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Araya, Alfaro, Paula Montserratt

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The Climate of Democracy: Effects of Exposure to Warmer Temperatures on Electoral Outcomes in Chile

Paula Montserratt Araya Alfaro

Comisión

Francisco Gallego
Felipe Jordán

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Committee: Francisco Gallego, Felipe Jordán

Paula Araya Alfaro

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Abstract

The Intergovernmental Panel on Climate Change (IPCC) predicts an increase in global temperatures by the early 2030s, exacerbating regional climate shifts and extreme weather events beyond initial forecasts. This paper explores the nexus between cumulative exposure to warmer temperature shocks and voting behaviors in Chilean national and local elections. Drawing on a dataset spanning 1988 to 2021 and employing panel regression with location and time-fixed effects, I uncover nuanced electoral responses to temperature fluctuations. Results indicate a positive relationship between exposure to warmer temperatures in the year before an election and voter turnout, particularly in local elections, with minimal impact observed at the national level. Moreover, exposure to cumulative warmer temperatures correlates with increased support for left-wing and nontraditional candidates in local races. Heterogeneous analysis reveals that in populations with the least adaptive capacities, new entry votes go, in most cases, to support outsiders, i.e., the "punishment vote" comes from the population most vulnerable to climate shocks. Mechanisms underlying these findings include income reductions from climate shocks and altered perceptions of democratic efficacy in addressing climate challenges. This study contributes to understanding the political ramifications of climate change, particularly in developing democracies like Chile, and underscores the role of exposure to changing climatic conditions in shaping electoral dynamics.

Keywords: Climate Change, Voting Behavior, Exposure to climatic events, Electoral Dynamics, Chile.

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Comments at paraluc.cl

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1 Introduction

The Intergovernmental Panel on Climate Change (2023) predicts that the world will experience an average global temperature change of 1.5 °C during the first half of the 2030s. As global warming intensifies, regional changes in mean climate and extreme weather events become more widespread and with greater severity than initially predicted by experts (National Aeronautics and Space Administration (NASA), 2023), thereby heightening multiple risks to ecosystems and humans and imposing significant challenges on societies. In this context, research on climate change has highlighted the importance of collective actions in addressing these challenges. In democracies, voting represents the most direct form of political action through which citizens can demand stronger climate policies or advocate for public policies to compensate for or adapt to new climate conditions.

This paper investigates the relationship between cumulative exposure to warmer temperature shocks and voting behaviors for national and local elections in Chile. My results suggest that greater exposure to temperature fluctuations positively affects voter turnout and support for left-wing and nontraditional candidates in local elections, while they seem not to play a significant role in explaining electoral dynamics at the national level.

The country is an interesting setting for the study for two main reasons: First, it is located in a region with a high risk of experiencing early and pronounced temperature increases due to climate change. This heightened sensitivity increases the country's exposure to the consequences of various extreme weather events.[1] Additionally, its distinctive geographical features result in different climatic zones, adding more variation to the exposure to weather anomalies. Secondly, during the period under study, Chilean democracy experienced a surge in non-electoral political engagement with a decline in formal instances of political expression, such as voting or joining political parties. This phenomenon has contributed to the institutional crisis that the country has recently experienced (Medel, Somma, & Donoso, 2023). Therefore, the proposal is to examine whether and how temperature-related climate change shocks explain those political behavior dynamics.

I use the cumulative exposure to warmer maximum temperatures to construct degree-day measures as a proxy for climate change perturbations, which is a common practice in this literature (Aragón, Oteiza, & Rud, 2021; Carleton & Hsiang, 2016; Jessoe, Manning, & Taylor, 2018; Liu, Shamdasani, & Taraz, 2023). The nonlinearity of the degree days approach allows for a neutral, flexible, and theoretically informed examination of electoral responses to an additional average heat degree day without imposing preconceived functional constraints. I analyze the causal effects of temperature changes on political outcomes, relying

[1] The IPCC report of 2023 projects that the South American region will experience an increase in annual maximum daily temperature by 1.5-2 times the global warming level (1.5 °C)

on the randomness of weather events from a broader climatic distribution in a given spatial area. I use a panel dataset from 1988 to 2021 to regress my outcomes against degree-days with location and time-fixed effects, which account for observed and unobserved geographic characteristics.[2] [3] This strategy allows me to identify the effect of weather disturbances, isolating them from other possible sources of variation.

I find that an additional average heat degree day increases voter turnout by 2.47 percentage points in local elections, which represents almost a quarter of a standard deviation or a 5% increase in average turnout in local elections, equivalent to 55.39% of the local elections' turnout rate. I find that this increase in turnout rate is equally distributed to vote shares increase for left-wing and outsider candidates, which are 1.21 and 1.24 percentage points, respectively.

In line with the studies of Balcazar and Kennard (2022) and Cerkez (2023), I argue that cumulative exposure to warmer temperatures affects voting behavior through a mechanism of changing people's perceptions about climate change, in which citizens use democratic institutions to respond to this global issue and its consequences. Specifically, I propose that exposure to these shocks changes citizens' beliefs about the importance of climate change and who should act to address its challenges. Then, the change in beliefs and attitudes induces citizens to increase their electoral participation to support their candidates.

In the case of support for left-wing candidates, I explain the increase in vote share by arguing that left-wing parties have become more involved in the global warming debate and have incorporated it into their ideological discourse. Therefore, new voters concerned about this issue would naturally be attracted to left-wing parties. Despite this, I argue that the rise of outsider voting is consistent with a weak version of retrospective voting theory in which newcomers support outsider options while incumbents face no penalty in terms of votes.

However, a closer look at the characteristics of the counties reveals that there are economic differences in the impact on vote shares among municipalities according to their economic dependence on agriculture, rural status, poverty incidence, and years of schooling of their population. From a heterogeneous analysis, I find that the effect on the share of votes for outsiders is driven by highly vulnerable urban areas, which, according to the IPCC report (2023), are also the most exposed populations to climate change shocks. Meanwhile, in counties with more educated populations in urban non-agricultural zones, the new votes tend to favor left-wing parties to a greater extent. These results are consistent with recent findings from Angrist, Winseck, Patrinos, and Zivin (2024) that more human capital is associated with substantial increases in pro-climate

[2]The panel dataset merges daily weather data, aggregated annually, with election results for 328 municipalities across eight parliamentary elections (national) and eight mayoral elections (local).

[3]The degree-days approach considers two measures: the number of days above (HDD) or below (DD) a threshold temperature, multiplying each day by its temperature difference from the threshold.

beliefs, behaviors, and policy preferences.

This work contributes to the research on the political impacts of natural disasters and climate change (Malhotra & Kuo, 2008; A. Healy & Malhotra, 2009; A. J. Healy, Malhotra, & Mo, 2010; Cole, Healy, & Werker, 2012; Achen & Bartels, 2017). Additionally, it intersects with the growing body of research examining political reactions to climate change-induced shocks in developing countries (Amirapu, Clots-Figueras, & Rud, 2022; Balcazar & Kennard, 2022; Cerkez, 2023). In particular, this study adheres to the small and recent literature that attempts to estimate the response of the electorate to climate change-related disruptions in Latin America and is the first to study the Chilean case.

The rest of the paper proceeds as follows: Section 2 presents the conceptual framework. Section 3 examines the research design, revising the data and methodology. Section 4 discusses the main results and heterogeneity analysis. Finally, Section 5 concludes.

2 Motivating Theory

This section aims to shed light on the underlying explanations for the impact of cumulative exposure to warmer temperatures on citizens' political decisions and attitudes in Local and National elections.

Firstly, I consider citizens' decision-making regarding political participation through voting based on the expected utility that these action reports. I define the expected value of voting in a local (national) election, depending on income distribution and the extent to which they hold the local (national) government responsible.

It has been empirically demonstrated that extreme weather events cause a reduction in agricultural and labor productivity (Dell, Jones, & Olken, 2012; Schlenker & Lobell, 2010; Schlenker & Roberts, 2009), which negatively affects income at the time of the shock and expected income in the future. Then, income and participation can be related in two ways. On the one hand, I can consider that income reduction could lead to discontent and mobilize people to vote as a protest sign, as is found by Balcazar and Kennard (2022). On the other hand, Cerkez (2023) shows that weather anomalies could lead to a decrease in their support for democracy; in this case, the drop in income could negatively affect participation.

From a different perspective, individuals' beliefs, attitudes, and awareness of climate change play a crucial role in shaping voting patterns in response to temperature effects. As in the case of income, perceptions and the relationship of voting behavior vary depending on different factors. In the case of perceptions of climate change, I consider personal experience, information, and other socioeconomic determinants of adaptive capacity in the face of disasters to be the most important factors (Cutter et al., 2003;). Previous literature has shown that exposure to catastrophes and being informed about climate change lead to greater civic engagement, which could, in turn, lead to greater participation and support for sustainability policies. As for the latter determinants, think, for example, of factors such as wealth, geographic location, and educational level. One might assume that people with more resources or people living in urban areas are better equipped to deal with the challenges associated with weather-related shocks because they have better access to technology, markets, or institutions that could help mitigate such shocks. In addition, individuals with more human capital could have a better understanding of the available information on climate change and its consequences (Angrist et al., 2024). In any case, if individuals perceive climate change as an important issue, they may be more motivated to participate in elections to support candidates or political parties with stronger climate change mitigation and adaptation policies programs.

Secondly, I examine changes in vote shares for traditional coalitions (e.g., left-wing and right-wing parties) and outsiders' candidacies. I propose to understand support for the candidates of the different coalitions through two mechanisms. The first one derives from the representative democracy concept and explains that citizens vote for those candidates who: i.) mostly represent their partisan values, particularly their positions relative to policies related to addressing or mitigating the effects of climate shocks, and ii) for whom they think have more agency to successfully implement those policies. Alternatively, the second one can be influenced by retrospective voting theory, in which people respond to external adverse shocks, such as climate events or income shortfalls, by blaming their leaders and punishing incumbents in subsequent elections. Thus, not only could this lead to changes in turnout like a sign of protest (Balcazar & Kennard, 2022), but it could also induce to vote for non-conventional candidates as a means of penalizing traditional politicians and their policymaking, particularly concerning addressing climate change-related shocks.

Finally, I address the fact that voting patterns do not necessarily operate the same way in local and national elections (Warshaw, 2019). Indeed, there exists empirical evidence showing that an external shock produces different effects on local and legislative electoral processes in Chile (Leiva, 2018). I propose these differences could be due to political actors at the local and national levels having different functions and capacities in the policymaking process. More specifically, I suggest that people's beliefs about the extent to which they hold the local (national) government responsible for the disturbance and its consequences are a function of their perceptions of the capabilities of this entity to deal with them. In turn, public perceptions can be shaped by citizens' knowledge about the capabilities of the local (national) government and the effectiveness of these institutions' policies in similar events in the past.[4]

I argue that if citizens perceive a higher policy agency from the local (national) government to address the challenges related to climatic shocks, the greater the degree of accountability attributed to this entity will be and the higher the call in that electoral process.

[4]I rely on A. Healy and Malhotra (2009) and Balcazar and Kennard (2022) assumptions of citizens' (in)ability to directly observe leaders' policy choices such as implementing emergency aid programs (Fuchs & Rodriguez-Chamussy, 2014) or the development of adaptation capacities (Campbell, Kotcher, Maibach, Rosenthal, & Leiserowitz, 2021).

3 Research Design

3.1 Data

I have constructed a panel dataset comprising 5,274 observations of county-electoral processes. This dataset compiles information on daily temperature, political registers, and administrative data for at least 328 municipalities for each electoral process between 1989 and 2021 to determine the causal effect of severe weather events on election results.

Electoral data. To measure electoral behavior across Chilean municipalities, I compiled disaggregated electoral data sets for all legislative and local elections between 1989 and 2021 from the Electoral Service (SERVEL). These data include information on the type of election (i.e., local or national elections), year, candidate's name, political affiliation, office held, and number of votes in male, female, and mixed tables at the municipal level, among others. My political outcomes are turnout and the vote shares obtained by the two main competing political coalitions (left-wing and right-wing) and outsider candidates. A data limitation is that the electoral results available on the Electoral Service platform do not provide records of the number of voters for elections prior to the year 2000. Therefore, my turnout measure follows the literature by defining it as the proportion between the number of valid votes in a municipality and its population by interpolating census data to supplement this information. Regarding vote shares, they represent the proportion of valid votes obtained by right-wing, left-wing, and outsider candidates (such as independents, regional movements, and candidates with non-declared political affiliations), over the total population.

Defining which candidate represents which political coalition (i.e. left, right, or outsider) is also important. The criteria used for determining partisan candidates follow the classifications of political groups used in the research conducted by Cox and González (2017) and Depetris-Chauvin and González (2021).

Table 1: Mean and Standard Deviation of Electoral Behavior by Periods

Periods		Local		National		All	
		Mean	*Std. Dev*	*Mean*	*Std. Dev*	*Mean*	*Std. Dev*
Before 2000	Turnout	55.42	8.87	55.42	8.06	55.20	8.49
	Left-wing	50.29	14.15	46.89	15.12	48.13	15.22
	Right-wing	32.31	15.86	40.06	13.46	36.02	15.75
	Outsiders	17.40	16.21	13.05	15.81	15.85	16.87
		Mean	*Std. Dev*	*Mean*	*Std. Dev*	*Mean*	*Std. Dev*
2000-2010	Turnout	53.11	10.11	53.01	9.32	53.06	9.72
	Left-wing	49.13	13.75	46.30	11.66	47.72	12.83
	Right-wing	29.45	13.83	45.98	11.87	37.72	15.31
	Outsiders	21.42	15.21	7.72	11.55	14.57	15.14
		Mean	*Std. Dev*	*Mean*	*Std. Dev*	*Mean*	*Std. Dev*
After 2010	Turnout	48.64	11.57	51.47	8.77	49.77	10.63
	Left-wing	34.55	15.11	51.37	11.08	41.28	15.93
	Right-wing	41.10	14.14	40.06	13.46	41.75	12.86
	Outsiders	24.35	14.35	8.59	10.04	16.97	15.57

Table 1 shows descriptive statistics for the main electoral variables. The mean turnout rate has been decreasing since 1989. Despite this, the rates for local elections remain a bit higher than legislative ones, except for the last decade, resulting in a major fall in local turnout rates relative to congressional races: Local turnout rates fall from 55% to approximately 48% relative to 55% to 52% in congressional elections. For vote shares, I highlight the fall of support for left-wing parties with a rise in outsider candidates.[5] Although traditional parties received the highest preference in both local and national elections, support for left-wing party candidates seems to be decreasing in local elections. The vote share has dropped 15

[5]In this section, vote shares are defined over the total of votes in each election.

percentage points between 1989 and 2021. Meanwhile, votes for right-wing parties have shown a little increase in the last 20 years, and outsider candidacies, have shown an important race of vote shares, going from 17% in 1989 to almost reaching one-quarter of the votes after 2010. However, the phenomenon is not reflected in congressional elections. During the last decade, the percentage of votes for the left has increased to the same extent that it has decreased for the outsiders.[6].

As a means of visualizing the political trends that these variables have followed throughout the studied period, Figures 1.A of Appendix depict the participation and percentage of votes obtained by left, right, or outsider candidates trends among capital regions. This confirms that there has been a significant decrease in voter turnout since voluntary voting was passed in 2012, especially for local elections. However, it can be observed a recent increase in turnout around 2021, which may be attributed to the high public interest in this election as it coincided with the constituent council voting. Additionally, I notice a prominent trend of increasing vote shares for outsiders, particularly in local elections.

[6]This disparity in the electoral process is probably due to two facts. First, it can be assumed that in local processes, familiarity between voters and candidates induces more people to participate and, at the same time, obtain higher percentages of votes for outsider candidates. Second, outsider candidates are more likely to achieve success in local elections as compared to congressional seats because of legislative election mechanisms: Prior to 2012, the legislative procedures in place were characterized by a binominal system that imposed considerable barriers to entry for non-party candidates looking to be elected, which meant that they had to obtain a higher number of votes than their counterparts running on the electoral lists of the established parties

Weather data. I utilize data with a 0.05-degree latitude-longitude grid sourced from the Center for Climate and Resilience Research (CR2).[7] This ground station dataset is combined with various data sets, including different variables from the ECMWF ERA5 reanalysis, topographic parameters, and land surface temperature estimates from the Moderate Resolution Imaging Radiometer Satellite Sensor (MODIS). This combination of data enables me to gain valuable insights into daily precipitation and maximum near-surface temperatures.

Since this work aims to find the effects of cumulative exposure to temperature shocks, I processed the gridded temperature data using the following steps. First, I assigned each pixel with daily maximum temperature information to a county and then averaged it at that level daily. With this measure, I constructed the regressors that will be discussed in more detail in the next section. Following the same procedure, I obtained the variables needed to control my estimates. Table 1.A in the Appendix shows the evolution of descriptive measures for temperature and accumulated precipitation through the election years.

In addition, to illustrate the evolution of the meteorological variables over the period studied, I averaged the maximum temperatures for the period before 2000 and after 2010. Next, in Figure 1, I plot the differences in the number of days in which the average maximum temperature was higher than the average temperature of (22 °C) and the difference with respect to the mean in degrees Celsius. Similarly, Figure 2.A plots the variation among counties in these temperature measures for each year.

[7] To put it into context, each degree of latitude is approximately 111 kilometers at the equator. Hence, 0.05-degree latitude is approximately 5.55 kilometers near the equator.

Figure 1 Changes on Average Maximum temperatures

Note: Changes in temperature are constructed using counties' maximum daily temperatures across 1989-2021. The differences are taken by (i) counting the days over 22 °C and ii) measuring the difference in Celsius degrees between two periods: before 2000 and after 2010.

Figure 1 illustrates that the frequency of days with temperatures exceeding 22 °C increased, albeit with considerable variation observed across municipalities. Furthermore, approximately 25% of municipalities exhibited a temperature rise of at least 0.4 °C between the initial and final decades of my panel. This trend aligns with the overall increase in maximum temperatures, which rose from 32 °C in 1989 to 35.5 °C in 2021. It also is consistent with lesser accumulated rainfall, as shown in Figure 3.*A* in the Appendix.

Sociodemographic data Finally, I aggregate individual-level data from the 2017 national survey and census to obtain a socio-demographic characterization of the population in 328 municipalities. Since these estimations control for county and year-fixed effects, I use this information to study heterogeneity. Table 2 shows summary statistics.

Table 2: Descriptive Statistics

	Mean	Median	Std. Dev.
Rural	0.34	0.32	0.26
Poverty	0.11	0.10	0.06
Schooling	9.86	10.00	14.12
Labor Force in Agriculture	0.08	0.07	0.06

3.2 Methodology

In the pursuit of understanding how citizens respond politically to cumulative exposure to warmer temperature shocks, my empirical analysis employs a Two-Way Fixed Effects (TWFE) regression. My primary specification is:

$$\begin{aligned} y_{cet} = \beta \times g(HDD_{cet}, DD_{cet}, PP_{cet}) + \gamma \times g(HDD_{cet}, DD_{cet}, PP_{cet}) \times National_e \\ + \theta_{ce} + \delta_{te} + \phi\left(\theta_{ce} \times National_e\right) + \psi\left(\delta_{te} \times National_e\right) + \epsilon_{cte} \end{aligned} \tag{1}$$

where y_{ct} represents political outcome variables, which are turnout rates and vote shares for left-wing, right-wing, and independents in county c at year t.[8] In the right-hand side of equation (1), $g(HDD_{cet}, DD_{cet}, PP_{cet}))$ is a non-linear function of maximum temperatures (HDD_{cet}, DD_{cet}) and total precipitation (PP_{cet}) during the year preceding the election day. I include location-election type and year-location type fixed effects to exploit within-district variation. To evaluate if the effects differ by the type of electoral process, I interact with an indicator variable for national elections (National) all the elements contained in weather term, $g(.)$, and the fixed effects (θ_{ce}) and (δ_{te}).

Non-linear relation between weather and political outcomes $g(HDD_{cet}, DD_{cet}, PP_{cet})$

I explore the relationship between weather and my dependent variables using the concept of degree days. The function $g(HDD_{cet}, DD_{cet}, PP_{cet})$ is composed of good degree days (DD), heat-degree days (HDD), and precipitation presented as a second-order polynomial. This approach is extensively used in the past literature to capture non-linear effects of temperature on various outcomes (Schlenker & Roberts, 2009; Burke, Hsiang, & Miguel, 2015; Dell et al., 2012) and enable me to measure the frequency and intensity a unit of interest (i.e., county c at year t) is exposed to temperatures between a given lower and upper bound. Although these measures are traditionally used in agronomic studies, I adapt them to make them relevant for my context as Amirapu et al. (2022). Then, the degree days variables are:

$$DD = \frac{1}{n} \sum_{d=1}^{n} \left(t_d - 10\right) \mathbb{1}\left(10 \leq t_d \leq \tau\right) \tag{2}$$

[8] These variables are defined as the total votes and the number of votes obtained for each group divided by the total population in the county c at year t.

$$HDD = \frac{1}{n} \sum_{d=1}^{n} (t_d - \tau) \, \mathbb{1} (t_d > \tau) \tag{3}$$

where t_d is the average daytime maximum temperature on the day d, and n is the total number of days in the year before election day.[9] The threshold τ is defined at 22 °C, the mean of the maximum daily temperature distribution because it provides a balanced reference point that reflects the typical maximum temperature experienced over the study period.

[9] I count 365 days back to the election day for most of the electoral process and 366 days back on leap years (1992, 1996, 2000, 2004, 2008, 2012, and 2016).

4 Main Results

In this section, I present my main empirical results on citizens' responses to cumulative exposure to warmer temperatures.

4.1 Effects on Voter Behavior

Table 3 presents the main specification's results on the effect of an additional average heat degree day on electoral outcomes in local and national elections from 1989 to 2021. I report the coefficients for local elections (β_{HDD}), national elections ($\beta_{HDD}+\gamma_{HDD}$), and the difference between them (γ). In all regressions, I control non-observables using county and year-fixed effects. Standard errors are clustered at municipality level.

Table 3: Non-linear effect of temperature measures on political outcomes

	Turnout	Vote share: Left-wing	Vote share: Right-wing	Vote share: Outsiders
β_{HDD}	2.467***	1.214**	0.0267	1.237**
	(0.684)	(0.520)	(0.402)	(0.491)
$\beta_{HDD} + \gamma_{HDD}$	-0.2331	-0.9743	-0.0747	0.8338
	(0.732)	(1.122)	(0.704)	(0.989)
γ_{HDD}	-2.700**	-2.189*	-0.101	-0.403
	(1.067)	(1.236)	(0.830)	(1.079)
Observations	5,248	5,248	5,248	5,248
Adj. R-squared	0.707	0.603	0.580	0.377

Notes: The coefficients report the effect of an additional HDD in local elections (β) and national elections ($\beta + \gamma$). For clarity, I also report γ, which is the coefficient of HDD interacted with the "National" indicator in Equation (1). All specifications include county-type of election and year-type of election fixed effects. Standard errors (in parentheses) are clustered at the constituency level. Stars indicate statistical significance $*p \leq 0.10$, $**p \leq 0.05$, $***p \leq 0.01$. Table 1.B in Appendix shows robustness by considering climatic zone fixed effects.

Looking at turnout, an additional average heat degree day increases turnout in local elections by 2.47 percentage points, which is significant at the 1% level. This effect differs significantly from national elections, where the effect is zero. Then, in the analysis of the vote shares, column 2 shows that an additional average HDD leads to different effects on the left voting across electoral processes at the 10% level. I find that the vote for left-wing increases by 1.21 percentage points in local elections, while, again, the effect in national elections is not statistically significant. Regarding right-wing vote share, column 3 presents no significant differences between local and national elections. The effect is non-different from zero in both cases. Finally, column 4 shows that even if there are no statistically significant differences across election types, in local elections, the effect on voting for outsiders is positive, 1.24 percentage points at 5% of significance. Meanwhile, the effect is statistically zero in national races.

Overall, Table 3 shows that while political outcomes in legislative elections do not respond to temperature increases, in local elections, the increase in turnout goes almost equally to votes for the left and outsiders.

In Section 2, I outline some plausible hypotheses to explain these political outcomes' responses to temperature increments. One of the suggested mechanisms says that the increase in voter turnout could be attributed to a rise in the marginal utility of voting due to consequences of weather fluctuations, such as income reductions. This impact on livelihoods can lead to more civic engagement among citizens, encouraging them to demand policies that mitigate harm and promote adaptation, ultimately motivating them to vote. However, since public policies in Chile are mostly made at the congress level, it became less likely to believe that a greater demand for mitigation policies is the main driver of the effect in local elections. Instead, the results seem better explained by the fact that cumulative exposure to higher temperatures could increase people's awareness about climate change, which has been shown to lead to greater willingness to engage in political participation. (Feldman & Hart, 2016; Obradovich, 2017; Hoffmann, Muttarak, Peisker, & Stanig, 2022).

However, understanding not only why people vote more, but also for whom they vote, is necessary to have a complete picture of electoral behavior. At this point, it is important to reflect on the determinants of citizens' decision-making process with respect to the candidates they choose to support. Personal experiences and partisan coincidences could explain the effects on vote shares. For example, to explain why almost half of the turnout increase is directed to support external actors, the retrospective voting theory suggests that the distress caused by the experience of the event may change voters' preferences. This would lead citizens to blame their leaders and punish their incumbents in the next election. Although in Table 3, I do not find any reduction in the vote shares of any coalition, I will try to evaluate this hypothesis using the data. Table 4 aims to assess whether the coalition in power before each contest (i.e., the incumbent coalition) is punished in local elections.

Table 4: Effects on the incumbent's voting share

	Vote Share: Incumbent
β_{HDD}	1.200**
	(0.551)
Observations	2,624
Adj. R-squared	0.441

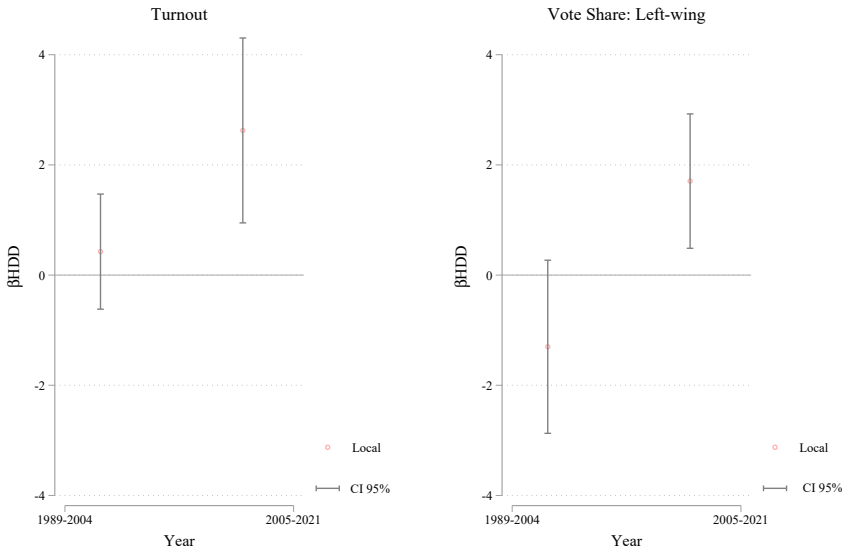
Notes: Incumbent is defined as the previous winner coalition. The coefficients report the effect of an additional average HDD in local elections (β). All specifications include county-type of election and year-type of election fixed effects. Standard errors (in parentheses) are clustered at the constituency level. Stars indicate statistical significance $*p \leq 0.10$, $**p \leq 0.05$, $***p \leq 0.01$.

As seen in Table 4, the effect of an additional average heat degree day on the vote share for the incumbent coalition suggests that cumulative exposure to warmer temperatures increases the share of votes for the current coalition in power by 1.2 percentage points (p-value 0.03). Therefore, there is currently no evidence to suggest that citizens take action to directly punish incumbents. Then, support for outsiders versus party candidacies can be interpreted as some new voters wanting to punish the establishment for not supporting party logic. Given that parties are key institutional actors in a democracy, greater support for outsiders is along the same lines as found by Cerkez (2023), who finds that greater exposure to droughts leads people to develop bad attitudes toward democracy.

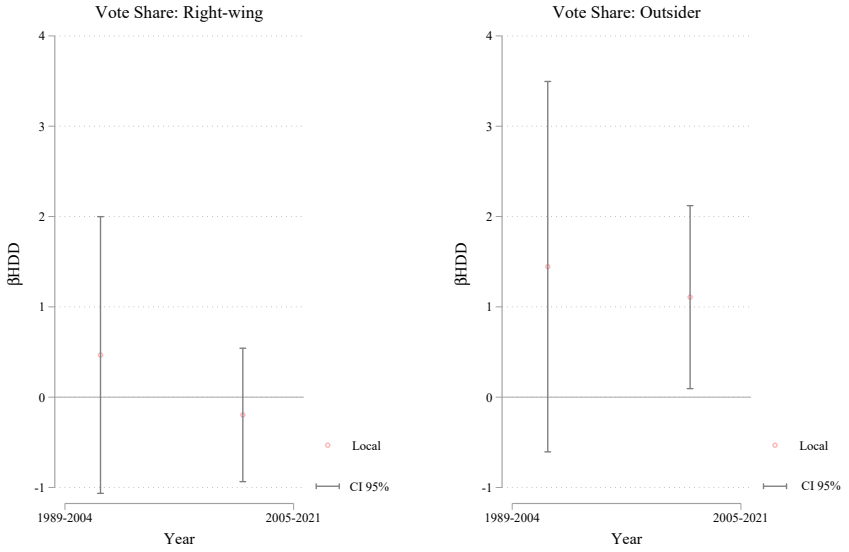
However, traditional left-wing candidates receive the other half of the new votes. Consistent with the perception-shaping mechanism, I argue that greater exposure to rising temperatures leads people to perceive climate change as an important issue, and then to vote for those candidates who have similar positions on the matter. Finally, it is important to keep in mind that the effect on the vote share of left-wing and of incumbent coalition is statistically the same. Moreover, given that the incumbent corresponds to the left coalition 58% of the time, I suggest that the effect on the votes of the incumbent is mainly driven by the votes of citizens who decide to participate in the process, attracted by the left environmentalist discourse.

An important limitation of these interpretations lies in the inability to separate the speech effects from the rising trends in temperatures. Despite this, it would be interesting to observe the evolution of the estimates over time. According to the literature, one should expect the effects to be greater during the last years of the period studied than in the first part, either due to an intensification of warmer temperature fluctuations or because of a greater spread of awareness about global warming. To visualize this, I divided the data into two groups: the first 15 years and the last 15 years of the original panel, and the estimated equation (1). Figure 2 shows the impact on four local election outcomes over the periods 1989-2004 and 2005-2021. The estimates indicate that the effects reported in Table 2 are mainly driven by the last 15 years, consistent with the increase in temperatures and the spread of information about global warming.

Figure 2. Non-linear Effects of temperature on Political Outcomes by periods



Notes: This figure plots the effects of an additional HDD on four local election outcomes over the periods 1989-2004 and 2005-2021.



Notes: Estimates of additional average HDD during the 1989-2004 and 2005-2021 periods for local and national elections. Effects are detailed in Table 2.B in Appendix.

In the remainder of the analysis, I will focus only on local elections to better understand these voting patterns and examine closely possible determinants explaining the results presented in this section.

4.2 Heterogeneity results

After analyzing the general effects of temperature on turnout and vote share in different types of elections, it is useful to see how these effects vary across units of analysis. Through these exercises, I expect to shed light on the underlying mechanisms driving the effects presented above. In Section 2 I discussed two main channels. The first one is related to a growing body of research that has shown that extreme temperatures lead to strong impacts and reductions in crop yields, which, in turn, affect citizens' livelihoods, triggering different political reactions. In this sense, Amirapu et al. (2022) assess HDD effects on agricultural yields and find that this falls almost in the same proportion as voter turnout increases, being more pronounced in places with a higher degree of economic dependence on agriculture. Alternatively, the second way to explain the impact of warmer temperatures on electoral outcomes is through perceptions of climate change, which are influenced by individuals' abilities to adapt to or recover from disasters (Kahn, 2005; Cutter, 2003).

Thus, to assess the influence of possible mechanisms in explaining the effects of temperature on voting patterns, I modify equation (1), changing the term interacted by the voting type (National) indicator for an indicator that accounts for the following characteristics: agricultural labor rate, rural area, poverty incidence, and average years of schooling. The indicator takes value one if the municipality is above the national median of 2017 according to census and household survey data. The heterogeneous effects of cumulative exposure to warmer temperatures on voting patterns in local elections are presented in Table 5.

Table 5: Heterogeneous effects on Local Elections

	Turnout	Vote Share: Left-wing	Vote Share: Right-wing	Vote Share: Outsiders
A. Agricultural dependency				
Low dependency	2.064***	1.176**	-0.0879	1.011*
	(0.669)	(0.582)	(0.452)	(0.526)
High dependency	2.382***	0.048	0.079	2.002***
	(0.891)	(0.826)	(0.619)	(0.704)
Diff	0.318	-1.128	0.167	0.991
	(1.115)	(1.010)	(0.766)	(0.878)
Adj. R-squared	0.700	0.658	0.506	0.345
B. Urban vs. Rural settlement				
Urban	1.976***	1.138**	-0.143	1.000**
	(0.647)	(0.553)	(0.434)	(0.498)
Rural	0.689	-0.967	0.006	1.060
	(1.072)	(0.920)	(0.670)	(0.850)
Diff	-1.288	-2.105**	0.149	0.0594
	(1.239)	(1.058)	(0.788)	(0.964)
Adj. R-squared	0.700	0.659	0.514	0.363
C. Households in Poverty				
Low incidence of poverty	1.770***	0.886	0.0822	0.829
	(0.664)	(0.557)	(0.453)	(0.533)
High incidence of poverty	-0.607	-0.592	-2.109	1.866***
	(1.078)	(0.940)	(0.538)	(0.697)
Diff	-2.377*	-1.478	-2.191**	1.038
	(1.239)	(1.074)	(0.854)	(0.850)
Adj. R-squared	0.692	0.662	0.515	0.347
D. Population Schooling years				
Less than 10 years of education	1.771**	0.767	-0.442	1.439***
	(0.814)	(0.488)	(0.405)	(0.514)
More than 10 years of education	3.005**	1.985	0.538	0.4993
	(1.422)	(1.210)	(0.856)	(0.998)
Diff	1.235	1.218	0.980	-0.940
	(1.652)	(1.297)	(0.959)	(1.100)
Adj. R-squared	0.696	0.672	0.550	0.372

Notes: Standard errors (in parentheses) are clustered at the constituency level. Stars indicate statistical significance $*p \leq 0.10$, $**p \leq 0.05$, $***p \leq 0.01$. All specifications include county-type of election and year-type of election fixed effects. Each regression has 2,480 observations.

Agricultural Dependency

For local elections, Panel A in Table 4 presents the effects in municipalities with labor force participation rates in the agricultural sector that are either below or above the national median. I do not find statistical heterogeneity in turnout and vote shares among municipalities according to their agriculture dependency (i.e., the share of the labor force in the agriculture sector). However, the effects are economically different when left- and outsider-voting is considered. Temperatures may influence the electorate's behavior through an agricultural channel since new voters tend to support non-traditional options, which can be interpreted as a slight punishment of traditional parties. The vote for the left is significant only in areas with less dependence on agricultural activity, and the effect on the vote for outsiders is almost half that in areas with greater agricultural intensity. Temperatures can influence the electorate's behavior through an agricultural channel. In agricultural areas, new voters tend to support non-traditional options, which can be interpreted as a slight punishment to traditional parties.

Next, Panel B examines the impact of rurality status on the relationship between temperature and voting for left-leaning candidates in local elections. The results indicate that units located in urban areas demonstrate a positive and statistically significant effect of temperature on voting for left-leaning candidates compared to those located in rural areas (p-value 0.048). Additionally, economic differences in turnout and outside voting favor urban settlements. Although warmer temperatures do not seem to affect rural counties, urban areas experience a significant increase in voter turnout, benefiting both traditional and non-traditional parties equally.

These results are noteworthy for several reasons. At first glance, it might be expected that rural residents would be more interested in participating in local elections, either because they are closer to the candidates or because they benefit more from politics at the local level than at the national level. However, the data do not support this hypothesis. One way to interpret the political preference results is to consider that temperature effects in urban areas are a result of perception change mechanisms. This is because urban residents have greater access to information and are more aware of climate change debates, which could explain their increased support for "greener" political agendas associated with left-wing parties. Additionally, it is noteworthy that the number of outsider votes tends to increase in urban centers. As explained in the previous section, the outsider vote is often used as a protest by new voters against their current leaders.

Socioeconomic factors

Panel C shows estimates based on poverty incidence levels. The results indicate that cumulative exposure to warmer temperatures in the year prior to a local election leads to higher turnout rates in counties with lower

levels of poverty incidence (i.e., wealthier counties) relative to those with more poor households (p-value 0.056). However, looking at how voting shares change, new votes are almost equally distributed between the left and outsiders in counties with fewer poor households. In contrast, I find that support for traditional coalitions decreases while that for outsiders increases significantly in areas with higher incidence of poverty. Since this support for outsiders is accompanied by a non-significant decrease in turnout, I take this as evidence of substitution in preferences from traditional to non-traditional politicians, which supports the idea of punishment in municipalities with more vulnerability. Similarly, Panel D presents the effects in municipalities according to the average schooling years of its populations. Although the coefficient of the interaction term does not indicate significant statistical differences between them, in counties with more schooling years, the increase in turnout is almost twice that in those with less than ten years of schooling. Furthermore, in this first one, most of the vote goes for left, while in the last one, the increment in turnout goes almost completely to outsider options, increasing the vote share by 1.44 percentage points significant at 1% level.

In light of these results, there is one key question worth mentioning in regard to outsider voting. As was previously seen, the results presented in this section show that the increase in vote share shown in Table 3 is driven by districts in urban areas, with higher dependence on agricultural activities, higher prevalence of poverty, and lower educational levels. Thus, the "punishment vote" comes from the most vulnerable sectors, which at the same time are also the most exposed to the effects of climate shocks (IPCC, 2023). This evidence also confirms the importance of social determinants in modeling voting patterns in contexts of climatic disturbances.

5 Conclusion

Given the projections from the Intergovernmental Panel on Climate Change (IPCC, 2023) regarding a significant rise in annual global maximum temperatures, it becomes urgent to comprehend the implications of climate change on various aspects of human life, including political processes. This study is part of a very incipient literature that attempts to understand how exposure to warmer temperatures influences citizens' decisions and attitudes toward democracy in developing countries. Mainly, I focus the analysis on national and local elections in Chile because of their vulnerability to weather changes and the political dynamics observed since democracy's return in 1989.

Using data from 1988 to 2021, I employ a nonlinear empirical approach to understand the complex interaction between climate variability and electoral behavior. The results suggest that, while no significant changes in voting patterns are observed for national elections, in local elections, an additional average heat degree day the year before the election significantly increases voter turnout by 2.47 percentage points, which accounts for approximately a quarter of the turnout standard deviation in local races. In addition, cumulative exposure to warmer temperatures increases the vote for traditional left-wing parties and outsider candidates by 1.21 and 1.24 percentage points, respectively.

I argue that the increase in voter turnout and left-wing votes is consistent with a mechanism of changing perceptions about climate change. According to this, experiencing climate change shocks and their consequences leads to greater civic engagement and support for sustainability policies, which are more common in left-wing speech. To validate this argument, I show that the effect on political patterns becomes greater and more significant in the late years of the panel. In those years, temperature rises have been accompanied by a major spread of climate change discourse. As the left-wing and outsiders get nearly equal distribution of votes for new entries in local elections, I explain that the increase in the support for outsiders responds to a weak version of retrospective theory in which the negative shocks related to warmer temperatures induce new voters to punish traditional coalitions by supporting outsider options. From a heterogeneity analysis, I find that in populations with the least adaptive capacities, new entry votes go, in most cases, to support outsiders, i.e., the "punishment vote" comes from the population most vulnerable to climate shocks. While in counties with better capacities (less agricultural economic dependency, urban, less poverty incidence, and more educated population) the new votes go predominantly to the candidates who belong to traditional left parties. These results are consistent with recent investigations of sociodemographic characteristics' relation to pro-climate beliefs, behaviors, and policy preferences.

The evidence presented in this work has provided valuable insights into the effects of cumulated exposure to warmer temperatures on electoral behavior in a democratic context in the developing world. However, it is crucial to address the limitations of this work to shed some light on future research.

Firstly, although the meteorological data used here represent accurate ground-level measurements and provide complete spatial coverage, the meteorological data set only covers the area of continental Chile. Furthermore, during the development of this work, CR2MET has added information on minimum temperatures. In this case, extending the original research question to evaluate the effects on electoral behavior in the presence of lower minimum and higher maximum temperatures would be beneficial. Second, in terms of political data, it would be beneficial for future research to use a finer classification of parties according to their level of support for pro-environmental policies. This could be achieved through the application of word recognition methods in the party's statement of principles or through the analysis of congressional votes on environmental laws. Additionally, the interpretation of the mechanisms is also constrained by the lack of data, which precludes the possibility of testing for changes in the perception of climate change.

In addition to acknowledging the limitations of the data, it is also necessary to discuss some limitations of this work's methodology. For example, I discard using an alternative approach to reveal nonlinear effects through a nonparametric model because it is very programming-demanding, considering the length of the period studied. Although employing bins to estimate the effects directly allows a more flexible way to estimate the effects of temperature, it requires that high-resolution data be aggregated after the bin construction, which is not possible in my case. Finally, another potential limitation is the debate surrounding the ability of panel estimates to provide insight into the economic impacts of climate change when short average periods (e.g., annual) are employed. In the long and medium term, agent adaptation or uncertainty about the intensity of future weather disruptions may play a role in the causal inference. Despite employing an empirical framework that appears to effectively simulate climate change—a stochastic series of yearly disturbances exhibiting an upward trend—forthcoming research could potentially enhance understanding by employing longer-term averages to analyze the intricate interplay between climate change and political dynamics.

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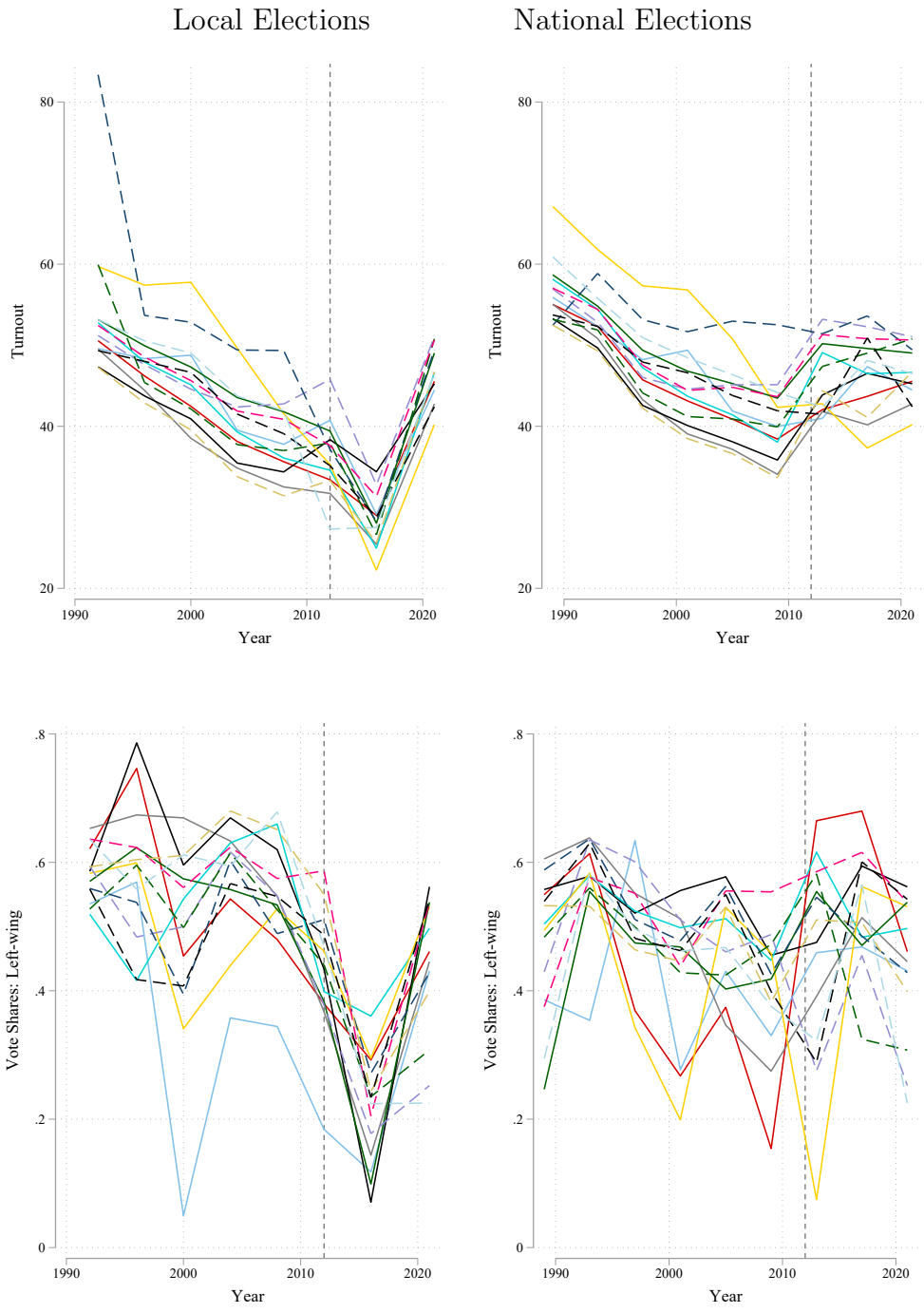
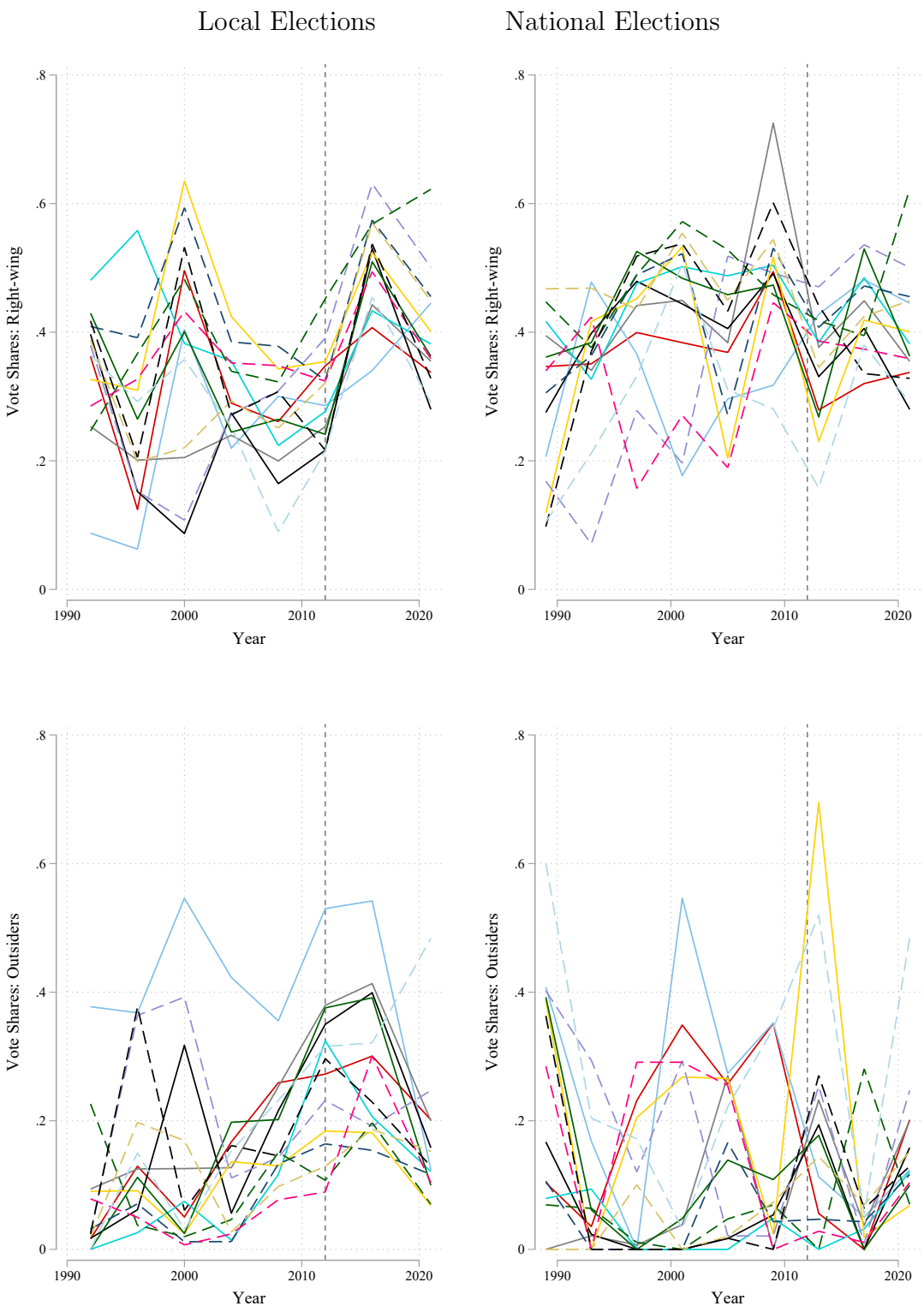
Appendix

A. Summary Statistics

Fig. 1.A: Political Outcomes



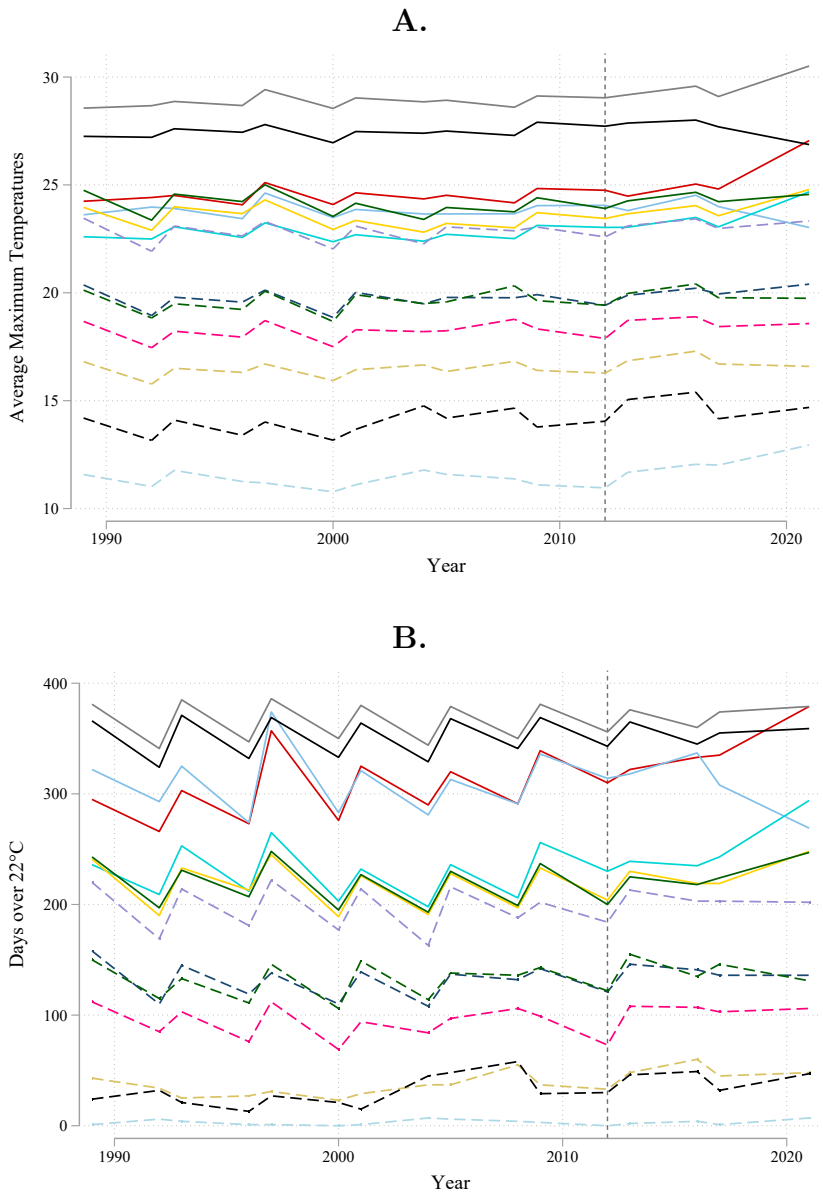


Notes: Evolution of political variables through the years in capital regions in local and national elections

Table 1.A Descriptive weather data

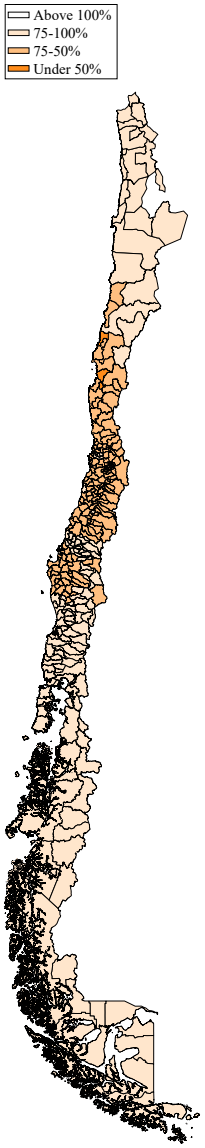
	Maximum temperature in C°		Accumulated precipitation in lts/m^2	
	(One year prior to election)		(One year prior to election)	
Year	Mean	Std. Dev	Mean	Std. Dev
1989	22.12	3.28	948.18816	821.67541
1992	21.31	3.42	1331.6302	912.1408
1993	21.90	3.42	1222.8779	1047.0656
1996	21.93	3.46	799.19751	723.61232
1997	22.19	3.43	1491.9204	883.62717
2000	21.23	3.40	1226.0775	793.41064
2001	21.76	3.37	1258.0656	882.78776
2004	21.61	3.07	1104.4057	922.95448
2005	21.63	3.29	1259.7202	898.37603
2008	21.94	3.05	1126.6485	840.04918
2009	21.84	3.42	1075.7552	923.95701
2012	21.63	3.33	862.28137	758.92194
2013	21.97	3.27	945.766	884.78561
2016	22.41	3.17	817.95913	529.83644
2017	21.89	3.34	1173.8129	959.8284
2021	22.43	3.76	624.32627	463.99577

Fig. 2.A: Heterogeneity in temperature among counties



Notes: Trends of maximum daily temperatures in capital regions. Panel A shows the changes in the Celsius degrees relative to 22 °C. Panel B shows heterogeneity in the number of days over the mean temperature. The application of voluntary voting is indicated by the dashed line.

Fig. 3.A: Rate of Precipitation among 1989-2021



Note: Rate of precipitation shows the change in average accumulated rainfall between two periods: before 2000 and after 2010.

B. Regressions

Table 1.B: Controlling by zone temperature trends

	(1)	(2)	(3)	(4)
VARIABLES	Turnout	Vote share: left-wing	Vote share: right-wing	Vote share: independents
HDD Local	2.505***	1.301**	0.210	1.012*
	(0.782)	(0.594)	(0.421)	(0.554)
HDD National	0.110	-1.306	1.383	0.002
	(0.764)	(0.736)	(0.868)	(0.806)
Observations	5,248	5,248	5,248	5,248
Adj. R-squared	0.710	0.620	0.595	0.397

Notes: Standard errors (in parentheses) are clustered at the constituency level. Stars indicate statistical significance $*p \leq 0.10$, $**p \leq 0.05$, $***p \leq 0.01$. Local HDD is the proportion of days above the threshold temperature (22°C), with each day weighted by its temperature difference from the threshold averaged over the year before election day. The term Local HDD corresponds to the effect of the HDD term in equation (5). All specifications include fixed effects by county, year, and their interactions with the type of election indicator, and zone trends and control for a second-order polynomial of one period of cumulative rainfall, as well with their interacted terms.l.

Table 2.B: Effects by of temperature on political outcomes by periods

	Before 2004	After 2004	Before 2004	After 2004	Before 2004	After 2004	Before 2004	After 2004
	Turnout	Turnout	Vote share: Left-wing	Vote share: Left-wing	Vote share: Right-wing	Vote share: Right-wing	Vote share: Outsiders	Vote share: Outsiders
β_{HDD}	0.332	2.563***	-0.180	0.287	-0.866	-2.995***	1.045	2.708***
	(0.510)	(0.829)	(1.211)	(0.840)	(1.107)	(0.705)	(1.415)	(0.722)
γ_{HDD}	-0.270	0.175	0.141	-0.319	0.175	0.963**	-0.316	-0.644
	(0.252)	(0.259)	(0.778)	(0.410)	(0.769)	(0.461)	(0.850)	(0.543)
Observations	2,624	2,624	2,624	2,624	2,624	2,624	2,624	2,624
R-squared	0.890	0.686	0.528	0.691	0.557	0.697	0.382	0.525

Notes: β_{HDD} is the proportion of days above the threshold temperature (22 °C), with each day multiplied by its temperature difference from the threshold averaged over the year before election day. γ_{HDD} corresponds to the effect of the HDD term in equation (5). All specifications include county-type of election and year-type of election fixed effects. Standard errors (in parentheses) are clustered at the constituency level. Stars indicate statistical significance $*p \leq 0.10$, $**p \leq 0.05$, $***p \leq 0.01$.