and 0.73 Celsius degrees with surface and GDP weights,

Figure 2: The evolution of the yearly precipitation and temperature (weighted by the surface area of each region) for each macrozone during the period 1950-2017. Minimum, Maximum and Mean values are from January to December of each year.

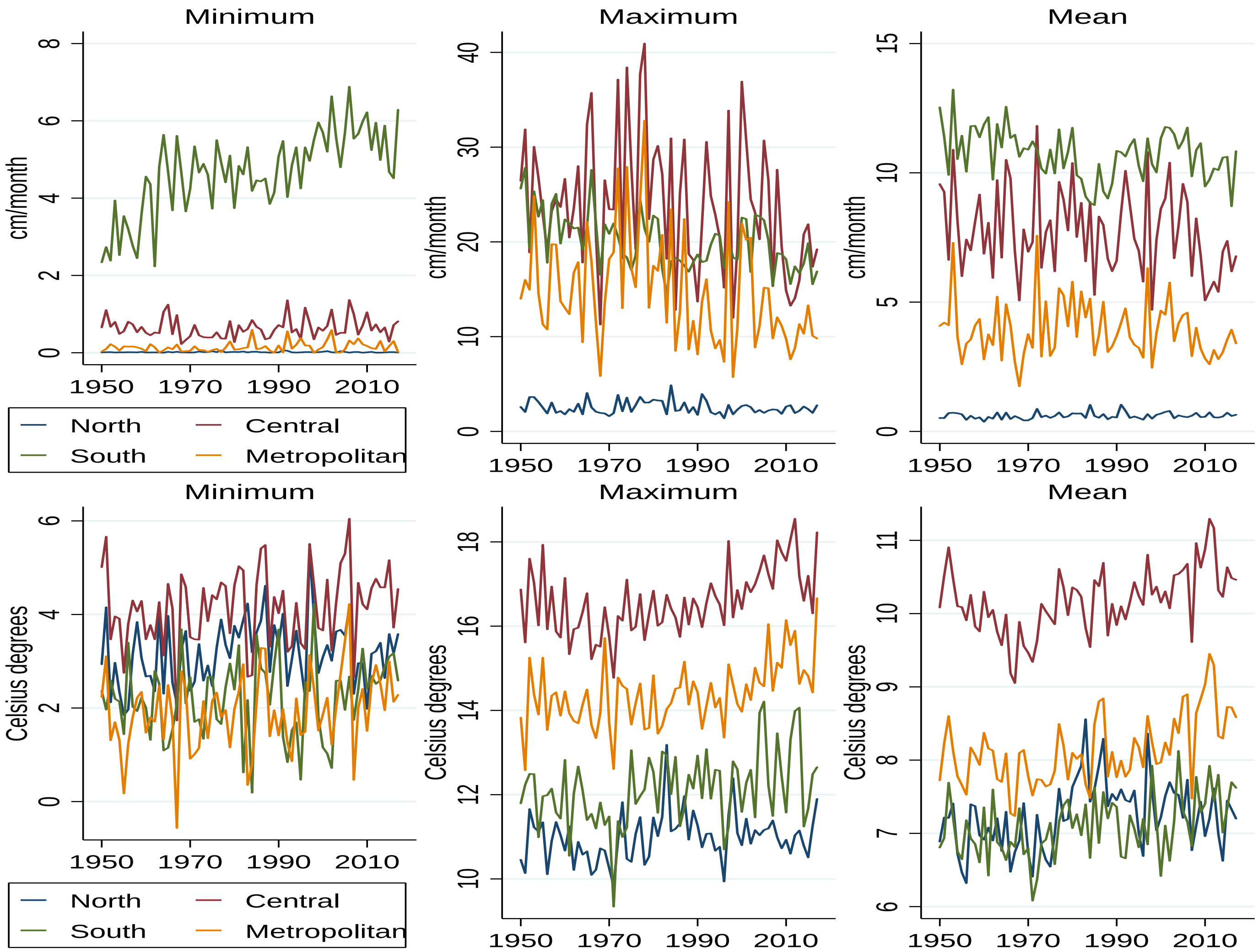


Table 4: Changes in yearly minimum, maximum and mean precipitation (centimeters per month) and temperature (Celsius degrees) between the averages for the decades 1950-1959 and 1980-1989 and between the averages for 1980-1989 and 2010-2017. Results for Chile and each macrozone weighted by region's surface area and regional GDP in 2017.

Period	Macrozone	Precipitation (cms/month)			Temperature (Celsius degrees)		
		Min	Max	Mean	Min	Max	Mean
		Regional surface weights					
1989-1959	Chile	0.64	-2.19	-0.84	0.41	0.37	0.43
2017-1989	Chile	0.49	-1.70	-0.06	-0.02	0.13	-0.03
1989-1959	North	0.00	0.20	0.05	0.88	0.59	0.81
2017-1989	North	-0.01	-0.45	-0.03	-0.63	-0.51	-0.63
1989-1959	Central	-0.14	-0.67	-0.56	0.20	-0.21	-0.03
2017-1989	Central	0.11	-6.90	-1.54	0.19	1.11	0.52
1989-1959	South	1.46	-4.86	-1.77	0.06	0.35	0.24
2017-1989	South	1.06	-1.10	0.40	0.45	0.37	0.33
1989-1959	Metro	0.02	-0.57	0.11	0.30	0.18	0.16
2017-1989	Metro	0.01	-5.27	-1.08	0.31	1.07	0.67
		Regional GDP weights					
1989-1959	Chile	0.02	-0.79	-0.28	0.29	0.16	0.20
2017-1989	Chile	0.08	-4.50	-0.89	0.13	0.73	0.37
1989-1959	North	0.01	0.18	0.05	0.79	0.52	0.74
2017-1989	North	-0.01	-0.43	-0.04	-0.60	-0.47	-0.60
1989-1959	Central	-0.12	-0.21	-0.38	0.12	-0.13	-0.01
2017-1989	Central	0.08	-6.53	-1.38	0.21	1.01	0.51
1989-1959	South	0.44	-5.11	-2.41	-0.23	0.11	-0.07
2017-1989	South	0.61	-3.32	-0.30	0.47	0.72	0.44
1989-1959	Metro	0.02	-0.57	0.11	0.30	0.18	0.16
2017-1989	Metro	0.01	-5.27	-1.08	0.31	1.07	0.67

respectively. Again, the North macrozone differs from the others in the sense that it experienced a large increase of 0.81 Celsius degrees between 1950-1959, followed by a strong decrease of -0.63 Celsius between 1980-1989 and 2010-2017. The Central, South and Metropolitan macrozones experienced a strong increase in mean and maximum temperatures in the recent period between 1980-1989 and 2010-2017. Mean temperatures for the Central, South and Metropolitan macrozones increased, respectively, by 0.52, 0.33 and 0.67 Celsius degrees between 1980-1989 and 2010-2017 with surface weights, while maximum temperatures in the same macrozones increased by 1.11, 0.37 and 1.07 Celsius degrees. When weighted by regional GDP, the results for the period between 1980-1989 and 2010-2017 are very similar. With GDP weights, the mean temperatures increased by 0.51, 0.44 and 0.67 Celsius degrees for the Central, South and Metropolitan macrozones, respectively, while the maximum temperatures increased by 1.01, 0.72 and 1.07 Celsius degrees. Overall, the results in Table 4 document a decrease in precipitation and increase in temperatures for Chile and all its macrozones (except the North) between 1980-1989 and 2010-2017.

2.3 Econometric model

The econometric model follows a panel structure of log GDP growth ($y_{r,i,t} = \ln(GDP^{adj}_{r,i,t})$) as the dependent variable, with explanatory variables including the lagged GDP growth, the average temperature and precipitation of each season plus fixed-effects for region-industry ($\alpha_{r,i}$) and year (α_t):

3) $\Delta y_{r,i,t} = \sum_{s \in S} \beta_{s,i} T_{r,s,t} + \rho_i \Delta y_{r,i,t-1} + \alpha_{r,i} + \alpha_t + \varepsilon_{r,i,t}$

where s is the season (either every quarter or every month of the calendar year), $T_{r,s,t}$ is a vector of the weather variables (average temperature, precipitation) affecting the region r in season s of year t. We estimate the models by OLS with robust standard-errors clustered by region and year.

3 Results for Chile: 1985-2017

3.1 Main results

Since the Chilean GDP series for region-industry are available only at an annual frequency, then it is hard to estimate the impact of each month on the yearly GDP of each region-industry (too many coefficients for a 32 year period). However, using only quarterly averages for the weather can mask strong highs and lows in temperature and rainfall. Both the models with monthly weather (too many coefficients and low precision) and quarterly weather (too little identification from weather shocks) are problematic. Therefore we present both results as alternative models and then comment on their findings.

The quarterly model results (Table 5) only shows a statistically negative impact of temperature on the Agriculture-Silviculture and Fishing sectors. The results by month (Table 6) show a statistically significant negative impact for the temperature of the January month in Agriculture-Silviculture, Fishing, EGA (Electricity, Gas, and Water) and Construction sectors. Therefore our analysis shows that the Agriculture-Silviculture and Fishing sectors in Chile were negatively impacted in a direct way by higher Summer temperatures over the last 35 years, with results being robust for both the monthly and quarterly models. The impact is estimated in terms of reduced-form coefficients, since we cannot verify which channels (such as input-output networks in Chile or value chains effects at the global level) are driving the reduced-form coefficient estimates.

3.2 Robustness checks

The main results are unweighted regressions, with all region-industry pairs with a weight of 1 observation, independently of their economic value. As a robustness check, we repeated the same models with constant weights for each industry and different clustering options (clusters just by year or clusters by region-year). The results were qualitatively similar, although the coefficients for Fishing lost statistical significance (see Table A1 in the Appendix). We also include an exercise that aggregates regions I and XV plus regions X and XIV, therefore presenting 13 regions for the

Table 5: Coefficients for the impact of temperature and precipitation (quarterly averages) on regional industry GDP

	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home	Pers. serv.	Public adm.
Quarter						*Coefficients for Temperature*						
1 Jan-Mar	-0.019**	-0.108*	0.052	0.015	-0.024	-0.023	0.005	0.007	0.006*	-0.002	0.001	0.001
	(0.009)	(0.060)	(0.032)	(0.013)	(0.018)	(0.020)	(0.008)	(0.005)	(0.003)	(0.003)	(0.002)	(0.002)
2 Apr-Jun	0.012	0.007	-0.078**	0.009	0.018*	0.019	-0.010	-0.003	-0.003	0.001	-0.003	0.000
	(0.009)	(0.034)	(0.032)	(0.009)	(0.010)	(0.015)	(0.009)	(0.006)	(0.004)	(0.001)	(0.002)	(0.002)
3 Jul-Sep	-0.012	0.034	0.077*	-0.008	0.018	0.011	0.005	0.000	0.005	-0.003	0.003	-0.002
	(0.011)	(0.039)	(0.043)	(0.013)	(0.018)	(0.016)	(0.004)	(0.007)	(0.004)	(0.003)	(0.003)	(0.002)
4 Oct-Dec	0.028*	-0.003	-0.066	0.010	-0.013	0.000	0.010*	-0.001	-0.001	-0.002	0.002	-0.003
	(0.015)	(0.043)	(0.041)	(0.016)	(0.024)	(0.027)	(0.006)	(0.008)	(0.005)	(0.002)	(0.002)	(0.002)
Quarter						*Coefficients for Precipitation*						
1 Jan-Mar	0.005	-0.001	0.017	0.010**	0.007	-0.003	-0.001	-0.002	-0.000	-0.000	0.001*	-0.001
	(0.004)	(0.012)	(0.018)	(0.005)	(0.008)	(0.010)	(0.002)	(0.002)	(0.001)	(0.000)	(0.001)	(0.001)
2 Apr-Jun	0.001	-0.011	-0.002	-0.002	0.009*	-0.005	0.000	-0.001	-0.000	0.000	0.000	0.000
	(0.002)	(0.008)	(0.006)	(0.002)	(0.005)	(0.004)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
3 Jul-Sep	0.002	0.020**	-0.005	0.004	0.005	0.006	0.001	-0.001	0.001	0.001	0.001	-0.001
	(0.002)	(0.010)	(0.008)	(0.004)	(0.004)	(0.005)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)
4 Oct-Dec	0.000	-0.002	-0.011	-0.007**	0.007*	0.009	-0.000	-0.006**	-0.001	-0.000	0.000	-0.000
	(0.004)	(0.008)	(0.010)	(0.003)	(0.004)	(0.007)	(0.002)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
N	465	436	395	465	460	465	465	465	465	465	465	465
R-squared	0.112	0.055	0.058	0.028	0.041	0.025	0.025	0.049	0.047	0.095	0.026	0.025

Observations not weighted for GDP in regressions.

Lagged industry GDP growth included in each regression.

Robust standard errors clustered by year and region in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 6: Coefficients for the impact of temperature (monthly averages) on regional industry GDP

	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home	Pers. serv.	Public adm.
						Coefficients for Temperature						
Jan	-0.028***	-0.121***	0.019	0.006	-0.039***	-0.015*	0.004	0.006	0.002	-0.000	0.001	-0.001
	(0.009)	(0.027)	(0.028)	(0.010)	(0.012)	(0.008)	(0.005)	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)
Feb	0.008	0.004	0.018**	0.006	-0.001	0.010	0.004*	0.005	-0.003	-0.000	0.001	-0.001
	(0.005)	(0.023)	(0.007)	(0.011)	(0.004)	(0.025)	(0.002)	(0.005)	(0.003)	(0.001)	(0.001)	(0.001)
March	0.006	0.035	0.026	0.014	0.006	-0.026	0.002	-0.008	0.010***	-0.004	0.000	0.003
	(0.010)	(0.034)	(0.030)	(0.010)	(0.016)	(0.018)	(0.006)	(0.006)	(0.003)	(0.002)	(0.002)	(0.002)
April	0.008	-0.042	-0.020	-0.015	0.023	0.009	-0.011*	0.005	0.000	0.000	-0.005	-0.000
	(0.006)	(0.050)	(0.025)	(0.010)	(0.016)	(0.023)	(0.006)	(0.003)	(0.004)	(0.001)	(.)	(0.002)
May	-0.007*	-0.023	-0.038*	0.003	-0.004	-0.009	-0.003	-0.006	-0.003	0.002	-0.000	0.001
	(0.004)	(0.027)	(0.021)	(0.012)	(0.013)	(0.017)	(0.004)	(0.005)	(0.003)	(0.001)	(0.002)	(0.001)
June	0.005	0.044	-0.030***	0.009	0.004	0.017	-0.001	-0.001	-0.001	-0.001	0.000	-0.000
	(0.005)	(0.034)	(0.009)	(0.011)	(0.010)	(0.019)	(0.005)	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)
July	0.004	0.007	0.055***	0.001	-0.014	0.005	-0.001	0.008	-0.000	0.001	0.002	-0.001
	(0.008)	(0.023)	(0.017)	(0.008)	(0.019)	(0.019)	(0.005)	(0.005)	(0.003)	(0.001)	(0.002)	(0.002)
Aug	-0.000	0.019	-0.018	0.009	0.037	0.047***	0.007	-0.006	-0.000	-0.002	-0.001	0.001
	(0.009)	(0.023)	(.)	(0.019)	(0.028)	(0.018)	(0.004)	(0.006)	(0.003)	(0.003)	(0.002)	(0.001)
Sept	-0.018***	-0.049	0.036	-0.022**	0.001	-0.035**	-0.000	0.002	0.007*	-0.001	0.001	-0.002
	(0.007)	(0.049)	(0.024)	(0.009)	(0.018)	(0.017)	(0.006)	(0.002)	(0.004)	(0.002)	(0.002)	(0.002)
Octo	0.012**	0.047	-0.003	0.003	0.007	-0.016	0.002	-0.003	-0.006	-0.001	0.002*	-0.000
	(0.005)	(0.042)	(0.020)	(0.009)	(0.017)	(0.021)	(0.005)	(0.005)	(0.005)	(0.002)	(0.001)	(0.002)
Nov	0.023	-0.010	-0.027	0.009	-0.020	-0.003	0.001	0.001	0.005	-0.001	0.001	-0.002
	(0.015)	(0.042)	(0.027)	(0.016)	(0.016)	(0.028)	(0.006)	(0.003)	(0.005)	(0.001)	(0.001)	(0.002)
Dec	0.000	0.001	-0.037	0.002	0.019	0.028	0.006*	-0.001	-0.000	-0.000	-0.001	0.000
	(0.006)	(0.027)	(0.029)	(0.016)	(.)	(0.026)	(0.003)	(0.005)	(0.002)	(0.001)	(0.001)	(0.001)
N	465	436	395	465	460	465	465	465	465	465	465	465
R-sq.	0.187	0.113	0.087	0.065	0.112	0.082	0.058	0.087	0.106	0.158	0.060	0.054

Observations not weighted in regressions.

Lagged industry growth rate and monthly precipitation included in regressions.

Robust standard errors clustered by region and year in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

entire period of 1985 to 2017 (see the Appendix for Table A2 with the quarterly temperatures' model and Table A3 with the monthly temperatures' model).

3.3 Calibrated projections of the climate change impact for 2050 and 2100

Now we use the estimated coefficients from the model with the monthly weather fluctuations (Table 6) to implement a calibrated exercise using the global temperature projections of the IPCC (2014) to project how a uniform temperature increase throughout the entire year may affect the Chilean GDP. The quantitative exercise considers the impact of a given global temperature change in climate change, T_t^{RCP-x}, in year t for each $RCP-x$ path (with $x = 2.6, 4.5, 6.0, 8.5$) on the GDP growth rate and on the GDP level of each industry i: $I-growth_{i,t} = (\sum_{s=1}^{12} \beta_{s,i})(T_t^{RCP-x} - T_{2017})$ and $I-level_{i,t} = \exp(\sum_{t'=2017}^{t} I-growth_{i,t'}) - 1$. These RCP paths scenarios are obtained from the average path values of the United Nations modeling experts (IPCC 2014). These path values are widely used in macro-financial stress tests with climate change factors (NGFS 2021). We then obtain the estimates of the impact on the aggregate GDP by summing up across all industries, $I-growth_t = \sum_{i=1}^{12} w_{i,t} I-growth_{i,t}$ and $I-level_t = \sum_{i=1}^{12} w_{i,t} I-level_{i,t}$, with $w_{i,t}$ denoting the weight of each industry i in the total GDP at time t. Notice that the GDP growth rate and level impact costs are measured relative to a world with no climate change and not relative to 2017.

We produce 3 estimates of the impact of climate change on each industry i at horizon t: 1) using all the model's estimated point coefficients for the effect of the temperature on the industrial GDP ($\beta = (\hat{\beta}_{1,1}, .., \hat{\beta}_{s,i}, .., \hat{\beta}_{12,12})$ with $s = 1, .., 12$ denoting month and $i = 1, ..., 12$ denoting industry); 2) using only the statistically significant coefficients at a level of 10% or lower ($\beta = (.., \beta_{s,i}, ..)$ with $\beta_{s,i} = \hat{\beta}_{s,i} 1(\frac{|\hat{\beta}_{s,i}|}{SE(\hat{\beta}_{s,i})} \leq 1.65)$, with $1(.)$ being the indicator function); and 3) using only negative coefficients (that is, disregarding positive impacts of climate change) that are statistically significant ($\beta = (.., \beta_{s,i}, ..)$ with $\beta_{s,i} = \hat{\beta}_{s,i} 1(\frac{|\hat{\beta}_{s,i}|}{SE(\hat{\beta}_{s,i})} \leq 1.65) 1(\hat{\beta}_{s,i} < 0))$.

Table 7 denotes the values of the estimated sum of the coefficients for all months for each industry i ($\sum_{s=1}^{12} \beta_{s,i}$) under each of these separate assumptions, which represents the impact on the GDP growth rate of each industry in a given year for a uniform increase in temperature of 1 °C throughout all the months of the year. If one considers the quarterly weather model from Table 5, then Fishing and Mining are the only industries which are negatively impacted by climate change

Table 7: Total impact on the industry GDP growth rate (in %) of the estimated models for a one degree Celsius temperature increase throughout the year

Sum of the coefficients' impact	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.
Quarterly weather fluctuations model (Table 5)												
All quarters	0.9	-7.0	-1.5	2.6	-0.1	0.7	1.0	0.3	0.7	-0.6	0.3	-0.4
Stat. significant	0.9	-10.8	-0.1	0.0	1.8	0.0	1.0	0.0	0.6	0.0	0.0	0.0
Significant & negative	0.0	-10.8	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monthly weather fluctuations model (Table 6)												
All months	1.3	-8.8	-1.9	2.5	1.9	1.2	0.4	0.2	1.1	-0.7	0.1	-0.2
Stat. significant	-3.0	-12.1	0.5	-2.2	-3.9	-0.3	-0.7	0.0	1.7	0.0	0.2	0.0
Significant & negative	-3.0	-12.1	0.0	-2.2	-3.9	-0.3	-0.7	0.0	0.0	0.0	0.0	0.0

with a statistical significance, although the coefficient for Mining is very small. By considering the monthly fluctuations model from Table 6, then we find a statistically significant impact of an increase of 1 °C in temperature that reduces the growth rate in Agriculture, Fishing, Manufacture, EGA (Electricity, Gas, and Water), Construction and Commerce of -3%, -12.1%, -2.2%, -3.9%, -0.3% and -0.7%, respectively.

Table 8 shows the impact of the average global temperature increase according to different climate emission paths (IPCC 2014) under the assumption that we apply all the model's coefficients in the forecast. Under this assumption, Fishing, Mining, Home property and Public administration are the only industries hurt by climate change whether at the horizons of 2050 or 2100. In particular, Fishing's GDP almost disappears by 2100, even with just a 1.0 °C increase in temperature. With all the model's estimated coefficients, Mining and Home property would also decrease by at least 55% and 25.5%, respectively, by 2100. However, climate change would have a strong positive impact on the other economic sectors and therefore the total Chilean GDP would increase across all scenarios in 2050 and 2100. It is unlikely that such large positive impacts of climate change may materialize, however, since these projections obviously assume that the coefficients are fixed over time. Probably it is more realistic to assume that the positive impacts of climate change may decline over time and even turn into negative effects.

Table 9 shows the impact of the average global temperature increase according to different climate emission paths (IPCC 2014) under the assumption that we apply only the model's coefficients

Table 8: Simulated impact (in %) of the climate change on the industry and overall GDP level and growth rates in Chile for the period 1985-2017 and for the future (monthly model, all coefficients, Table 6)

Temper. increase	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP growth rate in 2017 relative to no warming after 1985													
0.26 °C*	0.3	-2.3	-0.5	0.6	0.5	0.3	0.1	0.1	0.3	-0.2	0.0	-0.1	0.1
Impact on GDP level in 2050 relative to no warming after 2017													
1.0 °C	24.7	-77.6	-27.6	53.0	38.1	22.6	7.0	3.5	20.6	-11.2	1.7	-3.3	9.8
1.3 °C	33.3	-85.7	-34.3	73.8	52.2	30.4	9.2	4.5	27.5	-14.3	2.2	-4.3	14.0
1.4 °C	36.3	-87.7	-36.4	81.3	57.2	33.1	10.0	4.9	29.9	-15.3	2.4	-4.6	15.5
2.0 °C	55.6	-95.0	-47.6	134.0	90.8	50.4	14.6	7.0	45.4	-21.2	3.5	-6.6	26.0
Impact on GDP level in 2100 relative to no warming after 2017													
1.0 °C	72.6	-97.5	-55.0	185.8	122.1	65.5	18.3	8.8	58.7	-25.5	4.3	-8.1	36.3
1.8 °C	167.2	-99.9	-76.2	561.9	320.6	147.7	35.3	16.3	129.7	-41.1	7.9	-14.0	105.6
2.2 °C	232.4	-100	-82.7	907.4	478.7	203.1	44.7	20.3	176.3	-47.6	9.7	-16.9	164.4
3.7 °C	654.0	-100	-94.8	4766.7	1815.6	545.5	86.2	36.5	452.6	-66.3	16.8	-26.7	738.0

* Global temperature increase over the period 1985-2017.

Table 9: Simulated impact (in %) of the climate change on the industry and overall GDP level and growth rates in Chile: Only statistically significant coefficients (monthly model, Table 6)

Temper. increase	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP growth rate in 2017 relative to no warming after 1985													
0.26 °C*	-0.8	-3.1	0.1	-0.6	-1.0	-0.1	-0.2	0	0.4	0	0.1	0	-0.1
Impact on GDP level in 2050 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.0 °C	-40.0	-87.2	8.9	-31.2	-48.5	-5.0	-11.2	0	33.5	0	3.5	0	-2.3
1.3 °C	-48.5	-93.1	11.7	-38.5	-57.8	-6.4	-14.3	0	45.6	0	4.5	0	-1.9
1.4 °C	-51.0	-94.4	12.6	-40.8	-60.5	-6.9	-15.3	0	49.9	0	4.9	0	-1.7
2.0 °C	-63.9	-98.4	18.5	-52.7	-73.4	-9.7	-21.2	0	78.2	0	7.0	0.0	0.4
Impact on GDP level in 2100 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.0 °C	-71.6	-99.4	23.4	-60.3	-80.6	-11.8	-25.5	0	104.2	0	8.8	0	3.2
1.8 °C	-89.6	-100	45.9	-81.0	-94.8	-20.3	-41.1	0	261.5	0	16.3	0	25.3
2.2 °C	-93.7	-100	58.7	-86.9	-97.3	-24.2	-47.6	0	381.0	0.0	20.3	0	44.0
3.7 °C	-99.1	-100	117.5	-96.7	-99.8	-37.3	-66.3	0	1303.8	0	36.5	0	193.2

* Global temperature increase over the period 1985-2017.

Table 10: Simulated impact (in %) of the climate change on the industry and overall GDP level and growth rates in Chile:
Only statistically significant coefficients with a negative value (monthly model, Table 6)

Temper. increase	Agri- culture	Fish- ing	Min- ing	Manu- facture	EGA	Const- ruction	Com- merce	Trans- ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP growth rate in 2017 relative to no warming after 1985													
0.26 °C*	-0.8	-3.1	0	-0.6	-1.0	-0.1	-0.2	0	0	0	0	0	-0.2
Impact on GDP level in 2050 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.0 °C	-40.0	-87.2	0	-31.2	-48.5	-5.0	-11.2	0	0	0	0	0	-9.0
1.3 °C	-48.5	-93.1	0	-38.5	-57.8	-6.4	-14.3	0	0	0	0	0	-10.9
1.4 °C	-51.0	-94.4	0	-40.8	-60.5	-6.9	-15.3	0	0	0	0	0	-11.5
2.0 °C	-63.9	-98.4	0	-52.7	-73.4	-9.7	-21.2	0	0	0	0	0	-14.8
Impact on GDP level in 2100 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.0 °C	-71.6	-99.4	0	-60.3	-80.6	-11.8	-25.5	0	0	0	0	0	-16.8
1.8 °C	-89.6	-100	0	-81.0	-94.8	-20.3	-41.1	0	0	0	0	0	-22.9
2.2 °C	-93.7	-100	0	-86.9	-97.3	-24.2	-47.6	0	0	0	0	0	-24.9
3.7 °C	-99.1	-100	0	-96.7	-99.8	-37.3	-66.3	0	0	0	0	0	-29.6

* Global temperature increase over the period 1985-2017.

that are statistically significant at the 10% level at least. Under this assumption, Agriculture, Fishing, Manufacture, EGA, Construction and Commerce are the only industries hurt by climate change whether at the horizons of 2050 or 2100. Even with just a 1.0 °C increase in temperature, Agriculture, Fishing, Manufacture, EGA, Construction and Commerce would decline by 71.6%, 99.4%, 60.3%, 80.6%, 11.8% and 25.5%, respectively, around 2100. However, climate change would have a strong positive impact on the other economic sectors and therefore the total Chilean GDP would change only slightly in 2050 and it would even increase across all scenarios in 2100. Again, however, this result is strongly dependent on the positive effects of climate change estimated for some sectors and these effects may not materialize, since such positive effects may decline over time and even turn into negative effects.

Finally, Table 10 shows the impact of the average global temperature increase according to different climate emission paths (IPCC 2014) using only the model's coefficients that are both negative and statistically significant. Again, under this assumption, Agriculture, Fishing, Manufacture, EGA, Construction and Commerce are the only industries hurt by climate change whether at the horizons of 2050 or 2100. In terms of the negative impact of climate change on the total GDP, it could range between 9% and 14.8% in 2050 and between 16.8% and 29.6% in 2100.

Therefore our model predicts a large and positive impact of climate change on the total Chilean GDP if one uses all the model's coefficients both in 2050 and 2100, a small impact of climate change in 2050 if the forecasts use just the statistically significant coefficients, and a moderately negative impact of climate change both in 2050 and 2100 if the forecasts apply just the negative and statistically significant coefficients. It is possible that the forecasts using all the model's coefficients are way too optimistic, while the forecasts with just the negative and statistically significant coefficients can be too pessimistic since the coefficients are selected to clearly present a negative scenario. The appendix at the end of the article shows a counterfactual exercise with the most recent temperature projection paths of the IPCC (2021), but the results are broadly similar, both qualitatively and quantitatively.

3.4 Calibrated projections for Chile using industry coefficients estimated for the USA

The counterfactual exercises considered in Tables 7, 8 and 9 implemented the coefficients estimated from our model in Table 6. However, Chile only has 15 regions and many of those regions have a zero value for some industries or an extremely low value. The small number of Chilean regions and the low economic value of several of those regions makes it harder to estimate the economic impact of climate change in a reliable way. For this reason, we also implement a counterfactual exercise where the impact coefficient of the temperature increase induced by climate change is obtained from a model estimated by Colacito, Hoffmann and Phan for the 50 states and 12 industries of the USA. Since the USA' states are relatively large economies and it includes a large number of states, then the impact of climate change on each industry can be estimated in a more precise way and with lower standard errors. The difference is that we are applying the value of each Chilean industry on GDP to make the projection for total GDP and this considers that Chile has higher shares of some industries such as Mining or Agriculture and lower shares of other industries. One small note is that we apply the same US coefficients for Agriculture-Fishing and Finance-Insurance-Real Estate to the separate Chilean industries of Agriculture and Fishing plus Financial services and Home

Table 11: Simulated impact (in %) of the climate change on the industry
and overall GDP level and growth rates in Chile for the future:
climate change temperature coefficients estimated for the USA industry (post-1997)
from Table A21 (both years) in Colacito, Hoffmann and Phan (2019)

Temper. increase	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP level in 2050 relative to no warming after 2017													
1.0 °C	-4.6	-4.6	53.4	-9.1	7.0	-12.7	-6.2	0.2	-10.3	-10.3	-7.7	-5.6	-0.8
1.3 °C	-5.9	-5.9	74.4	-11.7	9.1	-16.2	-8.0	0.3	-13.2	-13.2	-9.9	-7.2	-0.4
1.4 °C	-6.3	-6.3	82.0	-12.5	9.9	-17.3	-8.6	0.3	-14.1	-14.1	-10.6	-7.7	-0.2
2.0 °C	-8.9	-8.9	135.2	-17.4	14.4	-23.8	-12.0	0.4	-19.5	-19.5	-14.8	-10.9	2.0
Impact on GDP level in 2100 relative to no warming after 2017													
1.0 °C	-10.9	-10.9	187.7	-21.0	18.1	-28.5	-14.6	0.5	-23.5	-23.5	-18.0	-13.2	5.0
1.8 °C	-18.7	-18.7	570.0	-34.6	34.9	-45.4	-24.8	1.0	-38.3	-38.3	-30.0	-22.5	36.1
2.2 °C	-22.4	-22.4	922.4	-40.5	44.2	-52.3	-29.4	1.2	-44.5	-44.5	-35.3	-26.8	69.4
3.7 °C	-34.7	-34.7	4889.2	-58.2	85.0	-71.2	-44.3	2.0	-62.9	-62.9	-52.0	-40.9	477.6

property, since those industries are treated separately in the Chilean national accounts data.

Table 11 shows the counterfactual exercise of applying the coefficients from Table A21 in Colacito, Hoffmann and Phan (2019). It shows its strongest impact in 2050 on Construction, which would decline between 12.7% and 23.8%. Home property, Financial Services and Manufactures would also be strongly hit, declining between 9% and 19.5% relative to a scenario with no climate change. However, due to the positive coefficient estimated for the Mining industry, the impact of climate change on the Chilean GDP in 2050 would be limited to a decline of 0.8% or less. In 2100 the projections for climate change's impact on total GDP would again become very positive, because the counterfactual would assume that the log-growth of Mining would add up linearly over time.

Table 12 shows a very similar counterfactual exercise with impact coefficients for temperature estimated for the US, but it considers only the statistically significant coefficients from Table A21 in Colacito, Hoffmann and Phan (2019). The exercise also applies the Agriculture-Fishing and Manufacturing industries coefficients from Table A20 in Colacito, Hoffmann and Phan (2019), since those coefficients were estimated with a smaller standard-error, perhaps due to the higher importance of such industries for the US economy before 1997. The results show a negative

Table 12: Simulated impact (in %) of the climate change on the industry
and overall GDP level and growth rates in Chile for the future:
climate change temperature coefficients estimated for the USA industry (post-1997)
from Table A21 (both years, only statistically significant coefficients) plus Agriculture-Fishing and
Manufacturing industries coefficients from Table A20 (pre-1997)
in Colacito, Hoffmann and Phan (2019)

Temper. increase	Agri- culture	Fish- ing	Min- ing	Manu- facture	EGA	Const- ruction	Com- merce	Trans- ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
	Impact on GDP level in 2050 relative to no warming after 2017												
1.0 °C	-18.7	-18.7	0.0	-4.6	0.0	-12.7	-6.2	0.0	-10.3	-10.3	-7.7	-5.6	-6.8
1.3 °C	-23.6	-23.6	0.0	-5.9	0.0	-16.2	-8.0	0.0	-13.2	-13.2	-9.9	-7.2	-8.7
1.4 °C	-25.2	-25.2	0.0	-6.3	0.0	-17.3	-8.6	0.0	-14.1	-14.1	-10.6	-7.7	-9.3
2.0 °C	-33.9	-33.9	0.0	-8.9	0.0	-23.8	-12.0	0.0	-19.5	-19.5	-14.8	-10.9	-12.9
	Impact on GDP level in 2100 relative to no warming after 2017												
1.0 °C	-40.0	-40.0	0.0	-10.9	0.0	-28.5	-14.6	0.0	-23.5	-23.5	-18.0	-13.2	-15.5
1.8 °C	-60.2	-60.2	0.0	-18.7	0.0	-45.4	-24.8	0.0	-38.3	-38.3	-30.0	-22.5	-25.4
2.2 °C	-67.5	-67.5	0.0	-22.4	0.0	-52.3	-29.4	0.0	-44.5	-44.5	-35.3	-26.8	-29.6
3.7 °C	-84.9	-84.9	0.0	-34.7	0.0	-71.2	-44.3	0.0	-62.9	-62.9	-52.0	-40.9	-42.3

impact of climate change for most industries, except for Mining, Energy-Gas-Water (EGA) and Transports-Communications. The strongest impact of climate change is now estimated to be for the Agriculture and Fishing sectors, followed by Construction, Financial services and Home property. In particular, Agriculture and Fishing may decline between 18.7% and 33.9% in 2050, relative to a scenario with no additional climate change. Construction, Financial services and Home property would decline between 10.3% and 23.8% in 2050 due to the impact of worsening climate change. In terms of the total GDP, the effect of climate change in 2050 would imply a deterioration between 6.8% and 12.9%. By 2100 the Agriculture and Fishing industries would decline between 40% and 84.9%, while the Construction, Financial services and Home property would decline between 23.5% and 71.2% due to climate change. Climate change by 2100 could imply a deterioration between 15.5% and 42.3% on the total Chilean GDP.

4 A review of estimates on the future impact of climate change in Chile

Since Agriculture-Silviculture and Fishing represent just 4% of GDP (Table 1), our empirical analysis shows a negligible impact of climate change in Chile over the 1985 to 2017 period. Even if we add the January temperatures effect on the Construction (6.8% of GDP) and Electricity, Gas, and Water (4.0% of GDP) sectors, the analysis for the past 35 years would show that less than 15% of the economic activity in Chile was negatively affected by average changes in temperature and precipitation. It is possible that the higher dispersion of extreme weather between lower minimum and higher maximum values in precipitation and temperature may also have an effect, but it is hard to capture this in GDP data with annual frequency.

Therefore it does not appear that climate change had an economically significant impact for the Chilean economic activity in the past. This matches other studies showing that Chile so far has received very little impact from climate change in terms of temperature[2], in blue and green water availability (Gerten et al. 2011) or water availability in food producing units (World Bank 2013). Furthermore, Krusell and Smith (2018) estimate that Chile has one of the lowest sensitivity ratios to global temperature, with a sensitivity coefficient of just 0.5 on a scale from 0.4 to 5.2, therefore Chile's temperature is forecasted to change little and gradually for the next century.

Other approaches to measuring climate change's impact have analyzed other variables, such as annual labor hours lost to high temperatures between 2001 and 2017 (Watts et al. 2018, 2019), which shows that Chile lost few work hours due to extreme heat or weather shocks. This is in strong contrast to other countries, since Watts et al. (2018) show that extensive areas of the USA, Southern Europe, Middle East, Sub-Saharan Africa, Australia, East Asia and the Pacific, have lost between 0 and 5 annual labor hours per person in the 2000-2017 period relative to the 1986-2005 baseline. However, Senegal, India, Saudi Arabia and Southeast Asia have lost an estimated 40 to 70 annual labour hours per person due to climate change during the 2000-2017 period (Watts et

[2] Kahn et al. (2019) find that Chile during the period 1960-2014 experienced a temperature increase of just 0.0102°C per year. This was one of the lowest temperature rises in the world during this period, being less than half the temperature increase experienced by Belgium, Jamaica, China, France or Canada (Kahn et al. 2019). The same was observed for the period 1900-2014, in which Chile experienced a temperature increase of just 0.0017°C per year.

al. 2018). Chile, Canada, New Zealand, Northern Europe and most of Russia are the only regions unscathed by lost labor hours during this period.

Other outcomes besides GDP in which Chile is already being affected by climate change, such as an increase in persons exposed to wildfires between 2001 and 2018 (Watts et al. 2019), downtime in ports operational hours[3], drought mortality risk (Dilley et al. 2005, World Bank 2013), increased water scarcity and reduced crop yields (Gerten et al. 2011). Chile's central area (Metropolitan and Valparaíso Regions) is in the top 30 to 18 percent of the globe land area associated with higher exposure to drought mortality risk during the period 1981-2000 (Dilley et al. 2005). Furthermore, it is extremely hard to measure the loss of natural capital such as the decline of bio-diversity and damages to habitats and local eco-systems in Chile, although such analysis are starting to take place (Albagli 2021). Our article is limited to studying climate change's impact on regional-industry GDP, because the data is easily accessible and a simple way to measure economic impact.

How may Chile be affected according to different global weather paths in the future? In a review of the future path of climate change and its impact on the Chilean national weather (see Table 13), it is expected that Chile will experience a substantial sea level rise (Bárcena et al. 2019) and a temperature increase during the 21st century (Harris et al. 2017), although less than the rest of the world (Collins et al. 2013). Finally, a multivariate measure of climate change exposure estimated by Diffenbaugh and Giorgi 2012[4] (Table 13) shows that Chile can expect a moderate level of climate change under a moderate climate change path (RCP 4.5), but that Chile could be quite negatively

[3] In 2018 the 7 major Chilean ports (Arica, Iquique, Mejillones, Antofagasta, Coquimbo, Valparaiso, San Antonio, San Vicente/Talcahuano) lost a total of 3,022 hours due to weather downtime (according to official statistics from the General Directorate of Maritime Territory and Merchant Marine, DIRECTEMAR), which is a huge increase from the 17 operational hours lost in 2008 just 10 years before.

Experts estimate a large increase in downtime due to Climate Change by 2050 for the Antofagasta and San Antonio ports, but the national downtime only suffers a slight increase because other ports may be unaffected and the port of San Vicente/Talcahuano may improve (ARCLIM 2021: https://arclim.mma.gob.cl/atlas/view/puertos/). By 2100 all the 7 major ports in Chile will experience a reduction in downtime, but ports will experience higher costs due to wave overtopping from climate change (Winckler et al 2021).

[4] The climate indicators are: absolute change in mean surface air temperature, fractional change in mean precipitation, fractional change in interannual standard deviation of de-trended surface air temperature, fractional change in interannual coefficient of variation of de-trended precipitation, frequency of occurrence of seasons above the baseline maximum seasonal surface air temperature, frequency of occurrence of seasons below the baseline minimum seasonal precipitation, and frequency of occurrence of seasons above the baseline maximum seasonal precipitation.

affected in a more serious climate change evolution (RCP 8.5). Using a different methodology, the German Watch (2019) study found that Chile overall was in the middle of the countries in terms of the economic costs related to climate change in 2018 (rank 87 in 169 countries), since it suffered few human fatalities, although a substantial fraction of GDP loss (rank 53 in 169 countries). This contrasts somewhat with the average German Watch findings for the period 1999-2018, during which Chile suffered less from climate change (rank 93 in 169 countries), with even fewer fatalities (rank 121 in 169 countries) and less GDP costs (rank 83 in 169 countries). An analysis of the climate change impact over the previous decade for 67 countries by HSBC (2018) also found that Chile is one of the economies that is the least vulnerable to the costs imposed by climate change, in terms of its ability to manage the physical risks, energy transition risks and the resources available to respond to climate change (Table 13). However, the HSBC (2018) study also finds that Chile was one of the 14 most sensitive economies to the physical risk induced by extreme climate events during the period 2007-2016 (Table 13).

How may climate change impact economic activity for Chile in the future? Burke et al. (2015a) provide estimates for 165 countries for each year between 2010 to 2099. Using a non-linear model of economic activity that estimates the sensitivity of GDP growth in relation to temperature based on past historical GDPpc data and on future temperature projections (using the median temperature projection for the RCP8.5 emissions trajectory from the IPCC CMIP5), Burke et al. (2015a) predict a strong decline of GDPpc from climate change for most countries. In particular, the authors predict that relative to a no climate change scenario, the climate change impact on World GDP pc implies a reduction of 0% or more with a 71% probability, a reduction larger than 10% with a 63% probability, a reduction larger than 20% with a 51% probability and a reduction larger than 50% with a 12% probability. However, in the case of Chile the mean projection of Burke et al. (2015a) is that the country, due to its distance from the Equator and relatively mild temperatures, will benefit from climate change steadily throughout the 21st century, with an increase in GDP pc of 2.1%, 7.7% and 32% by 2030, 2050 and 2099, respectively (Burke et al. 2015a).

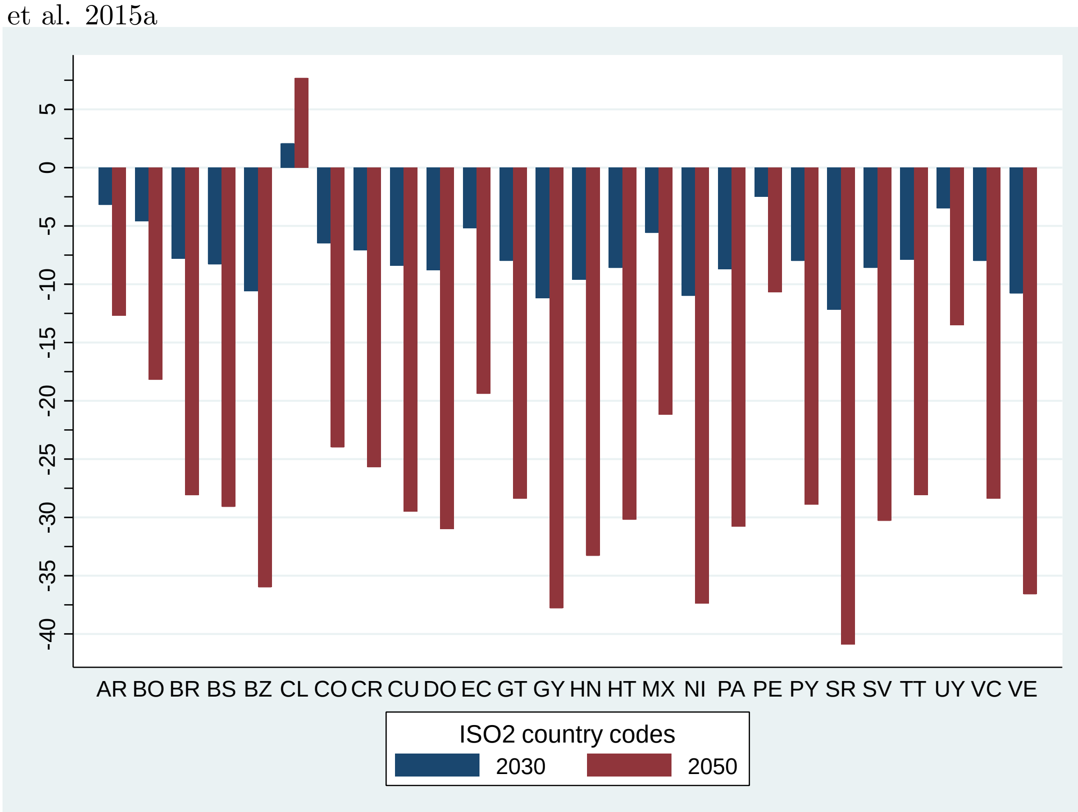
In fact, from the 26 countries of Latin America and the Caribbean (LAC) in the empirical study of Burke et al. (2015a), Chile is the only country that will have a positive impact on GDP from the climate change (Figure 3). According to the results of Burke et al. (2015a), the median LAC country will suffer a loss of -8% and -28.65% in GDPpc by 2030 and 2050, respectively. With the

Table 13: Review of estimates from multinational studies of the climate change impact for Chile in terms of temperature, precipitation and sea level rise

Authors	Time horizon	Outcome	Estimated / simulated impact for Chile
Collins et al. 2013	2081-2100	Temperature	0.5 to 0.75°C increase per 1°C in global temperature
Harris et al. 2017	2081-2100	Temperature	0.5 to 0.75°C increase (best scenario)
Harris et al. 2017	2081-2100	Temperature	3 to 4°C increase (worst scenario)
Collins et al. 2013	2081-2100	Precipitation	-3% to -6% rainfall per 1°C in global temperature
World Bank 2013	2100	High temperature months (in %)	0% to 10% (RCP 2.6) 10% to 20% (RCP 8.5)
World Bank 2013	2100	Sea level rise	0.7m (RCP 2.6), 1.0m (RCP 8.5)
World Bank 2013	2071-2099	Precipitation	-10% to -15% (RCP 2.6), -30% to -35% (RCP 8.5)
Bárcena et al. 2019	2010-2040	Sea level rise	+2.4 mm per year
Bárcena et al. 2019	2040-2070	Sea level rise	+3.4 mm per year
Diffenbaugh and Giorgi 2012	2016-2035	Climate change$^{a)}$	0.85 (RCP 4.5), 0.95 (RCP 8.5)
Diffenbaugh and Giorgi 2012	2045-2065	Climate change$^{a)}$	1.35 (RCP 4.5), 1.50 (RCP 8.5)
Diffenbaugh and Giorgi 2012	2080-2099	Climate change$^{a)}$	1.45 (RCP 4.5), 2.60 (RCP 8.5)
German Watch Climate Risk Index ranking of 168 countries (higher values imply lower risk)			
German Watch 2019	1999-2018	Climate Risk Index rank: 93	
German Watch 2019	1999-2018	Fatalities per 100,000 people rank: 121	
German Watch 2019	1999-2018	Losses per unit of GDP in % rank: 83	
German Watch 2019	2018	Climate Risk Index rank: 87	
German Watch 2019	2018	Fatalities per 100,000 people rank: 115	
German Watch 2019	2018	Losses per unit of GDP in % rank: 53	
HSBC 2018 scoring of climate risks across 67 countries (lower values mean higher vulnerability):			
HSBC 2018	2007-2016	Overall climate vulnerability rank: 51	
HSBC 2018	2007-2016	Physical impacts rank: 64	
HSBC 2018	2007-2016	Sensitivity to extreme events rank: 14	
HSBC 2018	2007-2016	Energy transition rank: 59	
HSBC 2018	2007-2016	Potential to respond to climate change rank: 43	

a) This is a multivariate measure of climate change with an Euclidean distance of the relative changes across seven climate indicators (including extreme temperature and precipitation) for four weather seasons. The Euclidean scale goes from 0.5 (low climate change) to 3.0 (high climate change).

Figure 3: Impact of Climate Change on the GDP per capita of the Latin American countries from Burke et al. 2015a



exception of Chile, the impact on GDPpc may range from -2.5% to -12.2% in 2030 and from -10.7% to -40.9% in 2050 for other 25 LAC countries (Burke et al. 2015a).

Besides Burke et al. (2015a), several other studies also report low estimates for the physical damages and output loss of climate change projections in Chile, measured as changes of GDP, labor productivity, and other economic variables. These studies have methodological differences, which can help us understand how much uncertainty is involved in projecting economic outcomes over periods of several decades. A quick summary of these methodological climate change studies includes: i) Burke et al. 2015a (which estimate a panel growth model that accounts for fixed country effects, common global shocks, country-specific quadratic trends and non-linear effects of temperature and precipitation, with the effects changing as countries grow richer); ii) Kahn et al. 2019 (which use similar data to Burke et al. 2015a, but also consider the effect of country-specific climate variables[5] and estimate a panel data model that corrects for small T bias); iii) OECD 2015

[5] In Burke et al. 2015a there is an ideal weather that is the same for all countries, although its effect changes with

(which is mostly based on an ENV-Linkages model that specifies a global dynamic computable general equilibrium framework with several economic sectors, regions, trade flows and feedback effects between activity and greenhouse gas (GHG) emissions); iv) McKinsey 2020 (which is based on a standard measurement of the impact of high heat distress on labor productivity[6]); v) Cruz and Rossi-Hansberg 2020 (which is based on a spatial growth model of general equilibrium with labor, capital, land, the global climate, country-specific weather[7], plus endogenous technological innovation, international trade, migration and carbon tax policies); vi) Krusell and Smith 2018 (which uses a dynamic stochastic Integrated Assessment Model (IAM) with forward looking consumers and firms in each country-region, green technology, carbon taxes, plus an elaborate climate system, carbon cycle and damages); vii) Carleton et al. 2020 (which estimate a set of age mortality sensitivities to temperature for a wide range of countries[8] and then extrapolate the mortality costs from future demographic dynamics for a range of weather scenarios); viii) Roson and Sartori 2016 (which estimate damage functions for 140 different countries, based on sea level rise, agricultural productivity, heat effects on labor productivity, human health, tourism flows, and households' energy demand); Kalkuhl and Wenz 2020 (which use an annual panel dataset for countries-regions with climate change impacting GDP through temperature and precipitation, including both linear and quadratic terms plus interaction terms between temperature and precipitation).

the income and development level of the countries. In Kahn et al. 2019, however, the effects depend on the historical norm for the weather of each country. A 13°C temperature may be optimal for all countries in the Burke et al. 2015a model, but for Kahn et al. 2019 some countries would suffer because such weather is outside of their norm. Also, for Kahn et al. 2019 some countries have already adapted to their extreme weather through an accustomed labor force, heating or air-conditioning, therefore such countries could suffer less from climate change while other countries would suffer more because the new levels of high temperatures would demand higher adaptation costs.

[6] The idea of this approach is to obtain a robust estimate of the lower bound for the costs of climate change. Therefore the advantage of the McKinsey 2020 measure is that it does not depend on a complex modeling with extensive assumptions on the production functions of each economic sector and the sensitivity of damages relative to temperature. However, the McKinsey 2020 approach is very likely to be a lower bound for the economic damages of climate change, since it does not account for damages to capital, trade disruptions and non-linear negative effects.

[7] Cruz and Rossi-Hansberg 2020 consider that the effect of the weather in each country is a function of latitude, longitude, elevation, distance to coast, distance to ocean, distance to water, vegetation density and albedo. This is a more multi-dimensional modeling of the country-specific weather relative to Kahn et al. 2019.

[8] Carleton et al 2020 estimate a U-shaped impact of the weather on mortality for all ages, with extreme cold and hot temperatures causing higher damages. This function is allowed to change with adaptation to the local climate and the economic development of each country.

Table 14 (which is divided in Table 14.1 and Table 14.2) provides a summary of the results for Chile from a wide range of studies with projections of the costs of climate change on economic activity at a multinational level, while Table 15 compares the impact in Chile with the mean estimates for the world plus the minimum and maximum impacts for the different countries. Table 16 provides a summary of estimates of the climate impact on the Chilean agriculture sector, while Table 17 (which is divided in Table 17.1 and Table 17.2) reviews the effects on the Chilean non-agricultural economic sectors such as health, transports, tourism, energy, water stress, outdoor labor and flood damages. Finally, Table 18 (which is divided in Table 18.1 and Table 18.2) reviews the impact of climate change for non-economic outcomes in Chile, such as mortality, ecosystem or land classification, population and welfare.

Table 14 shows that most estimates for the impact of climate change on economic activity in Chile report either low damages or even a positive outcome. The OECD 2015 reports a negative impact of -0.6% on GDP and -0.275% of GDP if mitigation policies are implemented, Burke et al. 2015a reporting GDP increases between 2.1% and 32% over the 21st century, Kalkuhl and Wenz 2020 estimate a GDP loss between 5% and 10% (while for the world they estimate a GDP loss of 13%), Cruz and Rossi-Hansberg 2020 estimating a loss of 1.9% of GDP, Krusell and Smith 2018 reporting a GDP increase of 14%, McKinsey 2020 reporting a loss of just -0.1% of GDP, and Carleton et al. 2020a reporting gains (in terms of lower mortality costs) between 2% and 4% of GDP. Furthermore, both McKinsey 2020 and Dasgupta et al. 2021 estimate that Chile will suffer only a negligible loss in terms of labour productivity due to climate change, while some regions such as India, Brazil, North and Central Africa, Arabia and the northern Australia may lose 10% or more of their labour productivity (McKinsey 2020, Dasgupta et al. 2021). The reason for these estimates is fairly simple, since Chile is far from the Equator, still has a mild weather over its regions, and also presents a lower sensitivity of the local weather relative to global changes. It is also worth noting that Chile was among the countries in the RoA1 region that Eboli et al. (2010) predicted would benefit from climate change in 2050 and 2100 in terms of overall GDP and also in terms of the Agriculture, Energy demand, Health care and Tourism flows activities.

Furthermore, an OECD exercise also shows that Chile could avoid 54% of the potential damages from climate change to GDP through policy mitigation (see the exercise with mitigation policies on Table 8 of OECD 2015), which is primarily related to their model assumptions about how green

Table 14.1: Review of estimates from multinational studies of the climate change impact on the economic activity in Chile relative to a scenario without climate change

Authors	Time horizon	Outcome	Estimated / simulated impact for Chile
Simulations of the impact on GDP, GDP pc, labor productivity and mortality damages			
OCDE 2015	2060	GDP	-0.6% (no mitigation policies)
OCDE 2015	2060	GDP	-0.75% (from domestic factors)
OCDE 2015	2060	GDP	+0.15% (from global factors)
OCDE 2015	2060	GDP	-0.275% (after mitigation policies)
Roson and Sartori 2016	2100	GDP	-0.26% (RCP 8.5: +3°C scenario)
Swiss Re 2021	2050	GDP	-0.9% (RCP 2.6)
Swiss Re 2021	2050	GDP	–2.1% (RCP 4.5)
Swiss Re 2021	2050	GDP	–2.3% (RCP 6.0)
Swiss Re 2021	2050	GDP	–3.0% (RCP 8.5)
Krusell and Smith 2018	2050	GDP	+14%
Kalkuhl and Wenz 2020	2100	GDP	-5% to -10% (RCP 8.5)
Burke et al. 2015a	2030	GDP pc	+2.1%
Burke et al. 2015a	2050	GDP pc	+7.7%
Burke et al. 2015a	2099	GDP pc	+32.0%
Kahn et al. 2019	2030	GDP pc	-0.50% (RCP 2.6)
Kahn et al. 2019	2050	GDP pc	-1.68% (RCP 2.6)
Kahn et al. 2019	2100	GDP pc	-5.18% (RCP 2.6)
Kahn et al. 2019	2030	GDP pc	-1.23% (RCP 8.5)
Kahn et al. 2019	2050	GDP pc	-3.97% (RCP 8.5)
Kahn et al. 2019	2100	GDP pc	-11.08% (RCP 8.5)

RCP 2.6 is the best scenario, in which climate change is reversed.

RCP 8.5 is the worst scenario, in which no policies are implemented for climate change.

Table 14.2: Review of estimates from multinational studies of the climate change impact on the economic activity in Chile relative to a scenario without climate change

Authors	Time horizon	Outcome	Estimated / simulated impact for Chile
Simulations of the impact on GDP, GDP pc, labor productivity and mortality damages			
McKinsey 2020	2019	Labor productivity	-0.1% in GDP
McKinsey 2020	2030	Labor productivity	-0.1% in GDP
McKinsey 2020	2050	Labor productivity	-0.1% in GDP
Dasgupta et al. 2021	2100	Labor productivity	-1% (RCP 8.5)
OECD 2015	2015	Mortality damages	0.3 billions of USD
OECD 2015	2030	Mortality damages	1.5 billions of USD
OECD 2015	2050	Mortality damages	3.5 billions of USD
OECD 2015	2080	Mortality damages	7.5 billions of USD
Carleton et al. 2020[a)]	2100	Mortality damages	-2% to -4% (as a share of GDP)
Cruz & Rossi-H. 2020	2200	Labor productivity	-5%
Cruz & Rossi-H. 2020[b)]	2200	GDPpc (baseline)	-1.9%
Cruz & Rossi-H. 2020	2200	GDPpc (with Migration only)	-3.1%
Cruz & Rossi-H. 2020	2200	GDPpc (with International Trade)	-2.3%
Cruz & Rossi-H. 2020	2200	GDPpc (with Innovation only)	-4%
Cruz & Rossi-H. 2020	2200	GDPpc (with Carbon Taxes only)	-3.6%

a) Negative mortality damage numbers mean lower damages (positive for welfare).
b) Baseline includes positive effects of Trade, Innovation, Migration and Carbon Taxes.
RCP 8.5 is the worst scenario, in which no policies are implemented for climate change.

investments impacts health, energy and tourism (OECD 2015). Krusell and Smith (2018), however, estimate that Chile would neither gain nor lose much from a global carbon tax: in their study a common carbon tax implemented across the globe would impose a small loss of -0.2% of GDP for Chile, while benefitting 40% of the Chilean population. It is also interesting to note that Cruz and Rossi-Hansberg 2020 expect Chile's losses to be more mitigated by International Trade and Migration rather than from Technological Innovation and Carbon Tax policies. Using a gravity model for migration between countries, Gaska (2021) also finds that climate change under an RCP 8.5 path could increase the number of immigrants in 5% of the Chilean population by 2080. This can have important implications for Chile in the near term, since the last few years saw a strong increase of migration to Chile from poorer Latin American countries (Arias and Guerra-Salas 2019, Aldunate et al. 2019). Therefore as climate change impacts the neighboring countries in a more negative way, one could expect that migration to Chile may increase even more in years to come.

It is relevant to note that all these studies report high estimates for the costs of climate change for the world and other countries, which can be observed in Table 15. Therefore Chile is one of the least affected countries in those studies, even if the same studies forecast high costs of climate change for the globe as a whole, especially for developing countries such as India, Brazil or Mexico. Other countries that may benefit from climate change include Canada and Russia, which are also far from the Equator and have cold weather (Burke et al. 2015a, Krusell and Smith 2018, Cruz and Rossi-Hansberg 2020, Carleton et al. 2020a). Therefore past studies show that the world could suffer a loss in GDP much larger than Chile, with the OECD (2015) reporting -1.82% (almost 3 times more than Chile), Roson and Sartori (2016) estimating an average GDP loss of 3.7% for the world (with Chile losing just 0.26%), Krusell and Smith 2018 reporting a loss of -2.19% (while Chile benefits in 14%), Cruz and Rossi-Hansberg 2020 find a loss of 2.1% for the world (slightly worse than Chile's 1.9% loss), while Burke et al. 2015a report that Chile would be the only country in the Latin American region to benefit from climate change (see Figure 3 in this article) and that the world would suffer losses of -5%, -19% and -48% in GDP pc by 2030, 2050 and 2099. Finally, Carleton et al. 2020 estimate a cost of 3.2% of GDP in mortality damages for the world (Table 15), while Chile in fact would receive health benefits between 2% and 4% of GDP.

The major exception of these low costs and even economic benefits of climate change for Chile comes from Kahn et al. 2019, who find that Chile always performs worse than the world average

Table 15: Comparison of the climate change impact for Chile and other countries in the world in a scenario with no mitigation policies

Authors	Time horizon	Outcome		Estimated / simulated impact	
				Chile	World: min / mean / max
OCDE 2015	2060	GDP		-0.6%	-4.35% / -1.82% / 1.20%
OCDE 2015	2060	World GDP:		-1.82% (range between -4.4% to -0.6%)	
Krusell and Smith 2018	2050	GDP		+14%	-21.50% / -2.19% / 33%
Burke et al. 2015a	2030	GDP pc		+2.1%	-15.16% / -5.49% / 16.56%
Burke et al. 2015a	2050	GDP pc		+7.7%	-47.79% / -19.36% / 81.07%
Burke et al. 2015a	2099	GDP pc		+32.0%	-95.74% / -48.46% / 1413.39%
Roson & Sartori 2016	2100	GDP	RCP 8.5	-0.26%	-18.3% / -3.7% / 2.8%
Swiss Re 2021	2050	GDP	RCP 2.6	-0.9%	-2.6% / -0.5% / 0%
Swiss Re 2021	2050	GDP	RCP 4.5	–2.1%	-4.8% / -1.3% / 0%
Swiss Re 2021	2050	GDP	RCP 6.0	–2.3%	-11.6% / -1.7% / 0%
Swiss Re 2021	2050	GDP	RCP 8.5	–3.0%	-12.2% / -2.2% / 0%
Kalkuhl and Wenz 2020	2100	GDP	RCP 8.5	-5% to -10%	-20% / -5% to -10% / -0.2%
Kahn et al. 2019	2030	GDP pc:	RCP 2.6	-0.50%	-0.46% / 0.01% / 0.59%
Kahn et al. 2019	2050	GDP pc:	RCP 2.6	-1.68%	-1.48% / -0.16% / 0.94%
Kahn et al. 2019	2100	GDP pc:	RCP 2.6	-5.18%	-5.02% / -1.33% / 0.71%
Kahn et al. 2019	2030	GDP pc:	RCP 8.5	-1.23%	-1.37% / -0.85% / -0.34%
Kahn et al. 2019	2050	GDP pc:	RCP 8.5	-3.97%	-4.65% / -2.65% / -0.92%
Kahn et al. 2019	2100	GDP pc:	RCP 8.5	-11.08%	-14.33% / -7.51% / -2.56%
McKinsey 2020	2019	Labor productivity		-0.1% in GDP	-7.50% / -0.79% / -0.10%
McKinsey 2020	2030	Labor productivity		-0.1% in GDP	-15.1% / -1.15% / -0.10%
McKinsey 2020	2050	Labor productivity		-0.1% in GDP	-15.1% / -1.57% / -0.10%
OECD 2015[c)]	2015	Mortality damages		0.3 billions of USD	74.7 billions of USD
OECD 2015[c)]	2030	Mortality damages		1.5 billions of USD	232.2 billions of USD
OECD 2015[c)]	2050	Mortality damages		3.5 billions of USD	487.1 billions of USD
OECD 2015[c)]	2080	Mortality damages		7.5 billions of USD	1028.5 billions of USD
Carleton et al. 2020[a)]	2100	Mortality damages		-2% to -4% (GDP)	+3.2% (in GDP)
Cruz & Rossi-H. 2020	2200	Labor productivity		-5%	-40.7% / -8.6% / 73.4%
Cruz & Rossi-H. 2020[b)]	2200	GDPpc (baseline)		-1.9%	-4.6% / -2.1% / 2.6%

Source: Own calculations based on the authors estimates for the individual countries.

a) Negative mortality damage numbers mean lower damages (positive for welfare).

b) Baseline includes positive effects of Trade, Innovation, Migration and Carbon Taxes.

c) World in this estimate is OECD total only (OECD members in 2015).

and would be one of the countries more strongly affected by climate change (Table 15). In an optimistic scenario where climate change is entirely reversed (RCP 2.6), Kahn et al. (2019) expect Chile to suffer losses of 0.50%, 1.68% and 5.18% of GDP in 2030, 2050 and 2100, respectively (Table 14). In an worse scenario without any mitigation policies implemented by all countries (RCP 8.5), Chile would suffer losses of 1.23%, 3.97% and 11.08% in 2030, 2050 and 2100, respectively (Table 14). In both scenarios the estimates for Chile by Kahn et al. 2019 are quite negative relative to other countries (Table 15), with Chile being very close to the worst possible impact from climate change. The reason is that the model of Kahn et al. 2019 assumes that the higher temperatures in the future will be a stronger deviation from the historical weather norm for Chile and therefore Chile will suffer higher implicit costs of economic adaptation to the new weather. The Swiss Re 2021 study also predicts that Chile may suffer a GDP loss by 2050 between 0.9% and 3%, which is higher than their estimates for the world average and in this aspect contradicts substantially the results estimated by Roson and Sartori 2016 on which their model is based. It is worth noting that the Swiss RE 2021 study also considers the possibility that due to uncertainty the climate change costs could be 5 or 10 times larger for most countries in the world. The Swiss Re 2021 does confirm that other tropical countries may suffer substantially larger losses than Chile. Finally, Kalkuhl and Wenz 2020 estimate a GDP loss for Chile between 5% to 10% under the worst scenario (RCP 8.5), which is similar to most developed countries in the world, but far below the losses suffered by tropical countries.

Table 16 shows the impact estimates of climate change on the Chilean agriculture sector. The OECD 2015 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, Vergara et al. 2013 and Bárcena et al. 2019 showing negative estimates of climate change for the Chilean agriculture sector. Also, according to the OECD 2015, tourism expenditure in Chile would also benefit from climate change (Table 17). However, while Agriculture and Tourism could benefit, other Chilean sectors would suffer from climate change (Table 17), including Energy, Transports, other industries, other services, besides general damages from lower outdoors labor productivity, extreme precipitation, coastal zones exposure, flood damages and

Table 16: Review of estimates from multinational studies of the climate change impact for Chile for the Agriculture economic sector (relative to no climate change scenario)

Authors	Time horizon	Outcome	Estimated / simulated 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).			
IPCC 2014	2060	Maximum available fish catch	-6% to -20%
Roson and Sartori 2016	2100	Sea level rise	-0.0002% in GDP (RCP 8.5)
Roson and Sartori 2016	2100	Agriculture	+0.0103% in GDP (RCP 8.5)
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 ^{o}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 development)
Bárcena et al. 2019	2080	Agricultural GDP	-24% (without fertilization development)

Table 17.1: Review of estimates from multinational studies of the climate change impact for Chile for the non-agricultural economic sectors (relative to no climate change scenario)

Authors	Time horizon	Outcome	Estimated / simulated impact for Chile
Simulations of the impact on health, energy, outdoors labor, flood damages			
OECD 2015	2060	Tourism expenditure	+0.35% in GDP
OECD 2015	2060	Energy demand	-0.20% in GDP
OECD 2015	2060	Health costs	-0.90% in GDP
OECD 2015	2060	Extreme precipitation	-0.10% in GDP
OECD 2015	2060	Coastal zones	-0.05% in GDP
OECD 2015	2060	Labor productivity outdoors	-3% to -5% per 1°C increase in global temperature
OECD 2015	2030	Flood damages	0 to 0.3 billions of USD
OECD 2015	2080	Flood damages	2 billions of USD
OECD 2015	2060	Energy and extraction	-0.05% in GDP
OECD 2015	2060	Energy intensive industries	-0.15% in GDP
OECD 2015	2060	Other industries	-0.40% in GDP
OECD 2015	2060	Transport and construction	-0.65% in GDP
OECD 2015	2060	Other services	-1.05% in GDP
Roson & Sartori 2016	2100	Labor productivity	-0.0000% in GDP (RCP 8.5)
Roson & Sartori 2016	2100	Tourism flows	+0.0007% in GDP (RCP 8.5)

Table 17.2: Review of estimates from multinational studies of the climate change impact for Chile for the non-agricultural economic sectors (relative to no climate change scenario)

Authors	Time horizon	Outcome	Estimated / simulated impact for Chile
Simulations of the impact on health, energy, outdoors labor, flood damages			
Gerten et al. 2011	2080	Water availability	-10% in blue, green, and total water
Gerten et al. 2011	2080	Water scarcity	0 to 10% of population (minor effect)
Burek et al. 2016	2050	Water demand	+10% to +25%
World Bank 2013	2069-2099	Blue-water per capita	-0% to -10% (RCP 2.6) -10% to -20% (RCP 8.5)
McKinsey 2020	2050	Outdoor work hours affected by heat/humidity	Slight risk increase: 0.5% to 5%
McKinsey 2020	2050	Water stress (demand/supply ratio)	High risk increase: >7%
McKinsey 2020	2050	Time spent in drought	No or slight risk increase: 0 to 3%
McKinsey 2020	2050	Capital stock at risk of riverine floods	Risk decrease: <0%
Cruz & Rossi-H. 2020	2200	Amenities	+5%
Cruz & Rossi-H. 2020	2200	Innovation	-2%
U. Notre Dame´s ND-GAIN (2015) ranking of 181 countries' scores in climate change readiness for 2040-2070 (lower value means lower vulnerability)			
ND-GAIN 2018		Overall ND-Gain rank: 29	
ND-GAIN 2018		Vulnerability rank: 22	
ND-GAIN 2018		Readiness rank: 36	
ND-GAIN 2018		Economic rank: 37	
ND-GAIN 2018		Governance rank: 26	
ND-GAIN 2018		Social readiness rank: 52	

Table 18.1: Review of estimates from multinational studies of the climate change impact for Chile (relative to a scenario without climate change) in terms of non-economic outcomes

Authors	Time horizon	Outcome	Estimated / simulated impact for Chile
Simulations of the impact on mortality, health, biodiversity and other outcomes			
OECD 2015	2015	Mortality risk	0 persons
OECD 2015	2030-2050	Mortality risk	1000 persons per year
OECD 2015	2080	Mortality risk	3000 persons per year
OECD 2015	2060	Total Electricity demand for cooling	+8.4%
OECD 2015	2060	Ecosystem damages	0.3% of GDP (RCP 6.0)
OECD 2015	2060	Ecosystem damages	0.6% of GDP (RCP 8.5)
Roson & Sartori 2016	2100	Human health	-0.27% of GDP (RCP 8.5)
Carleton et al. 2020	2100	Mortality risk	-50 to -100 deaths (per 100,000 people)
McKinsey 2020	2050	Population with heat waves	No or slight risk increase: 0.5% to 5.0%
McKinsey 2020	2050	Land changing climate classification	High risk increase: >10%
Vergara et al. 2013	2050	Land changing climate classification	Very High risk

Table 18.2: Review of estimates from multinational studies of the climate change impact for Chile (relative to a scenario without climate change) in terms of non-economic outcomes

Authors	Time horizon	Outcome	Estimated / simulated impact for Chile
Simulations of the impact on mortality, health, biodiversity and other outcomes			
Gaska 2021	2080	Fraction of immigrants due to climate change	+5% (in % of the Chilean population)
Cruz & Rossi-H. 2020	2200	Population growth due to migration	+5%
Cruz & Rossi-H. 2020	2200	Welfare (no tax changes)	-5%
Cruz & Rossi-H. 2020	2200	Welfare (with carbon tax)	-6.5%
Cruz & Rossi-H. 2020	2200	International Trade	+0.4%
Patterson et al. 2020	2020	Climate and Nature Sovereign Index:	Middle level of risk
U. Notre Dame´s ND-GAIN (2015) ranking of 181 countries' scores in climate change readiness for 2040-2070 (lower value means lower vulnerability)			
ND-GAIN 2018		Ecosystem services: 54	
ND-GAIN 2018		Food: 4	
ND-GAIN 2018		Health: 54	
ND-GAIN 2018		Human habitat: 108	
ND-GAIN 2018		Infrastructure: 37	
ND-GAIN 2018		Water: 41	
ND-GAIN 2018		Adaptive capacity: 37	
ND-GAIN 2018		Exposure: 52	
ND-GAIN 2018		Sensitivity: 14	

health costs (here the OECD 2015 disagrees with the Carleton et al. 2020 positive assessment for Chile). Gerten et al. 2011, World Bank 2013, Burek et al. 2016 and McKinsey 2020 also estimate that Chile could suffer from higher water stress and lower water availability. This is consistent with a World Bank simulation, which shows that Chile suffers a high risk of drought, but a low damages due to flooding (World Bank 2021). The University of Notre Dame's ND-GAIN index for 181 countries in 2018 also estimates that Chile is one of the countries that is least vulnerable to climate change, but it is worse in terms of Social readiness (Table 17). Finally, the general equilibrium model of Cruz and Rossi-Hansberg 2020 finds that over the long-term (with an horizon for 2200) Chile would improve its amenities to deal with the transition implied by climate change, but its innovation rate would suffer moderately. It is also worth noting that the climate change damage functions estimated by Roson and Sartori (2016) imply a negligible effect of a RCP 8.5 scenario (with +3°C increase in temperature by 2100) on the sea level rise, agricultural productivity, heat effects on labor productivity, tourism flows, and households' energy demand in Chile and only a small effect of -0.27% of the GDP costs in terms of the human health.

Table 18 provides a summary of the results for Chile from a wide range of studies with projections of other non-economic costs of climate change at a multinational level. The studies of OECD 2015, Roson and Sartori 2016 and McKinsey 2020 expect that mortality risks from heat distress in Chile should increase slightly, although Carleton et al. 2020 predicts that mortality will fall in Chile as a consequence of climate change. Mortality from climate change, however, may increase substantially in India, North Africa and the Middle East (OECD 2015, Roson and Sartori 2016, McKinsey 2020, Carleton et al. 2020). One risk that Chile faces is ecosystem damages (between 0.3% and 0.6% of GDP, according to the OECD 2015) and changes to land surface changing climate classification according to the Koppen Climate Classification System (McKinsey 2020) and the Holdridge Life Zone Classification (Vergara et al. 2013), which both indicate that Chile suffers a strong risk of reduction in the biodiversity of fauna and flora, especially with the reduction of the polar areas in the south and the desertification of the north (Vergara et al. 2013). Patterson et al. 2020 estimate that Chile is in the group of countries with a middle level of risk arising from climate change, biodiversity loss, and other changes in natural capital, according to their Climate and Nature Sovereign Index. Dasgupta (2021) shows that Chile may suffer from a reduction of 4% to 10% in Mean Species Abundance (MSA) until 2100 under a stressed SSP 8.5

scenario, which adds to a decline in local species richness around 5% to 10% between since the colonial times until now. Chile also presents natural assets similar to most of the world's regions and an ecological deficit of 0% to 50%, showing an ecological footprint larger than its biocapacity (Dasgupta 2021).

The University of Notre Dame's study index for 181 countries estimates that Chile will suffer from climate change in terms of Human habitat, Health and Ecosystem, but it does well in terms of Food security and in terms of Sensitivity (the fraction of people susceptible to a climate change hazard). Finally, it is expected that Chile will face higher electricity costs for cooling in hot weather (according to the OECD 2015) and lower long-term welfare without any mitigation policies implemented at the global level (Cruz and Rossi-Hansberg 2020).

5 Conclusions and policy implications

Based on annual region-industry panel data for the period 1985 to 2017, our study finds that climate change had little effect on the different sectors of economic activity in Chile over the last 35 years, although there was a strong increase in national temperature of 0.37 Celsius degrees and a large decrease in precipitation in Chile during this period. Furthermore, these weather changes in precipitation and temperature affected all the Chilean regions, except for the North.

We found a statistically significant negative effect of climate change in Chile, with the channel coming from higher temperatures rather than fluctuations in precipitation. We find that high temperatures in the summer season (January to March) had a negative impact on the Agriculture-Silviculture and Fishing sectors. Furthermore, by separating the weather at a monthly level, we find that it is high temperature in January in particular, which causes the strongest negative impact. Higher temperatures in January may also cause some deterioration of activity for the Construction and EGA (Electricity, Gas, and Water) sectors. However, since Agriculture-Silviculture and Fishing represent just 4% of GDP and summing the sectors of Construction (6.8% of GDP) and Electricity, Gas, and Water (4.0% of GDP), the analysis for the past 35 years would show that 85% of the economic activity in Chile was not affected by climate change and that such effect was limited to either the summer season (January to March) or even just a single month (January).

Our results for the Agriculture-Silviculture and Fishing sectors are statistically significant, but represent little in terms of the overall GDP. We then use our model to present several projections of the impact of climate change on the GDP of each industry and the total national GDP by 2050 and 2100. These projections consider the average of the global climate paths published by the United Nations (IPCC 2014), which are widely used in climate stress tests (NGFS 2021). The results change whether we consider all the model's coefficients, only the statistically significant coefficients, or just the negative statistically significant coefficients (that is, ignoring potential positive effects of climate change). Considering all the model's coefficients we obtain a large and positive impact of climate change on the Chilean GDP level, with a range between +9.8% and +26.% in 2050 and between +36% and 738% by 2100. Note, however, that this positive impact of climate change depends on statistically insignificant coefficients and also on fixed coefficients that do not consider that its effects may change over time. Using only the model's statistically significant coefficients, we obtain an impact on the Chilean GDP level between -2.3% and +0.4% in 2050 and between +3.2% and +193.2% in 2100. In our worst forecasts, which apply only negative coefficients that are also statistically significant (that is, ignoring any potential positive effects), we then obtain an impact on the Chilean GDP level between -14.8% and -9% in 2050 and between -29.6% and -16.8% in 2100. That is, we only obtain a negative impact of climate change on the total Chilean GDP if we deliberately ignore any positive coefficients. A robustness exercise using the industry coefficients of a similar model estimated for the USA (Colacito, Hoffmann and Phan 2019) would imply that Chile's GDP would suffer a fall of at most 0.8% by 2050 and would increase substantially by 2100 due to the effects of climate change. However, a second robustness exercise that applies only the statistically significant coefficients estimated for the USA (Colacito, Hoffmann and Phan 2019) would imply that the Chilean GDP would fall between -6.8% and -12.9% in 2050 and between -15.5% and -42.3% in 2100 due to climate change.

Our estimates also imply a positive impact on the Chilean growth rate during the period 1985-2017 of +0.1% with all the model's coefficients, a negative effect of -0.1% with just the statistically significant coefficients, and a negative effect of -0.2% with just the negative statistically significant coefficients. Therefore it does not appear that climate change had an impact for Chilean economic activity in the past. Although there are other caveats, one that is directly related to the estimation is that the annual frequency of the region-industry data makes it harder to measure the impact of climate change associated with just one month. Another issue that causes uncertainty in our results is that our model has fixed coefficients instead of time-varying parameters that consider the dynamic impacts of climate change over time. Neither issue can be solved in a model based only on an annual frequency panel dataset.

These findings are consistent with previous studies such as HSBC (2018), which also show that Chile was one of the countries suffering the least from climate change physical costs in the past decade, although it suffered more in some aspects such as extreme weather events and draught. However, other studies such as German Watch (2019) show that although Chile suffered only moderately from climate change relative to other countries during the period 1999-2018, its costs have been increasing over time and in 2018 Chile is already on the top one-third of the countries suffering higher GDP costs from climate change. University of Notre Dame's international study (ND-GAIN 2018) also shows that overall Chile is robust to the costs of climate change and has a low fraction of the population susceptive to the hazards of climate change, but it does worse in other non-economic aspects such as human habitat and the social readiness due to its substantial economic inequality.

Since Chile is a country far from the Equator and with a mild and temperatures, estimates of the economic costs of climate change in the past (Watts et al. 2018) and projections for the future are relatively low (OECD 2015, McKinsey 2020, Cruz and Rossi-Hansberg 2020) or even positive (Burke et al. 2015a, Krusell and Smith 2018, Carleton et al. 2020), especially if compared to other countries in the Latin America and Caribbean region. However, there is substantial uncertainty about the economic effects of climate change (Stern 2007, Nordhaus and Moffat 2017) and the adequate model for projecting climate costs over such a long period. Some studies suggest high costs to Chile from climate change. Kahn et al. (2019) show that Chile could suffer a significant deterioration in economic growth due to adaptation costs for a new climate that is different from its historical norm. In an optimistic scenario where climate change is entirely reversed (RCP 2.6), Kahn et al. (2019) expect Chile to suffer losses of 0.50%, 1.68% and 5.18% of GDP in 2030, 2050 and 2100, respectively. In an worse scenario without any mitigation policies implemented by all countries (RCP 8.5), Chile would suffer losses of 1.23%, 3.97% and 11.08% in 2030, 2050 and 2100, respectively. The Swiss Re 2021 study also predicts that Chile may suffer a GDP loss by 2050 between 0.9% and 3%. Finally, Kalkuhl and Wenz 2020 estimate a GDP loss for Chile between 5%

to 10% under the worst scenario (RCP 8.5).

There is still plenty of room in Chile for expanding the climate adjustment policies, since, according to the Climate Action Tracker[9] 2020 country ratings, Chile is still in the middle of the table for the climate change efforts. For instance, in 2017 the gasoline prices per gallon were around 4.1 USD in Chile (which is somewhat higher than the 3.8 USD price observed in the USA or the 3.5 USD in Mexico), but for the European Union countries the prices ranged between 6.3 and 9.8 USD (Harris et al. 2017). Therefore there is a large room for Chile to increase gas taxes. In 2017 Chile imposed a price of 5 USD per ton of carbon dioxide and with a coverage of 42% at the national level (Bárcena et al. 2019, World Bank 2018). Higher coverage rates are more likely to have impact on reducing the effects of climate change. While the Chilean policy and its carbon price is not specially low at the international level (Bárcena et al. 2019, World Bank 2018), several studies show substantial uncertainty around the social cost and the optimal price for carbon dioxide (Pindyck 2013), with median estimates around 50 USD (Harris et al. 2017, Cai and Lontzek 2019) plus several estimates around 100 USD per ton or even above 200 USD per ton (Pindyck 2013, Golosov et al. 2014, Cai and Lontzek 2019). Estimates of the optimal carbon tax for Chile were around 18 USD per ton for the year 2019 (Espinosa and Fornero 2014). It is also possible that the Chilean economy may have added incentives to adopt more green policies in the future if developed economies such as the European Union create taxes or tariffs to account for the environmental costs of imported goods (Economist 2021). Recent measurements have shown that electricity generation and manufacturing are the sectors with the highest carbon emissions in Chile, but if you take into account the demand in economic activity generated through an input-output framework then the manufacturing and mining sectors (in particular, their exports) are the highest indirect sources of carbon emissions (Avilés-Lucero et al. 2021). However, an adequate calibration of carbon taxes must address the issue that such taxation lowers the consumption of poorer households (Känzig 2021) and exacerbates deflation by depressing economic activity (Konradt and Weder di Mauro 2021).

Furthermore, several stimulus "green" policies such as clean R&D, education, building efficiency retrofits, natural capital enhancement (afforestation, expanding parkland, enhancing rural ecosystems, biodiverse habitats, clean air and water, productive soils), and green infrastructure have large

[9] https://climateactiontracker.org/countries/chile/

multiplier effects in terms of economic growth, investment and employment (Hepburn et al. 2020, OECD 2017), therefore such green policies are likely to be pursued even in a post-pandemic age of deteriorated government finances (Hepburn et al. 2020). Climate policies also have added benefits in terms of lower waste, biodiversity, energy security, air quality and improved health (Karlsson et al. 2020).

Chile also has a high mortality cost due to drought risk (Dilley et al. 2005, World Bank 2013). This cost has become more salient over time due to a mega-drought affecting Chile's central region since 2010 (NASA Earth Observatory 2020), with annual rainfall deficits ranging between 25% to 45% (Garreaud et al. 2017), although with limited economic impacts on the local population so far are limited due to mitigation measures by the government and utility companies (Center for Climate and Resilience Research 2015). Chile's central area (Metropolitan and Valparaíso Regions) is in the top 30 to 18 percent of the globe land area associated with higher exposure to drought mortality risk during the period 1981-2000 (Dilley et al. 2005). This is consistent with a World Bank simulation, which shows that Chile suffers a high risk of drought, but a low damages due to flooding (World Bank 2021). However, McKinsey (2020) estimates only a slight increase in the drought risk for Chile for 2050. Chile also experienced an increase in the downtime hours of ports since 2008, with forecasts predicting a slight deterioration by 2050 (Winckler et al. 2021).

Other negative consequences of climate change in Chile are air pollution (Chile has the highest air pollution rates among OECD countries and this may cause around 4,000 premature deaths per year, Baum and Hurn 2021), predictions of ecosystem damages (between 0.3% and 0.6% of GDP, OECD 2015), risks to natural capital and biodiversity (Patterson et al. 2020, Dasgupta 2021), changes in land classification (Vergara et al. 2013, McKinsey 2020), a reduction of 4% to 10% in species until 2100, a reduction in the available fish catch between 6% and 20% until 2060 (IPCC 2014) and an increase in water stress between 7% and 25% for 2050 and 2100 (Gerten et al. 2011, World Bank 2013, Burek et al. 2016, McKinsey 2020). Mortality risks in Chile are also expected to increase slightly (OECD 2015, Roson and Sartori 2016, McKinsey 2020) or perhaps even to improve (Carleton et al. 2020).

It may also be important to account for the effects of climate change on non-economic outcomes such as civil conflict (Burke et al. 2015b, OECD 2015) or human migration (OECD 2015). Chile is already experiencing a rapid increase in immigration for economic motives from other Latin

American countries in recent years (Aldunate et al. 2019). Since Chile's neighboring countries are more likely to be negatively impacted by climate change in the future (Burke et al. 2015a, OECD 2015, Cruz and Rossi-Hansberg 2020, White House 2021), this could imply that the country should prepare for the economic trade-offs and adequate policies associated with increased migration flows (Cruz and Rossi-Hansberg 2020, Gaska 2021, White House 2021).

References

[1] Albagli, E. (2021), "Límites planetarios y capital natural," Central Bank of Chile.

[2] Aldunate, R., G. Contreras, C. De la Huerta and M. Tapia (2019), "Characterization of the Recent Immigration to Chile," Central Bank of Chile WP 830.

[3] Arias, A. and J. Guerra-Salas (2019), "Immigration in Emerging Countries: A Macroeconomic Perspective," Central Bank of Chile WP 857.

[4] Avilés-Lucero, F., G. Peraita and C. Valladares (2021), "Huella de Carbono para la Economía Chilena 2017", Economic Statistics Working Papers 135, Central Bank of Chile.

[5] Bárcena, A., J. Samaniego, W. Peres and J. Alatorre (2019), "La emergencia del cambio climático en América Latina y el Caribe," CEPAL.

[6] Batten, S. (2018), "Climate Change and the Macro-economy: A Critical Review," Bank of England Staff WP 706.

[7] Baum, C. and S. Hurn (2021), "Environmental econometrics using Stata," Stata Press.

[8] BIS (2021), "Climate-related risk drivers and their transmission channels," Bank for International Settlements.

[9] Burek, P. et al. (2016), "Water Futures and Solution – Fast Track Initiative (Final Report)," IIASA Working Paper, WP 16-006.

[10] Burke, M., S. Hsiang and E. Miguel (2015a), "Global non-linear effect of temperature on economic production," *Nature*, 527, 235–239.

[11] Burke, M., S. Hsiang and E. Miguel (2015b), "Climate and Conflict," *Annual Review of Economics*, 7(1), 577-617.

[12] Cai, Y. and T. Lontzek (2019), "The Social Cost of Carbon with Economic and Climate Risks," *Journal of Political Economy*, 127(6), 2684-2734.

[13] Carleton, T. et al. (2020), "Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits," CEPR Discussion Paper No. DP15139.

[14] Cavallo, E. and B. Hoffmann (2020), "Climate Change is a Threat to Economic Growth and to Reducing Income Inequality in Latin America and the Caribbean," IADB Blog.

[15] Center for Climate and Resilience Research (2015, "The 2010-2015 mega-drought: A lesson for the future", Report to the Nation, Chile.

[16] Colacito, R., B. Hoffmann and T. Phan (2019), "Temperature and Growth: A Panel Analysis of the United States," *Journal of Money, Credit and Banking*, 51(2-3), 313-368.

[17] Collins, M. et al. (2013), “Long-Term Climate Change: Projections, Commitments and Irreversibility,” Chap. 12 in Climate Change 2013: The Physical Science Basis, edited by Thomas F. Stocker et al. Cambridge University Press.

[18] Cruz, J.-L. and E. Rossi-Hansberg (2020), "The Geography of Global Warming," mimeo, Princeton University.

[19] Dasgupta, P. (2021), "The Economics of Biodiversity: The Dasgupta Review," HM Treasury.

[20] Dasgupta, S., N. van Maanen, S. Gosling, F. Piontek, C. Otto and C. Schleussner (2021), "Effects of climate change on combined labour productivity and supply: an empirical, multi-model study," *The Lancet Planetary Health*, 5(7), e455-e465.

[21] Dell, M., B. Jones and B. Olken (2012), "Temperature Shocks and Economic Growth: Evidence from the Last Half Century," *American Economic Journal: Macroeconomics*, 4 (3): 66-95.

[22] Deschenes, O. and E. Moretti (2009), “Extreme Weather Events, Mortality, and Migration,” *Review of Economics and Statistics*, 91(4), 659–681.

[23] Di Bella, G., L. Norton, J. Ntamatungiro, S. Ogawa, I. Samaké and M. Santoro (2015), "Energy Subsidies in Latin America and the Caribbean: Stocktaking and Policy Challenges," IMF WP 15/30.

[24] Diffenbaugh, N. and F. Giorgi (2012), "Climate change hotspots in the CMIP5 global climate model ensemble," *Climatic Change*, 114, 813–822.

[25] Dilley, M., R. Chen, U. Deichmann, A. Lerner-Lam and M. Arnold (2005), "Natural Disaster Hotspots: A Global Risk Analysis," World Bank.

[26] Eboli, F., R. Parrado and R. Roson (2010), "Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model," Environment and Development Economics, 15(5), 515-533.

[27] Economist (2021), "The EU proposes a carbon tariff on some imports," *The Economist*, July 17th 2021.

[28] Espinosa, C. and J. Fornero (2014), "Welfare Analysis of an Optimal Carbon Tax in Chile," *Economic Analysis Review*, 29(2), 75-111.

[29] Fernandes, E., A. Soliman, R. Confalonieri , M. Donatelli and F. Tubiello (2012), "Climate Change and Agriculture in Latin America, 2020-2050: Projected Impacts and Response to Adaptation Strategies," World Bank.

[30] Garreaud, R., et al. (2017), "The 2010–2015 megadrought in central Chile: impacts on regional hydroclimate and vegetation", Hydrol. Earth Syst. Sci., 21(12), 6307–6327.

[31] Gaska, J. (2021), "The impact of climate change on the Polish economy," Ph.D. thesis, Warsaw School of Economics.

[32] German Watch (2019), "Global Climate Risk Index 2020: Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2018 and 1999 to 2018," .

[33] Gerten, D., J. Heinke, H. Hoff, H. Biemans, M. Fader and K. Waha (2011),"Global Water Availability and Requirements for Future Food Production," *Journal of Hydrometeorology*, 12(5), 885–899.

[34] Golosov, M., J. Hassler, P. Krusell and A. Tsyvinski (2014), "Optimal Taxes on Fossil Fuel in General Equilibrium," *Econometrica*, 82(1), 41-88.

[35] González, R. and J. Velasco (2008), “Evaluation of the impact of climatic change on the economic value of land in agricultural systems in Chile”, *Chilean Journal of Agricultural Research*, 68(1), 56-68.

[36] Harnish, M. (2019), "Central Banks and Climate Risks," *Econ Focus*, 2019, 2Q-3Q, 8-13.

[37] Harris, J., B. Roach and A.-M. Codur (2017), "The Economics of Global Climate Change," Global Development and Environment Institute, Tufts University.

[38] Hepburn, C., B. O'Callaghan, N. Stern, J. Stiglitz and D. Zenghelis (2020), "Will covid-19 fiscal recovery packages accelerate or retard progress on climate change?," *Oxford Review of Economic Policy*, 36(S1), forthcoming.

[39] Hoffmann, B., T. i Jubert and E. Parrado (2020), "The Business Case for ESG Investing for Pension and Sovereign Wealth Funds," IDB-PB-338, IDB.

[40] HSBC (2018), "Fragile Planet: Scoring climate risks around the world," HSBC Global Research.

[41] Hsiang, S. and R. Kopp (2018), "An Economist's Guide to Climate Change Science," *Journal of Economic Perspectives*, 32(4), 3–32.

[42] IMF (2021), "No time to waste," *Finance and Development*, September 2021, vol. 58(3), International Monetary Fund.

[43] IPCC (2014), "AR5 Scenario Database," https://tntcat.iiasa.ac.at/AR5DB/.

[44] IPCC (2021), "IPCC Working Group I (WGI): Sixth Assessment Report," https://interactive-atlas.ipcc.ch/.

[45] IRENA (2015), "Renewable Energy in Latin America 2015: An Overview of Policies," International Renewable Energy Agency (IRENA), Policy Brief.

[46] Kahn, M., K. Mohaddes, R. Ng, M. Hashem Pesaran, M. Raissi and J. Yang (2019), "Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis," IMF WP 19/215.

[47] Kalkuhl, M. and L. Wenz (2020), "The impact of climate conditions on economic production. Evidence from a global panel of regions," Journal of Environmental Economics and Management, 103, 102360.

[48] Känzig, D. (2021), "The Unequal Economic Consequences of Carbon Pricing," mimeo.

[49] Karlsson, M., E. Alfredsson and N. Westling (2020), “Climate policy co-benefits: a review,” *Climate Policy*, 20(3), 292–316.

[50] Konradt, M. and B. Weder di Mauro (2021), “Carbon Taxation and Inflation: Evidence from Canada and Europe”, CEPR Discussion Paper 16396.

[51] Krusell, P. and A. Smith (2018), Climate Change Around the World," mimeo, Yale University.

[52] McKinsey (2020), "Climate risk and response: Physical hazards and socioeconomic impacts," McKinsey Global Institute, January 2020.

[53] NASA Earth Observatory (2020), "A Strained Water System in Chile," https://earthobservatory.nasa.gov/images/146577/a-strained-water-system-in-chile

[54] Nordhaus, W. and A. Moffat (2017), "A Survey of Global Impacts of Climate Change: Replication, Survey Methods, and a Statistical Analysis," NBER WP 23646.

[55] ND-GAIN (2018), "University of Notre Dame Global Adaptation Index (ND-GAIN): Country index technical report," University of Notre Dame.

[56] NGFS (2021), "NGFS Climate Scenarios for central banks and supervisors," Network for Greening the Financial System.

[57] OECD (2015), "The Economic Consequences of Climate Change," OECD, Paris.

[58] OECD (2017), "Investing in Climate, Investing in Growth," OECD, Paris.

[59] Patterson, D., S. Schmitt, S. Singh, P. Eerdmans, M. Hugman and A. Roux (2020), "Climate and Nature Sovereign Index."

[60] Pindyck, R. (2013), "Climate Change Policy: What Do the Models Tell Us?," *Journal of Economic Literature*, 51(3), 860-872.

[61] Roson, R. and M. Sartori (2016), "Estimation of Climate Change Damage Functions for 140 Regions in the GTAP 9 Database," *Journal of Global Economic Analysis*, 1(2), 78-115.

[62] Stern, N. (2007), "The Economics of Climate Change: The Stern Review," Cambridge University Press.

[63] Swiss Re (2021), "The economics of climate change: no action not an option," Swiss Re Institute.

[64] Vergara, W., A. Rios, L. Galindo, P. Gutman, P. Isbell, P. Suding and J. Samaniego (2013), "The Climate and Development Challenge for Latin America and the Caribbean: Options for Climate-Resilient, Low-Carbon Development," IDB.

[65] Watts et al. (2018), "The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come," *Lancet*, 392: 2479-2514.

[66] Watts et al. (2019), "The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate," *Lancet*, 394: 1836–1878.

[67] Winckler, P. et al. (2021), "Climate-driven Impacts in Ports on a Tectonically Active Coast Under Mid- and End-of-century RCP 8.5 Scenario," mimeo.

[68] White House (2021), "Report on the impact of climate change on migration," White House, DC, USA.

[69] World Bank (2013), "Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience," World Bank.

[70] World Bank (2018), "State and Trends of Carbon Pricing," World Bank.

[71] World Bank (2021), "Países de la Alianza del Pacífico analizan el impacto de los riesgos hidrometereológicos," World Bank, blog by J. Villalobos and Andrés Pérez.

6 Appendix

6.1 Other model estimates

Table A1: Coefficients for the impact of temperature and precipitation (quarterly averages) on regional industry GDP

	Agri-	Fish-	Min-	Manu-	EGA	Cons-	Com-	Trans-	Finan.	Home	Pers.	Public
	culture	ing	ing	facture		truction	merce	ports	serv.	prop.	serv.	adm.
Coefficients for Temperature												
Jan-Mar	-0.031**	-0.087	0.045**	0.006	-0.037	-0.012	0.007	0.007	0.007	0.001	-0.002	0.002
	(0.013)	(0.061)	(0.019)	(0.010)	(0.027)	(0.012)	(0.011)	(0.005)	(0.005)	(0.002)	(0.002)	(0.002)
Apr-Jun	0.025*	0.076*	-0.069**	0.025***	0.038	0.002	-0.007	-0.002	-0.013*	0.001	-0.004*	0.003
	(0.014)	(0.044)	(0.033)	(0.007)	(0.029)	(0.016)	(0.009)	(0.006)	(0.007)	(0.002)	(0.002)	(0.003)
Jul-Sep	-0.020	-0.002	-0.003	-0.013	0.012	-0.005	0.008	0.002	0.010*	-0.004	-0.001	-0.004
	(0.014)	(0.045)	(0.020)	(0.013)	(0.028)	(0.017)	(0.007)	(0.005)	(0.005)	(0.005)	(0.004)	(0.003)
Oct-Dec	0.023	-0.022	0.045**	0.019*	0.019	-0.014	-0.001	0.002	0.004	-0.003	0.006	-0.004
	(0.018)	(0.037)	(0.019)	(0.010)	(0.028)	(0.020)	(0.005)	(0.008)	(0.009)	(0.003)	(0.004)	(0.003)
Coefficients for Precipitation												
Jan-Mar	0.002	0.007	-0.013	0.010***	0.016	-0.007	-0.002	-0.001	-0.002	-0.001	0.002**	-0.001**
	(0.005)	(0.015)	(0.019)	(0.003)	(0.011)	(0.012)	(0.003)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Apr-Jun	0.003	-0.017*	-0.002	-0.000	0.013*	-0.004	-0.001	-0.000	-0.000	0.000	0.000	-0.000
	(0.002)	(0.010)	(0.004)	(0.001)	(0.007)	(0.004)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
Jul-Sep	-0.002	0.015	0.004	0.004	0.014**	0.005	0.002	0.002	0.002***	0.001	0.001	-0.001
	(0.003)	(0.010)	(0.004)	(0.004)	(0.006)	(0.007)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)
Oct-Dec	0.000	-0.013	0.030***	-0.005**	0.007	0.011	0.000	-0.003	-0.000	0.000	0.002*	-0.001
	(0.004)	(0.012)	(0.008)	(0.003)	(0.005)	(0.012)	(0.003)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
N	465	436	395	465	460	465	465	465	465	465	465	465
R^2	0.104	0.137	0.062	0.059	0.058	0.026	0.023	0.087	0.069	0.131	0.055	0.067

Observations weighted by constant regional industry GDP share. Lagged industry GDP growth included in each regression.

Lagged industry GDP growth included in each regression.

Robust standard errors clustered by year and region in parentheses. ** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A2: Coefficients for the impact of temperature and precipitation (quarterly averages) on the regional industry GDP for 13 regions

	Agri-	Fish-	Min-	Manu-	EGA	Cons-	Com-	Trans-	Finan.	Home	Pers.	Public
	culture	ing	ing	facture		truction	merce	ports	serv.	prop.	serv.	adm.
Coefficients for Temperature												
Jan-Mar	-0.021*	-0.047	0.060**	0.009	-0.033*	-0.017	-0.007	0.006	0.004	-0.003	0.001	0.000
	(0.011)	(0.035)	(0.028)	(0.016)	(0.019)	(0.019)	(0.005)	(0.006)	(0.003)	(0.003)	(0.003)	(0.002)
Apr-Jun	0.014	0.011	-0.077**	0.015	0.027**	0.016	0.002	-0.007	-0.004	0.001	-0.004	0.003
	(0.012)	(0.033)	(0.039)	(0.010)	(0.013)	(0.014)	(0.005)	(0.006)	(0.005)	(0.002)	(0.003)	(0.002)
Jul-Sep	-0.015	0.027	0.088*	-0.017*	0.014	0.015	0.003	-0.001	0.007**	-0.004	0.003	-0.003
	(0.013)	(0.041)	(0.050)	(0.010)	(0.019)	(0.020)	(0.004)	(0.007)	(0.004)	(0.004)	(0.003)	(0.002)
Oct-Dec	0.023	0.007	-0.069	0.024*	0.003	-0.027	0.005	0.005	-0.002	-0.002	0.003*	-0.003
	(0.018)	(0.043)	(0.043)	(0.015)	(0.025)	(0.021)	(0.006)	(0.006)	(0.007)	(0.002)	(0.002)	(0.003)
Coefficients for Precipitation												
Jan-Mar	0.003	0.005	-0.004	0.011*	0.006	-0.007	-0.003	-0.003**	-0.002	-0.000	0.001	-0.000
	(0.005)	(0.011)	(0.014)	(0.006)	(0.008)	(0.013)	(0.003)	(0.002)	(0.002)	(0.000)	(0.001)	(0.001)
Apr-Jun	0.002	-0.017***	-0.005	-0.002	0.011*	-0.004	0.000	0.000	-0.000	0.000	0.000	0.000
	(0.003)	(0.006)	(0.008)	(0.002)	(0.005)	(0.004)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Jul-Sep	0.001	0.035***	0.003	0.004	0.008*	0.009*	-0.000	-0.000	0.002*	0.001	0.001	-0.001
	(0.003)	(0.008)	(0.010)	(0.005)	(0.005)	(0.005)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Oct-Dec	0.001	0.018	-0.020*	-0.004**	0.006	0.018**	0.001	-0.005*	-0.001	-0.000	0.000	-0.001
	(0.004)	(0.012)	(0.011)	(0.002)	(0.004)	(0.009)	(0.002)	(0.003)	(0.001)	(0.000)	(0.001)	(0.001)

Observations not weighted for GDP in regressions. Lagged industry GDP growth included in each regression.

Regions 1 and 14, and regions 10 and 15 were merged for a total of 13 regions instead of 15 regions

Robust standard errors clustered by year and region in parentheses. ** p<0.01, ** p<0.05, * p<0.1

Table A3: Coefficients for the impact of temperature (monthly averages) on the regional industry GDP for 13 regions

	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Cons-truction	Com-merce	Trans-ports	Finan. serv.	Home prop.	Pers. serv.	Public adm.
Jan	-0.035***	-0.074***	0.038*	-0.003	-0.044***	-0.012	-0.005	0.011*	0.000	-0.001	0.001	-0.003**
	(0.011)	(0.012)	(0.022)	(0.015)	(0.015)	(0.012)	(0.003)	(0.005)	(0.003)	(0.001)	(0.001)	(0.001)
Feb	0.007	0.028*	0.011***	-0.001	0.001	-0.024	0.003	0.002	-0.004	0.000	0.001	0.001
	(0.007)	(0.016)	(0.003)	(0.010)	(0.002)	(0.024)	(0.003)	(0.005)	(0.004)	(0.000)	(0.001)	(0.002)
Mar	0.008	0.007	0.001	0.025*	-0.005	0.014*	-0.001	-0.007	0.010***	-0.005	-0.000	0.003
	(0.011)	(0.043)	(0.035)	(0.013)	(0.014)	(0.008)	(0.005)	(0.006)	(0.004)	(0.004)	(0.002)	(0.002)
Apr	0.011	-0.016	-0.027	-0.005	0.038**	0.022	-0.003	0.000	0.001	-0.000	-0.006***	0.001
	(0.009)	(0.053)	(0.031)	(0.005)	(0.018)	(0.018)	(0.004)	(0.001)	(0.004)	(0.000)	(0.001)	(0.002)
May	-0.004	-0.052*	-0.017	-0.010	-0.011	-0.005	-0.005	-0.006	-0.006*	0.003	0.000	0.000
	(0.005)	(0.028)	(0.017)	(0.011)	(0.016)	(0.020)	(0.004)	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)
Jun	0.004	0.041	-0.039***	0.017	-0.001	0.003	0.006**	-0.000	-0.000	-0.001	-0.000	0.000
	(0.005)	(0.038)	(0.008)	(0.014)	(0.011)	(0.010)	(0.003)	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)
Jul	-0.001	-0.009	0.058**	0.012	-0.015	-0.001	-0.000	0.004	0.001	0.001	0.003	-0.001
	(0.006)	(0.022)	(0.023)	(0.007)	(0.019)	(0.019)	(0.005)	(0.005)	(0.003)	(0.002)	(0.002)	(0.002)
Aug	0.011	-0.006	-0.005	-0.012	0.030	0.056***	0.007***	-0.004	-0.001	-0.003	-0.002	-0.000
	(0.008)	(0.023)	(.)	(0.019)	(0.028)	(0.019)	(0.003)	(0.006)	(0.003)	(0.003)	(0.002)	(0.001)
Sep	-0.031***	0.030	0.034	-0.019**	0.015	-0.036*	-0.004	0.004	0.008*	-0.003	0.001	-0.004***
	(0.005)	(0.037)	(0.024)	(0.009)	(0.018)	(0.019)	(0.006)	(.)	(0.004)	(0.002)	(0.003)	(0.001)
Oct	0.013**	0.048	0.007	0.007	0.011	-0.040***	0.006	-0.001	-0.003	-0.001	0.001	0.000
	(0.005)	(0.043)	(0.022)	(0.013)	(0.025)	(0.010)	(0.005)	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)
Nov	0.013	-0.005	-0.041*	0.015	-0.019	-0.006	-0.005	0.002	0.003	-0.001	0.004	-0.002
	(0.014)	(0.043)	(0.025)	(0.017)	(0.012)	(0.031)	(0.005)	(0.003)	(0.005)	(0.001)	(.)	(0.002)
Dec	0.006***	-0.003	-0.033	0.012	0.026	0.025	0.005	0.002	-0.002	-0.001	-0.002*	-0.000
	(0.002)	(0.033)	(0.031)	(0.016)	(.)	(0.022)	(0.003)	(0.006)	(0.002)	(0.001)	(0.001)	(0.001)
N	403	374	372	403	398	403	403	403	403	403	403	403
R^2	0.195	0.092	0.093	0.090	0.111	0.108	0.069	0.087	0.113	0.188	0.075	0.075

Observations not weighted for GDP in regressions. Lagged industry growth rate and monthly precipitation included.

Regions 1 and 14, and regions 10 and 15 were merged for a total of 13 regions instead of 15 regions.

Robust standard errors clustered by year and region in parentheses. ** $p<0.01$, ** $p<0.05$, * $p<0.1$

As a robustness check, Table A1, Table A2 and Table A3 estimate the same model of industry-region GDP with temperature and precipitation fluctuations using constant weights for each industry and different clustering options (clusters just by year or clusters by region-year). Table A1 shows the model with quarterly weather fluctuations and 15 regions. Table A2 and Table A3 also aggregate regions I and XV plus regions X and XIV, therefore presenting 13 regions for the entire period of 1985 to 2017. Table A2 presents the coefficients for the model with quarterly weather fluctuations and 13 regions. Table A3 presents the coefficients for the model with monthly weather fluctuations and 13 regions.

6.2 Calibrated projections of climate change for Chile using the new IPCC (2021) SSP scenarios

This appendix considers the same counterfactual exercises described in Tables 7, 8 and 9, but using the most recent "Shared Socioeconomic Pathways" (SSPs) scenarios published by the IPCC's Sixth Assessment Report (IPCC 2021). Tables 6, 7 and 8 considered the average temperature increase in the "Representative Concentration Pathways" (RCPs) available from IPCC Fifth Assessment Report (IPCC 2014), describing different levels of greenhouse gases and other radiative forcings that might occur in the future. The RCPs described four pathways, spanning a broad range of forcing in 2100 (2.6, 4.5, 6.0, and 8.5 watts per meter squared), but purposefully did not include any socioeconomic "narratives" to go alongside them. The IPCC's Sixth Assessment Report (IPCC 2021) published five "Shared Socioeconomic Pathways" (SSPs) scenarios, which expand on the RCPs by also modelling how socioeconomic factors may change over the next century. These include things such as population, economic growth, education, urbanization, the rate of technological development and how different levels of climate change mitigation could be achieved when the mitigation targets of RCPs are combined with the SSPs.

Five SSP narratives describe alternative pathways for future society (IPCC 2021). Each SSP looks at how the different RCPs could be achieved within the context of the underlying socioeconomic characteristics and shared policy assumptions of that world. The SSPs five alternative socio-economic futures compromise: sustainable development (SSP1), middle-of-the-road development (SSP2), regional rivalry (SSP3), inequality (SSP4), and fossil-fuelled development (SSP5). SSP5-8.5 represents the high end of the range of future pathways, corresponding to RCP8.5. SSP3-7.0 lies between RCP6.0 and RCP8.5, and represents the medium to high end of the range of future forcing pathways. SSP4-6.0 corresponds to RCP6.0, fills in the range of medium forcing pathways. SSP2-4.5 represents the medium part of the range of future forcing pathways and updates RCP4.5. The SSPs are based on five narratives describing broad socioeconomic trends that could shape future society. These are intended to span the range of plausible futures. They include: a world of sustainability focused growth and equality (SSP1); a "middle of the road" world where trends broadly follow their historical patterns (SSP2); a fragmented world of "resurgent nationalism" (SSP3); a world of ever-increasing inequality (SSP4); and a world of rapid and unconstrained growth in economic output and energy use (SSP5).

Table B1, Table B2 and Table B3 have the same counterfactual exercise of Table 8, Table 9 and Table 10, respectively, but using the median temperature increase of the SSP1-2.6, SSP2-4.5, SSP3-6.0, SSP4-7.0 and SSP5-8.5, which consider increasingly worse scenarios for global warming. The simulated impacts are very similar to Tables 7, 8 and 9, although with slightly worse temperature scenarios.

Table B1 applies all the model's coefficients in the forecast. Under this assumption, Fishing, Mining, Home property and Public administration are the only industries hurt by climate change whether at the horizons of 2050 or 2100. In particular, Fishing's GDP almost disappears by 2100, even with just a 1.0 °C increase in temperature. Mining and Home property would also decrease by at least 58% and 27%, respectively, by 2100. However, climate change would have a strong positive impact on the other economic sectors and therefore the total Chilean GDP would increase across all scenarios in 2050 and 2100, which depends obviously on the unrealistic assumption that the coefficients are fixed over time.

Table B2 applies only the model's coefficients that are statistically significant at the 10% level at least. Under this assumption, Agriculture, Fishing, Manufacture, EGA, Construction and Commerce are the only industries hurt by climate change whether at the horizons of 2050 or 2100. Even with just a 1.1 °C increase in temperature, Agriculture, Fishing, Manufacture, EGA, Construction and Commerce would decline by 75%, 99.6%, 63.8%, 83.5%, 12.9% and 27.6%, respectively, around 2100. However, climate change would have a strong positive impact on the other economic sectors and therefore the total Chilean GDP would change only slightly in 2050

Table B1: Simulated impact (in %) of the climate change on the industry and overall GDP level and growth rates in Chile for the period 1985-2017 and for the future (monthly model, all coefficients, Table 6)

Temper. increase	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP level in 2050 relative to no warming after 2017													
1.0 °C	24.7	-77.6	-27.6	53.0	38.1	22.6	7.0	3.5	20.6	-11.2	1.7	-3.3	9.8
1.3 °C	33.3	-85.7	-34.3	73.8	52.2	30.4	9.2	4.5	27.5	-14.3	2.2	-4.3	14.0
1.4 °C	36.3	-87.7	-36.4	81.3	57.2	33.1	10.0	4.9	29.9	-15.3	2.4	-4.6	15.5
1.4 °C	36.3	-87.7	-36.4	81.3	57.2	33.1	10.0	4.9	29.9	-15.3	2.4	-4.6	15.5
2.0 °C	42.4	-90.9	-40.4	97.4	67.7	38.6	11.5	5.6	34.9	-17.3	2.8	-5.3	18.7
Impact on GDP level in 2100 relative to no warming after 2017													
1.1 °C	82.3	-98.3	-58.4	217.4	140.6	74.1	20.3	9.7	66.2	-27.6	4.7	-8.8	42.4
2.0 °C	198.0	-99.9	-79.7	716.6	393.3	174.0	39.9	18.3	151.9	-44.5	8.8	-15.5	132.4
2.4 °C	270.8	-100.0	-85.3	1142.9	578.8	235.2	49.7	22.3	203.1	-50.6	10.6	-18.3	202.9
2.9 °C	387.1	-100.0	-90.1	2001.0	911.7	331.3	62.8	27.6	281.8	-57.4	13.0	-21.6	336.7
3.8 °C	696.3	-100.0	-95.2	5305.5	1974.7	578.8	89.3	37.6	478.7	-67.3	17.3	-27.3	813.4

and it would even increase across all scenarios in 2100. Again, however, this result is strongly dependent on the positive effects of climate change estimated for some sectors and these effects may not materialize, since such positive effects may decline over time and even turn into negative effects.

Table B3 uses only the model's coefficients that are both negative and statistically significant. Again, under this assumption, Agriculture, Fishing, Manufacture, EGA, Construction and Commerce are the only industries hurt by climate change whether at the horizons of 2050 or 2100. In terms of the negative impact of climate change on the total GDP, it could range between 9% and 12.7% in 2050 and between 17.8% and 29.8% in 2100.

Therefore our model predicts a large and positive impact of climate change on the total Chilean GDP if one uses all the model's coefficients both in 2050 and 2100, a small impact of climate change in 2050 if the forecasts use just the statistically significant coefficients, and a moderately negative impact of climate change both in 2050 and 2100 if the forecasts apply just the negative and statistically significant coefficients. It is possible that the forecasts using all the model's coefficients are way too optimistic, while the forecasts with just the negative and statistically

Table B2: Simulated impact (in %) of the climate change on the industry
and overall GDP level and growth rates in Chile:
Only statistically significant coefficients (monthly model, Table 6)

Temper. increase	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP level in 2050 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.0 °C	-40.0	-87.2	8.9	-31.2	-48.5	-5.0	-11.2	0.0	33.5	0.0	3.5	0.0	-2.3
1.3 °C	-48.5	-93.1	11.7	-38.5	-57.8	-6.4	-14.3	0.0	45.6	0.0	4.5	0.0	-1.9
1.4 °C	-51.0	-94.4	12.6	-40.8	-60.5	-6.9	-15.3	0.0	49.9	0.0	4.9	0.0	-1.7
1.4 °C	-51.0	-94.4	12.6	-40.8	-60.5	-6.9	-15.3	0.0	49.9	0.0	4.9	0.0	-1.7
2.0 °C	-55.8	-96.3	14.6	-45.0	-65.4	-7.8	-17.3	0.0	58.8	0.0	5.6	0.0	-1.2
Impact on GDP level in 2100 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.1 °C	-75.0	-99.6	26.0	-63.8	-83.5	-12.9	-27.6	0.0	119.3	0.0	9.7	0.0	5.0
2.0 °C	-92.0	-100.0	52.2	-84.2	-96.2	-22.3	-44.5	0.0	317.0	0.0	18.3	0.0	33.9
2.4 °C	-95.1	-100.0	65.5	-89.1	-98.0	-26.1	-50.6	0.0	454.9	0.0	22.3	0.0	55.8
2.9 °C	-97.4	-100.0	83.9	-93.1	-99.1	-30.6	-57.4	0.0	693.0	0.0	27.6	0.0	94.2
3.8 °C	-99.2	-100.0	122.1	-97.0	-99.8	-38.0	-67.3	0.0	1407.7	0.0	37.6	0.0	210.0

Table B3: Simulated impact (in %) of the climate change on the industry
and overall GDP level and growth rates in Chile:
Only statistically significant coefficients with a negative value (monthly model, Table 6)

Temper. increase	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP level in 2050 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.0 °C	-40.0	-87.2	0.0	-31.2	-48.5	-5.0	-11.2	0.0	0.0	0.0	0.0	0.0	-9.0
1.3 °C	-48.5	-93.1	0.0	-38.5	-57.8	-6.4	-14.3	0.0	0.0	0.0	0.0	0.0	-10.9
1.4 °C	-51.0	-94.4	0.0	-40.8	-60.5	-6.9	-15.3	0.0	0.0	0.0	0.0	0.0	-11.5
1.4 °C	-51.0	-94.4	0.0	-40.8	-60.5	-6.9	-15.3	0.0	0.0	0.0	0.0	0.0	-11.5
2.0 °C	-55.8	-96.3	0.0	-45.0	-65.4	-7.8	-17.3	0.0	0.0	0.0	0.0	0.0	-12.7
Impact on GDP level in 2100 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.1 °C	-75.0	-99.6	0.0	-63.8	-83.5	-12.9	-27.6	0.0	0.0	0.0	0.0	0.0	-17.8
2.0 °C	-92.0	-100.0	0.0	-84.2	-96.2	-22.3	-44.5	0.0	0.0	0.0	0.0	0.0	-24.0
2.4 °C	-95.1	-100.0	0.0	-89.1	-98.0	-26.1	-50.6	0.0	0.0	0.0	0.0	0.0	-25.7
2.9 °C	-97.4	-100.0	0.0	-93.1	-99.1	-30.6	-57.4	0.0	0.0	0.0	0.0	0.0	-27.5
3.8 °C	-99.2	-100.0	0.0	-97.0	-99.8	-38.0	-67.3	0.0	0.0	0.0	0.0	0.0	-29.8

Table B4: Simulated impact (in %) of the climate change on the industry
and overall GDP level and growth rates in Chile for the future:
climate change temperature coefficients estimated for the USA industry (post-1997)
from Table A21 (both years) in Colacito, Hoffmann and Phan (2019)

Temper. increase	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP level in 2050 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.0 °C	-4.6	-4.6	53.4	-9.1	7.0	-12.7	-6.2	0.2	-10.3	-10.3	-7.7	-5.6	-0.8
1.3 °C	-5.9	-5.9	74.4	-11.7	9.1	-16.2	-8.0	0.3	-13.2	-13.2	-9.9	-7.2	-0.4
1.4 °C	-6.3	-6.3	82.0	-12.5	9.9	-17.3	-8.6	0.3	-14.1	-14.1	-10.6	-7.7	-0.2
1.4 °C	-6.3	-6.3	82.0	-12.5	9.9	-17.3	-8.6	0.3	-14.1	-14.1	-10.6	-7.7	-0.2
2.0 °C	-7.2	-7.2	98.2	-14.2	11.4	-19.6	-9.7	0.4	-15.9	-15.9	-12.0	-8.8	0.4
Impact on GDP level in 2100 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.1 °C	-11.9	-11.9	219.8	-22.9	20.1	-30.9	-16.0	0.6	-25.5	-25.5	-19.6	-14.5	7.1
2.0 °C	-20.6	-20.6	727.7	-37.6	39.5	-48.9	-27.1	1.1	-41.5	-41.5	-32.7	-24.7	50.7
2.4 °C	-24.1	-24.1	1163.1	-43.2	49.1	-55.4	-31.6	1.3	-47.4	-47.4	-37.9	-28.9	93.0
2.9 °C	-28.4	-28.4	2042.3	-49.6	62.0	-62.3	-36.8	1.6	-54.0	-54.0	-43.7	-33.7	181.9
3.8 °C	-35.4	-35.4	5445.3	-59.2	88.1	-72.1	-45.2	2.1	-63.9	-63.9	-52.9	-41.7	535.9

significant coefficients can be too pessimistic since the coefficients are selected to clearly present a negative scenario.

Since the impact coefficients on each industry are more precisely estimated from USA data, we also implementing a counterfactual exercise by applying the industry coefficients from Table A21 in Colacito, Hoffmann and Phan (2019). This exercise in Table B4 shows its strongest impact in 2050 on Construction, which would decline between 12.7% and 19.6%. Home property, Financial Services and Manufactures would also be strongly hit, declining between 9.1% and 15.9% relative to a scenario with no climate change. However, due to the positive coefficient estimated for the Mining industry, the impact of climate change on the Chilean GDP in 2050 would be limited to a decline of 0.8% or less. In 2100 the projections for climate change's impact on total GDP would again become very positive, because the counterfactual would assume that the log-growth of Mining would add up linearly over time.

Table B5 shows a very similar counterfactual exercise with impact coefficients for temperature estimated for the US, but it considers only the statistically significant coefficients from Table A21 in Colacito, Hoffmann and Phan (2019). The exercise also applies the Agriculture-Fishing and Manufacturing industries coefficients from Table A20 in Colacito, Hoffmann and Phan (2019), since those coefficients were estimated with a smaller standard-error, perhaps due to the higher importance of such industries for the US economy before 1997. The results show a negative impact of climate change for most industries, except for Mining, Energy-Gas-Water (EGA) and Transports-Communications. The strongest impact of climate change is now estimated to be for the Agriculture and Fishing sectors, followed by Construction, Financial services and Home property. In particular, Agriculture and Fishing may decline between 18.7% and 28.2% in 2050, relative to a scenario with no additional climate change. Construction, Financial services and Home property would decline between 10.3% and 19.6% in 2050 due to the worsening climate change. In terms of the total GDP, the effect of climate change in 2050 would imply a deterioration between 6.8% and 10.5%. By 2100 the Agriculture and Fishing industries would decline between 43% and 85.7%, while the Construction, Financial services and Home property would decline between 25.5% and 72.1% due to climate change. Climate change by 2100 could imply a deterioration between 16.9% and 43% of the total Chilean GDP.

6.3 Precipitation and temperature evolution statistics between 1950 and 2017

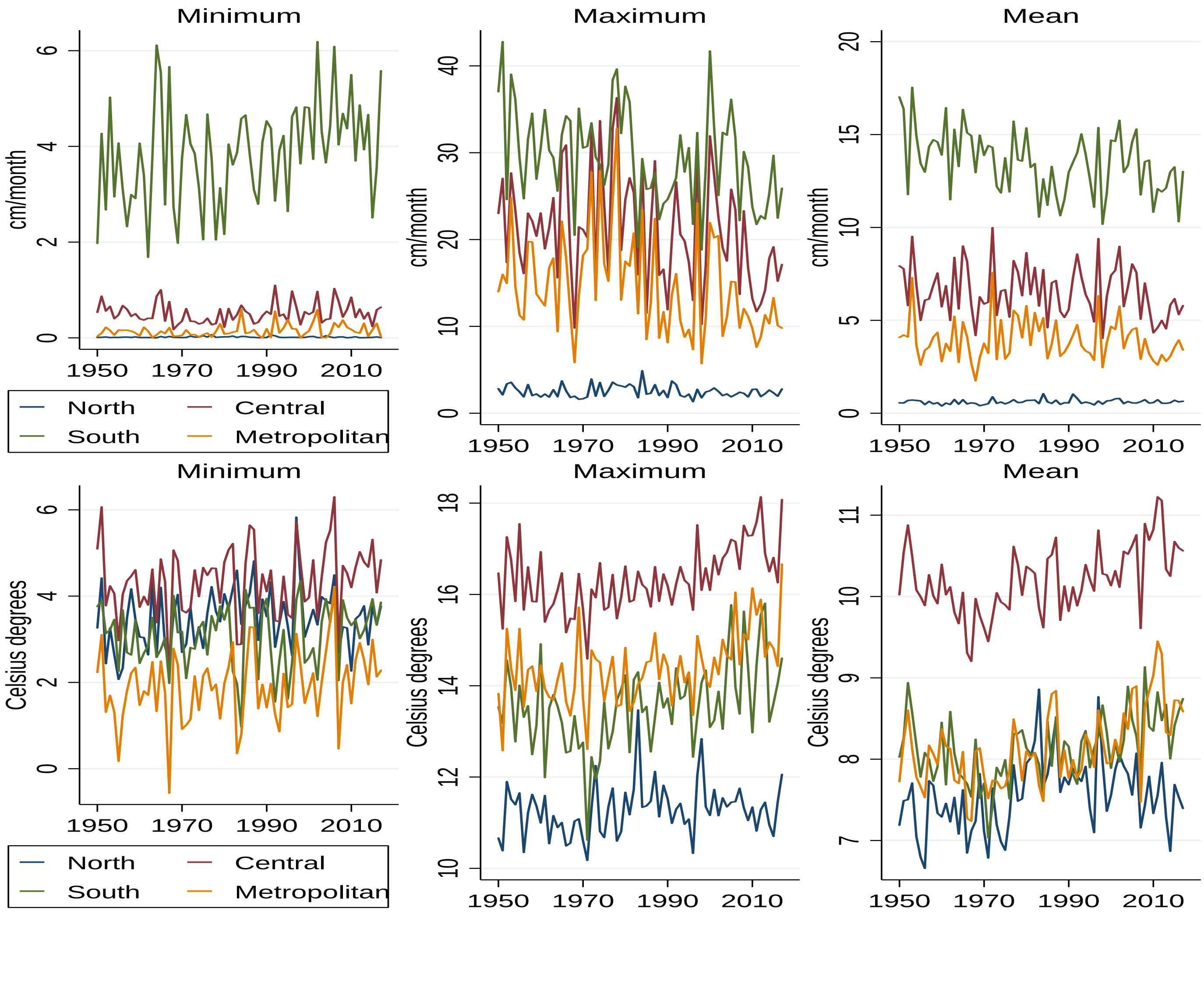
This appendix shows the results of the yearly temperature and precipitation fluctuations by macrozone weighted by the GDP of each region (instead of surface area, since some regions are large in area, but with little population and economic activity). To summarize the regional heterogeneity in a more succinct way, we create 4 macrozones, with macrozone 1 "North Chile" corresponding to regions I, II, III, IV and XV, macrozone 2 "Central Chile" corresponding to regions V, VI, VII, VIII, macrozone 3 "South Chile" corresponding to regions IX, X, XI, XII and XIV, and macrozone 4 "Metropolitan Region" corresponding to region XIII (which concentrates around 45% of the population and GDP of the nation). Figure 4 shows the yearly precipitation and temperature for each macrozone between 1950 and 2017 with weighted values according to the GDP of each region in 2017. Figure 4 shows that mean precipitation has been falling in the Central, South and Metropolitan macrozones, while mean temperatures have been increasing across all the macrozones. These patterns are qualitatively similar to the results weighted by surface area in Figure 2 of this

Table B5: Simulated impact (in %) of the climate change on the industry
and overall GDP level and growth rates in Chile for the future:
climate change temperature coefficients estimated for the USA industry (post-1997)
from Table A21 (both years, only statistically significant coefficients) plus Agriculture-Fishing and
Manufacturing industries coefficients from Table A20 (pre-1997)
in Colacito, Hoffmann and Phan (2019)

Temper. increase	Agri-culture	Fish-ing	Min-ing	Manu-facture	EGA	Const-ruction	Com-merce	Trans-ports	Finan. serv.	Home property	Pers. serv.	Public adm.	Total GDP
Impact on GDP level in 2050 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.0 °C	-18.7	-18.7	0.0	-4.6	0.0	-12.7	-6.2	0.0	-10.3	-10.3	-7.7	-5.6	-6.8
1.3 °C	-23.6	-23.6	0.0	-5.9	0.0	-16.2	-8.0	0.0	-13.2	-13.2	-9.9	-7.2	-8.7
1.4 °C	-25.2	-25.2	0.0	-6.3	0.0	-17.3	-8.6	0.0	-14.1	-14.1	-10.6	-7.7	-9.3
1.4 °C	-25.2	-25.2	0.0	-6.3	0.0	-17.3	-8.6	0.0	-14.1	-14.1	-10.6	-7.7	-9.3
2.0 °C	-28.2	-28.2	0.0	-7.2	0.0	-19.6	-9.7	0.0	-15.9	-15.9	-12.0	-8.8	-10.5
Impact on GDP level in 2100 relative to no warming after 2017 (RCP 2.6, 4.5, 6.0, 8.5)													
1.1 °C	-43.0	-43.0	0.0	-11.9	0.0	-30.9	-16.0	0.0	-25.5	-25.5	-19.6	-14.5	-16.9
2.0 °C	-64.1	-64.1	0.0	-20.6	0.0	-48.9	-27.1	0.0	-41.5	-41.5	-32.7	-24.7	-27.6
2.4 °C	-70.7	-70.7	0.0	-24.1	0.0	-55.4	-31.6	0.0	-47.4	-47.4	-37.9	-28.9	-31.6
2.9 °C	-77.3	-77.3	0.0	-28.4	0.0	-62.3	-36.8	0.0	-54.0	-54.0	-43.7	-33.7	-36.1
3.8 °C	-85.7	-85.7	0.0	-35.4	0.0	-72.1	-45.2	0.0	-63.9	-63.9	-52.9	-41.7	-43.0

article.

Figure 4: The evolution of the yearly precipitation and temperature (weighted by the regional GDP in 2017) for each macrozone during the period 1950-2017. Minimum, Maximum and Mean values are from January to December of each year.



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