How bad weather excludes marginal voters from turning out for election

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Abstract
Ostensibly random and trivial experiences of everyday life such as those related to local weather can have significant political effects. In the context of elections, there is conflicting evidence about whether bad weather decreases voter turnout by raising the cost of going to the polls. We provide new evidence by utilizing individual-level time series of validated voting behavior for a complete electorate merged with fine-grained meteorological observations. Bad weather does in fact reduce turnout by 1.1 percentage points per centimeter of rainfall. Importantly, marginal voters – specifically young voters (except for the youngest) – are up to five times more susceptible to the negative shocks caused by bad weather, but their turnout rate is also positively affected by nice weather (sunshine) on Election Day. These results suggest that bad weather can exacerbate inequalities in democratic participation by pushing low-propensity voters to abstain. The policy implication is that efforts to include marginal voters in the democratic process should be intensified at elections with poor weather – or possibly even be moved to another time of the year where the likelihood of pleasant Election Day weather is higher.

Keywords: electoral turnout, individual voter panel, weather, climate, marginal voter, cost of voting, participation.

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Introduction

More intense and frequent bad weather is one important way that global climate change directly and tangibly interferes in politics. Bad weather can depress voter turnout and with more extreme weather events happening in the future, we will likely see increasing influence from the weather on Election Day. The basic mechanism behind the negative effect of bad weather on turnout is simple and well-known – it increases the cost of voting, thus decreasing the net individual benefit of voting (Downs 1957, Riker & Ordeshook 1968). As the weather largely is exogenous to human actions, when measured objectively, experiences with poor Election Day weather provides an optimal way of testing the causal effect of increased voting costs on turnout in a very concrete sense. Multiple studies have confirmed that bad weather, particularly rainfall, depresses turnout in different electoral contexts around the globe. Nevertheless, there are some notable exceptions, e.g., a non-finding in Sweden (Persson et al. 2014) and a small positive effect of bad weather in Norway (Lind 2019). Through different literature databases, we have located 30 studies of the weather-turnout effect conducted across high and low salience elections, at different points in time, and with quite different research designs and data.[1] In Table 1, we present a meta-analysis of these 30 studies along with key study characteristics. On average, rainfall depresses turnout by -0.76 percentage points per centimeter of rainfall (-0.30 per inch) with estimates ranging between -3.17 and 0.003.

[1] We have primarily searched *Web of Science* and *Google Scholar* as well as *Google* to locate the 30 studies (completed August 2021). With a few exceptions, we have allowed one effect size estimate per research article in the meta-analysis. The exception is studies that apply multiple data sets or designs (e.g., Knack 1994, Persson et al. 2014, Shachar & Nalebuff 1999). We also include studies that revisit previously published data, e.g., the Gomez et al. (2007) data set, and only apply modifications in design and estimation approach.

Table 1: Meta-analysis of 28 studies of the effect of rainfall on voter turnout

Source	Country	Election(s)	Study level	Rain-turnout effect (%-points per cm)
Merrifield (1993)	US	General (1982)	Aggregate (state)	-2.36***
Knack (1994), I	US	Presidential (1984-1988)	Individual	No effect
Knack (1994), II	US	House (1986)	Individual	No effect
Shachar & Nalebuff (1999), I	US	Presidential (1948-1988)	Aggregate (state)	-1.37***
Shachar & Nalebuff (1999), II	US	Presidential (1948-1988)	Aggregate (state)	-3.17***
Gatrell & Bierly (2002)	US (Kentucky)	Presidential, state, gubernatorial (1990-2000)	Aggregate (county)	IC (claims negative effect)
Lakhdar & Dubois (2006)	France	Parliamentary (1986-2002)	Aggregate (département)	-1.50*
Gomez et al. (2007)	US	Presidential (1948-2000)	Aggregate (county)	-0.33**
Fraga & Hersh (2010)	US	Presidential (1948-2000)	Aggregate (county)	-0.26**
Eisinga et al. (2012)	The Netherlands	Parliamentary (1971-2010)	Aggregate (municipality)	-0.41***
Steinbrecher (2013)	Germany	Parliamentary (1994-2009)	Individual	No effect
Artés (2014)	Spain	Parliamentary (1986-2011)	Aggregate (municipality)	-0.53**
Lo Prete & Revelli (2014)	Italy	Multiple (2001-2010)	Aggregate (city)	IC (positive effect of rainfall dummy)
Persson et al. (2014), I	Sweden	Parliamentary (1976-2000)	Aggregate (municipality)	No effect
Persson et al. (2014), II	Sweden	Parliamentary (1991-2006)	Individual	No effect
Persson et al. (2014), III	Sweden	Parliamentary (2002-2010)	Individual	No effect
Sforza (2014)	Italy	Parliamentary (2008-2013)	Aggregate (municipality)	IC (negative effect of rainfall dummy)
Arnold & Freier (2016)	Germany (North-Rhine Westphalia)	Municipal and state (1975-2010)	Aggregate (municipality)	-1.20***
Fujiwara et al. (2016)	US	Presidential (1952-2012)	Aggregate (county)	-0.55**
Chen (2017)	Taiwan	Parliamentary (1998-2012)	Aggregate (county)	-1.59**
Cooperman (2017)	US	Presidential (1948-2000)	Aggregate (county)	No effect
Horiuchi & Kang (2017)	US	Presidential (1948-2000)	Aggregate (county)	-0.44**
Lee & Hwang (2017)	South Korea	Parliamentary and municipal (1995-1999)	Aggregate (municipality)	-2.17*
Arnold (2018)	Germany (Bavaria)	Municipal (1946-2009)	Aggregate (municipality)	-1.00***
Stockemer & Wigginton (2018)	Canada	Parliamentary (2004-2015)	Aggregate (districts)	-1.13***
Kang (2019)	South Korea	Parliamentary (2000-2012)	Aggregate (districts)	IC (negative effect of rainfall dummy)
Meier et al. (2019)	Switzerland	Direct democratic votes (1958-2014)	Aggregate (municipality)	IC (negative effect of heavy rain dummy)
Rudolph (2019)	UK	Brexit referendum (2016)	Aggregate (districts)	-0.59**
Garcia-Rodriguez & Redmond (2020)	Ireland	Parliamentary (1989-2016)	Aggregate (constituency)	-0.51**
Lind (2020)	Norway	Municipal (1972-2010)	Aggregate (municipality)	0.003***
			Average	-0.76
			Median	-0.51
			Range	[-3.17, 0.003]
			N	30 (25)

Notes: *p<0.1;**p<0.05;***p<0.01. IC = incalculable. All effect sizes are recalculated to centimeters. In IV-studies that use rainfall as an instrument, we only report the first-stage effect of rainfall on turnout. Because rainfall by far is the most dominant weather variable in the literature, we exclude any other weather effects from the overview. Studies that report non-significant effects are included in the average as 0.00. The effective N is 25 (five studies using rainfall dummies are excluded). Studies are sorted by year of publication (oldest first) and first author. See appendix for more details.

The most pronounced effect is found in research designs applied to an aggregate level, e.g., municipality or constituency, whereas rainfall effect estimates apparently tend to be non-significant when individual-level data and designs are used. There is no pattern across the studies when it comes to high versus low salience elections nor between electoral systems, as would have been expected from institutional theories of turnout. For example, the norm of voting as a citizen's duty should arguably be higher in high salience elections and in proportional electoral systems where all votes count, thus reducing the expected weather effect in such contexts (Blais 2000).

The research designs of turnout-weather studies have evolved tremendously over the past decades. They have progressed from aggregate studies, often based on self-reported data from turnout-surveys, to validated individual-level registry-based voter records – and to directly matching individuals with objective weather observations from the nearest weather station(s). We take our starting point in the latter approach and, additionally, use a panel setup with measurements across multiple elections – a superior approach to answering the question of how *individuals* decide (not) to turn out for election as a function of weather experiences. High-quality large-N data and an individual-level panel design also gives us a highly reliable measure of turnout, validated with actual voter files, thus allowing us to not just revisit the weather-turnout thesis, but contribute with much stronger evidence of the causal effects of weather on turnout.

Understanding the drivers of voter turnout is important because it is the key health indicator of modern democracy. If poor weather depresses turnout, this makes it indirectly associated with weakened democratic legitimacy (Lijphart 1997, Beetham 1991). Perhaps even more importantly, bad weather potentially increases inequalities in electoral participation because obstacles to turn out affect marginal voter more than core voters (Gomez et al. 2007, Bhatti et al. 2020). Whereas core voters with a strong sense of civic duty are immune to the costs associated with bad weather, marginal voter groups may be highly susceptible (Knack 1994).

Our approach to investigating the weather-turnout effect is novel in several ways. First, our study is the first to make use of validated turnout data at the individual level with repeated measurements of an (almost) complete electorate.

Secondly, these data enable us to employ individual-level panel models with two waves, which rules out certain types of omitted variable bias – itself a significant contribution to the literature.

Thirdly, previous work has focused almost exclusively on rainfall with the occasional addition of another weather variable, e.g., temperature (Gatrell & Bierly 2002, Stockemer & Wigginton 2018). However, poor and pleasant weather are compound phenomena determined not just by precipitation, but also temperatures, sunshine and cloud cover, humidity, wind speed, etc. Previous models of weather effects are therefore essentially underspecified. We take a first step toward a more comprehensive approach by simultaneously investigating the effects of rainfall, sunshine (solar irradiation), and temperature, which also makes it possible to explore if nice weather affects turnout positively.

Fourthly, we investigate how obstacles to voting affects participation among marginal voters to a higher degree than core voters, which is a question with major democratic implications.

Finally, the context is new both meteorologically and as an electoral setting. The media often make anecdotal references to the association between turnout and weather, but this relationship has yet to be critically examined in the Danish case. In fact, researchers have not found evidence of a negative bad weather effect in any of the Nordic countries so far (Bengtsson et al. 2014). Like the four other Nordic countries, Denmark has a highly cooperative multiparty system with automatic voter registration and a high average local election turnout around 70 percent (Hansen 2021). The country is highly geographically homogeneous: Small and flat with a temperate, predominantly coastal climate (see Figure 2).

We find that rainfall does have a negative effect on turnout. On average, the probability of turning out for election decreases by 1.1 percentage point when rainfall increases by 1 centimeter (0.43 inches). We also find positive turnout effects of nice weather, i.e., higher levels of sunshine and warmer temperatures. Both rainfall and temperature have non-linear effects on turnout – small amounts of rainfall does not make much difference on turnout, whereas heavy rain does and (November) temperatures near the freezing point have a significant effect, but it diminishes as temperatures become warmer and more pleasant. Young, potentially marginal voters are affected up to five times more by rainfall, but they are also attracted more to the polling station by nice weather.

Theory – how bad weather increases the cost of voting

A growing body of research has shown how the weather affects political opinions and behavior in a multitude of ways, through both dramatic extreme weather events and more subtle variations in personal weather experiences. For instance, individuals make use of the seasonality or normality of recent temperatures as a heuristic when forming and expressing their opinions on climate change and experiences of flooding events directly strengthens perceptions and concern of climate change (Damsbo-Svendsen 2020, Howe et al. 2019, Ogunbode 2020, Rüttenauer 2021). The effects of weather on turnout is thus another prime example of how the weather, increasingly as a consequence of global climate change, interferes directly in politics.

The intuitive mechanism of how bad weather depresses turnout is simply that it increases the cost of voting in a very tangible way. In bad weather, getting to and from the polling place and standing in line outside is unpleasant and involves more logistic considerations. Indirectly, campaigners also experience a higher cost of canvassing in bad weather, which can dampen their level of activity and reduce mobilization effects (e.g., Gomez et al. 2007, Eisinga et al. 2012). In addition, bad weather can induce a bad mood or even a state of light depression, which might also be part of the explanation of why both potential voters (Howarth & Hoffmann 1984, Meier et al. 2019) and campaigners are more like to stay at home during bad weather rather than participating in the election (Lamare 2013).

There is another side to this argument, which is rarely explored. What if the weather can not only be an obstacle to turnout, but nice weather actually is conducive to voting because it makes voting a more pleasant experience that also involves fewer costs? The limited research on positive weather effects suggests that more pleasant and warmer weather can in fact boost turnout rates (e.g., Lakhdar & Dubois 2006, Eisinga et al. 2012, Assche 2017). However, it has not yet been explored if nice weather increases turnout by a magnitude comparable to the depression caused by bad weather. Another important question requiring attention is if weather-turnout effects are linear. Does a centimeter of rain mean the same on an otherwise dry Election Day as it does when the election is soaking in heavy rain? Merrifield et al. (1993) found no evidence of non-linearity whereas Meier et al. (2019) more recently did.

We draw on Fowler's understanding of marginal voters as "*those whose decisions to turn out* [for election] *are sensitive to exogenous factors*" (2015: 205), i.e., citizens without a robust preexisting voting habit. In other words, the term refers to potential voters who, for various reasons, are at risk of being excluded from election if they experience significant external constraints and costs related to the act of voting. Young voters are typically marginal voters in this sense because they have not yet had the opportunity to establish a habit of voting (Bhatti et al. 2012, 2016). We expect weather effects, negative and positive, to exhibit a stronger causal influence on marginal voters, including young voters who are the empirical focus of this paper, but also, e.g., voters who live alone and are therefore disinclined to take part in voting as a social activity, which significantly increases the probability of voting

(Dahlgaard et al. 2021). This expected heterogeneity is the key to understanding the major implications poor Election Day weather can have for democratic representation. Put simply, the worse the weather is – the more extreme, in other words – the more the election will be suffering from electoral inequalities.

Research Design: Panel fixed effect models of individual turnout and local weather

Research on the influence of bad weather on electoral turnout has been carried out in different contexts with mixed results (see Table 1). We approach the question through the case of municipal elections in Denmark. Danish local elections take place every four years in all 98 municipalities simultaneously. They are proportional elections of the municipal councilors, who subsequently elect the mayor from among their midst. Danish municipalities administrate most of the large universal welfare state including schools, kindergartens, eldercare, local roads, and public transportation. The salience of the local elections is comparatively high with an average turnout of 70% over the last 50 years, yet there is still significant variation within individuals and across groups, which enables us to explore the weather effect on turnout (see Hansen 2021 for detailed turnout statistics). Voters are automatically included in voter files and all receive a polling card by mail prior to the election. Most vote in person (94.5% in 2017) while the remainder uses the absentee option. The high in-person voting rate allows for a reliable measure of individually experienced weather on Election Day. The local elections always take place on the third Tuesday of November, an often wet and windy month, which holds constant various seasonality and election type effects and makes a good case for exploring the effect of bad weather on turnout.

Voter turnout

Voter turnout is collected and validated for (almost) all voters eligible in the 2013 and 2017 local elections in Denmark.[2] We only use records for voters who voted on Election Day or abstained, thus excluding early voting (~3% of potential voters in the data set). This yields a binary outcome variable indicating voting on Election Day (1) or abstention (0). We restrict

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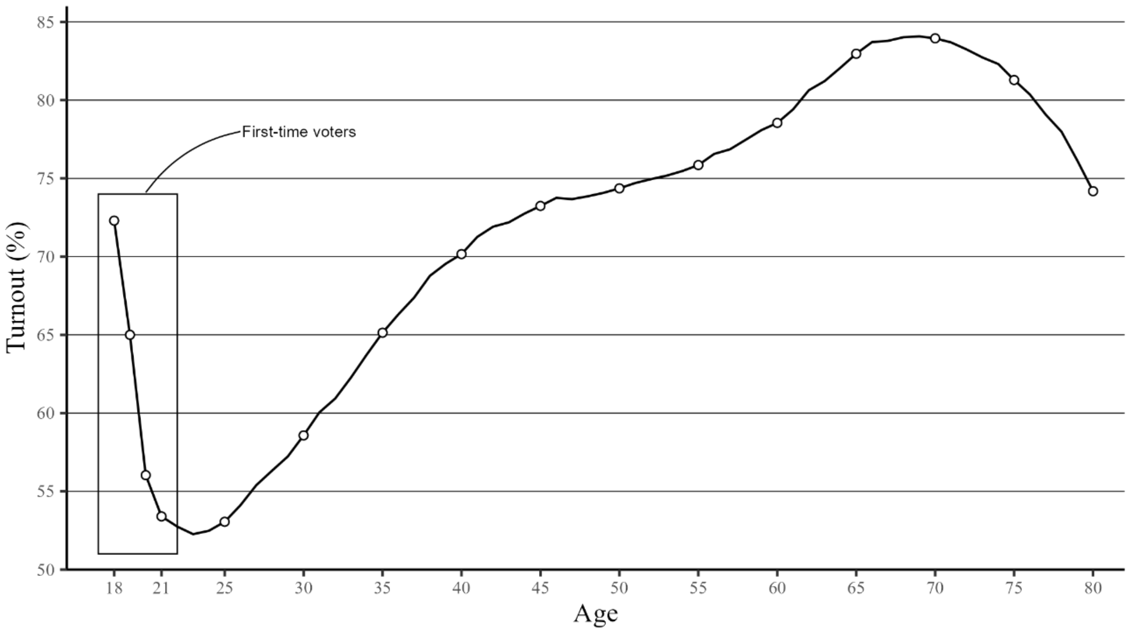
[2] Collection of voting record are based on administrative data from the voting system (voter lists) administrated by each municipality. At the 2013 local election, all municipalities took part in collecting voting records and we managed to collect validated records for 98.9% of eligible voters (the negligible data loss is due to system failure and administrative mistakes). At the 2017 local election, we managed to collect validated records for 91.3% of eligible voters. Seven municipalities found it too time consuming and decided not to participate. Crucially, there is no individual selection into the collection of voting records, which means that they are representative of the whole country (see Bhatti et al. 2014, Hansen 2017 for details on the voter lists).

our data set to voters of age 80 or younger because of significant selection among the elderly in who uses early mail-in voting, who stays sufficiently healthy to participate, and because of significant reductions in observations at older ages. We acknowledge the normative issues with such a step and encourage other researchers to tailor turnout studies to elderly voter groups (see Bhatti & Hansen 2012b).

Out of the 4,459,145 eligible in-person voters of age 18-80, 3,306,504 (~73%) were eligible at both elections and thus appear twice in our panel. The voter data includes residential address coordinates, municipality, gender, and age. We add a few key time-varying municipality-level control variables: Closeness of the election, i.e. vote share difference between the largest party and the runner-up (Fraga & Hersh 2020, Knack 1994), population size (natural log), and share of non-Western immigrants. The two latter factors, in particular, are important determinants of turnout at Danish local elections (Bhatti & Hansen 2019).

One of the most established descriptive findings from these turnout records, replicated in other Nordic countries and the US, is the "rollercoaster" relationship between age and turnout as illustrated in Figure 1 (Bhatti et al. 2012c). The key point is that the youngest voters (18-20 years), who often still live with their parents, have substantially higher turnout rates than their slightly older peers do. From the early twenties onwards, turnout grows until after age 70 where voters retire from voting (Bhatti 2012a, b, Hansen 2020).

Figure 1: The rollercoaster ride of turnout and age



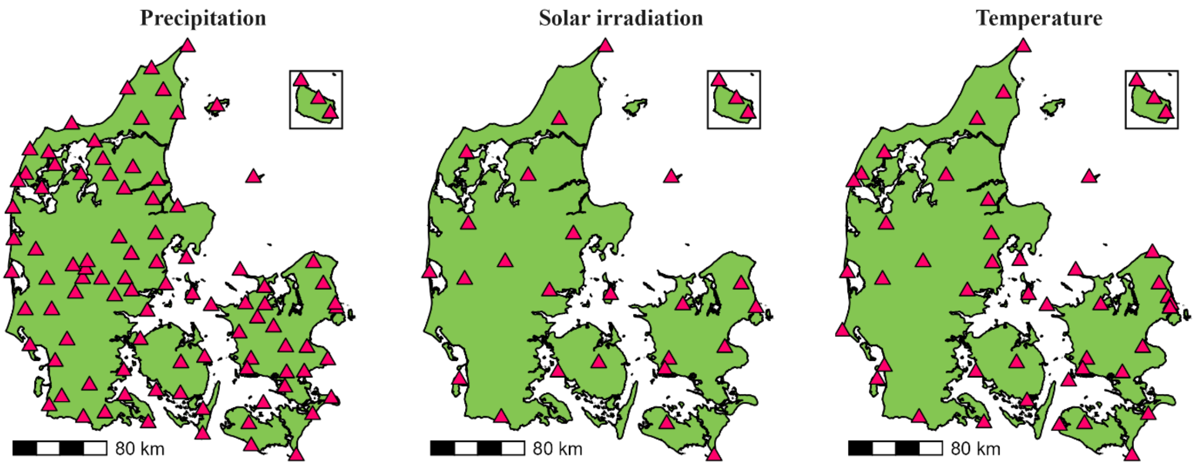
Note: Descriptive turnout rates by voter age on Election Day binned in years (18-80) and pooled across the 2013 and 2017 elections. N=7,855,649.

Weather treatments

The area of Denmark proper is 42,933 km^2 (16,577 square miles) – larger than Switzerland but smaller than Costa Rica, larger than Maryland but smaller than West Virginia. There are no mountains (the highest point is 171 meter above sea level) and the entire country shares a homogeneous temperate coastal climate (Danish Ministry of Energy, Utilities, and Climate 2017). Weather observations are collected from the Danish Meteorological Institute (DMI) through the novel publicly accessible C*limate Data* API (DMI 2021), which provides detailed weather observations validated by meteorologists. Observations are recorded for 95, 26, and 45 weather stations for precipitation, solar irradiance, and temperature, respectively (see geographical distribution in Figure 2). Three stations only active at one election were excluded.

Rainfall is measured as accumulated precipitation (mm), *sunshine* as average solar irradiation (W/m^2), and *temperature* as average degrees Celsius. We refer to solar irradiation as sunshine, however it also captures the sun's capacity to radiate though the cloud cover in the absence of visual sunshine. Aggregate Election Day weather is calculated as the accumulated sum for rainfall and simple averages for sunshine and temperature based on hourly observations until 8pm when the polling stations close.

Figure 2: Locations of 166 weather stations in Denmark by type



Matching weather observations to voters

For each voter, election date, and weather variable, we triangulate local weather from the three nearest weather stations and compute an inverse-distance weighted average value based on the following formula:

$$Local\ weather_v = \frac{\sum_i^3 \left(\frac{Observation_i}{Distance_i}\right)}{\sum_i^3 \left(\frac{1}{Distance_i}\right)},$$

where *i* indicates the weather station (from nearest to third nearest) and *v* indicates the voter (or voter-date for voters who move addresses). This implies that voters are assigned their own unique value based on the geographical coordinates of their residential address. If, for example, a voter lives 3, 10, and 20 km from weather stations measuring 0, 5, and 10 mm rainfall, the weighted average assigned to him or her is 2.07 mm. Compared to just matching voters to the nearest station, this considerably increases the validity of weather measures, especially for individuals living relatively far from the nearest weather station, and it furthermore increases variation in the weather treatments. The average distance between voters and the nearest weather station is short – 10.2 km (rainfall), 17.0 km (sunshine), and 13.4 km (temperature).

Table 2: Descriptive weather statistics

	Full data set		2013 Election		2017 Election	
Weather variable	Mean (SD)	Min – Max	Mean (SD)	Min – Max	Mean (SD)	Min – Max
Acc. rainfall (mm)	1.2 (1.5)	0.0 – 9.4	2.3 (1.5)	0.1 – 8.5	0.1 (0.4)	0.0 – 9.4
Avg. sunshine (W/m^2)	19.5 (6.4)	6.2 – 42.8	15.2 (5.0)	6.2 – 35.7	24.1 (4.1)	24.8 – 42.8
Avg. temperature (℃)	4.3 (2.2)	-0.4 – 7.8	6.2 (0.4)	5.2 – 7.8	2.3 (1.3)	-0.4 – 5.4

Source: DMI (2021). Measured at the level of individual voters. N=7,855,649.

Estimation strategy and models

We follow two estimation strategies. First, we pool all potential voters and regress Election Day voting on local weather (rainfall, sunshine, and temperature) with fixed effects for election and municipality to account for general differences between the two elections and spatial and institutional patterns in voting behavior and weather. The estimated effects have a causal interpretation to the extent that weather experiences are allocated as-if randomly within municipalities, which we think is a reasonably plausible assumption in small, flat, and temperate Denmark, except perhaps in a few extreme cases, e.g., along the West Coast.

Our second, more sophisticated estimation strategy is an individual-level panel design with two-way fixed effect for individual and election as well as municipality fixed effects. With this setup, weather effects are estimated within each individual (and municipality) over time, which importantly eliminates any omitted variable bias from factors that are invariant over time or between individuals, for instance stable factors such as gender, key personality traits, and previous voting behavior. In a study that spans just four years, controlled time-invariant factors also include climate change per se, i.e., changes in normal weather. Another question is if a centimeter of rain means the same thing everywhere in the country. It could be argued that people are more accustomed to and prepared for bad weather in some places, however any resulting differences would be marginal in this highly homogeneous climate. Importantly, the otherwise superior individual panel model is effectively based on only the approximately 73 percent of voters observed at both elections, i.e., the balanced portion of the panel, and thus effectively excludes voters who turned 18 after the 2013 election or turned 80 or died before the 2017 election. This is the price of the reduction in omitted variable bias gained from applying individual fixed effects. Conversely, the pooled model – the first strategy – includes all eligible voters in the data set, but with a higher risk of bias. We use linear probability models (OLS) but provide the same specifications as logistic regression models in the appendix.

Results

This section presents the results of our analysis of the relationship between Election Day weather (rainfall, sunshine, and average temperatures), on the one hand, and individual voting behavior, on the other hand. After investigating the weather-turnout thesis at a general level, we provide evidence that the rainfall and temperature effects are non-linear and we show how young voters are much more susceptible to weather effects, negative and positive, than more mature voters.

Table 3 presents our two main model – the pooled model and the panel model, which applies individual fixed effects on top of election and municipality fixed effects. The panel model is methodologically superior for identifying causal weather effects because it eliminates bias from time-invariant and unit-invariant factors, i.e., voter characteristics that are constant between the two elections, for instance voting habits, age, gender and most personal predispositions. The pooled model, i.e., with only election and municipality fixed effects, should yield similar results to the extent that individuals are exposed to certain weather in an as-if random fashion within each municipality and on a particular date.

As expected, the effect of rainfall on probability of voting is negative and statistically significant in both models. This means that voters are in fact deterred from voting when it rains more. Specifically, based on the panel model, each centimeter (10 mm) of rainfall – a fairly strong treatment in this context – reduces the probability of voting by 1.1 percentage points. In comparison, recall that the average effect based on the 30 rainfall-voting studies in the meta-analysis was -0.76. Our effect size estimate of -1.10 is thus higher than the average, but still sits nicely near the middle of the range ([-3.17, 0.003]) found in the existing literature (see Table 1).

Table 3: Voting and Election Day Weather

	Pooled model without voter FEs	**Panel model with voter FEs**
	Voting on Election Day	
	(1)	(2)
	OLS	OLS
Rainfall (mm)	-0.0024***	-0.0011***
	(0.0002)	(0.0002)
Sunshine (W/m^2)	0.0009***	0.0003***
	(0.0001)	(0.0001)
Temperature (Celsius)	-0.0002	0.0025***
	(0.0003)	(0.0003)
Voter FEs		+
Election FEs	+	+
Municipality FEs	+	+
Additional controls	+	+
N observations	7,855,649	7,855,649
N unique voters	4,549,145	4,549,145

Note: Additional controls include age, age^2, age^3, ln(population), non-western immigrant population share, closeness of the election, and (only in the pooled model) gender. Heteroscedastic-robust SEs in parentheses. ***p<0.001; **p<0.01; *p<0.05

Sunshine also affects voting propensity – positively – even after controlling for rainfall and temperature, of which it is a natural correlate.[3] A change from the lowest to the highest level of November sunshine recorded at the two elections (6.2-42.8 W/m^2) increases the probability of voting by 1.0 percentage points according to the panel model. Conversely, this also means that "bad weather" in the shape of a widespread or thick cloud cover permitting less solar irradiation reduces voter turnout. The fact that sunshine affects voting behavior after controlling for rainfall supports the notion that weather-turnout effects are not only about rain-induced costs and inconveniences, but also about whether the voting act is a nice experience. It is not clear yet, however, if the positive sunshine effect mostly reflects that brighter weather makes certain activities practically possible and more enjoyable, e.g., in relation to

[3] Since rainfall, solar irradiation, and temperatures are inherently correlated, this could raise suspicions of potential multicollinearity issues. More substantially, one could argue that it rarely rains when the sun is shining, for instance. However, this is mostly true at extreme values of the weather variables, i.e., well outside the actual observed range on the days studied here. Thus, bivariate weather correlations are weak to moderate – ranging from 0.00 (rainfall and sunshine in 2013) to -0.44 (sunshine and temperature in 2013) – mostly because the weather measures are aggregated for the Election Day as a whole. See Pearson's r weather correlations and separate models with the same general results in the appendix.

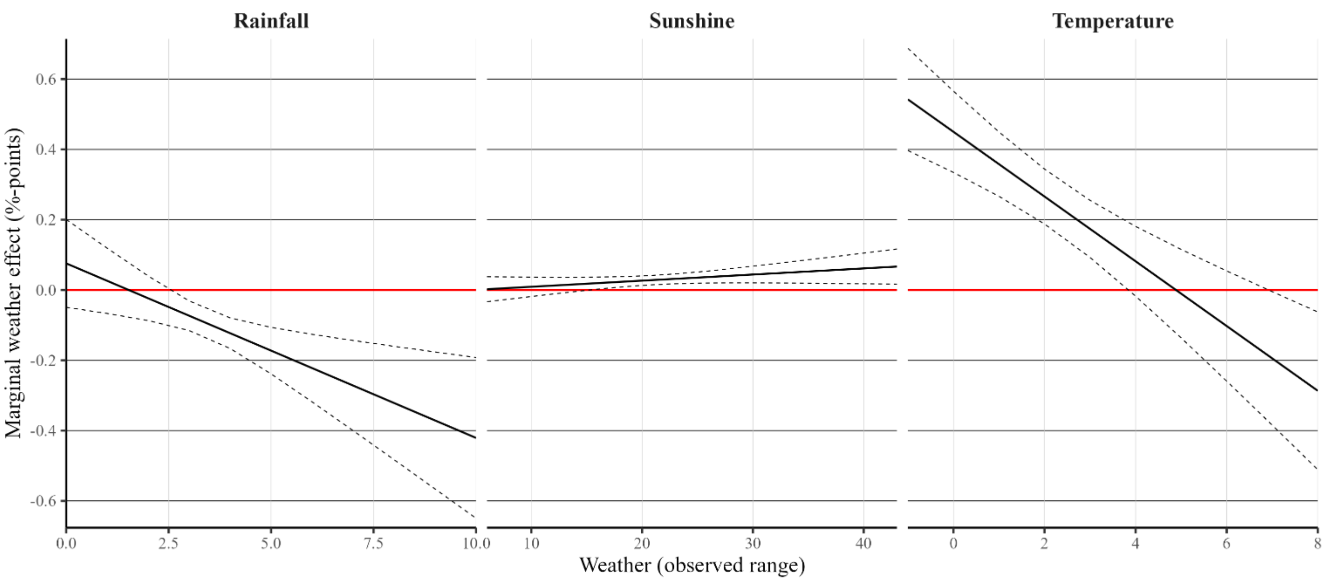
transportation to and from the polling place, or rather because of its psychological effects, e.g., on the mood.

For average temperatures, the picture is more mixed. According to the panel model, the partial effect of temperature is such that an increase of from the lowest to the highest observed Election Day temperature (-0.4-7.8 ℃) increases the probability of voting by a substantial 2.0 percentage points, however the pooled model does not support this conclusion.

Do weather effects depend on already experienced rainfall and temperatures?

The strength of weather effects on turnout possibly depend on the baseline weather. In other words, weather effects may be non-linear. For example, the next millimeter of rain could have very different implications depending on the amount of rain that has already fallen. We test the proposition that weather effects are non-linear by adding squared rainfall, sunshine, and temperature terms to the panel model. The marginal effects depending on each weather variable's baseline are shown in Figure 3.

Figure 3: Evidence of non-linear weather effects on voter turnout



Note: These marginal effect estimates are computed from the panel OLS model with both first-order and second-order weather terms added (see regression table in appendix). Marginal effects are presented for the full range of observed weather. 95% CIs (heteroscedastic-robust SEs).

Whereas the sunshine effect is linear (the quadratic term is statistically insignificant), the rainfall and temperature effects are clearly non-linear with statistically significant squared terms (Rainfall^2: -0.0002**; Temperature^2: -0.0005***). In the corner case of no rainfall, at the outset of the graph, an additional millimeter of rain or a small extra dose of sunshine does not affect voting behavior (p>0.1). The temperature effect, in contrast, is strong close to the freezing point (zero degrees) where a one-degree temperature on average would raises the probability of voting by 0.5 percentage points.

As Figure 3 shows, the rainfall effect kicks in after around 2.5 millimeters of rain, where it is likely to be noticed and to have real consequences for human activity and planning. The strongest marginal rainfall effect, at the maximum observed baseline precipitation of one centimeter (10 mm), is around -0.4 percentage points, i.e., 4 percentage points per centimeter. The partial temperature effect disappears when the temperature moves comfortably far away from the freezing point (beyond approximately four degrees), and it even shows signs of reversing to negative, possibly reflecting a reconfiguration of opportunity costs (Kang 2019).[4]

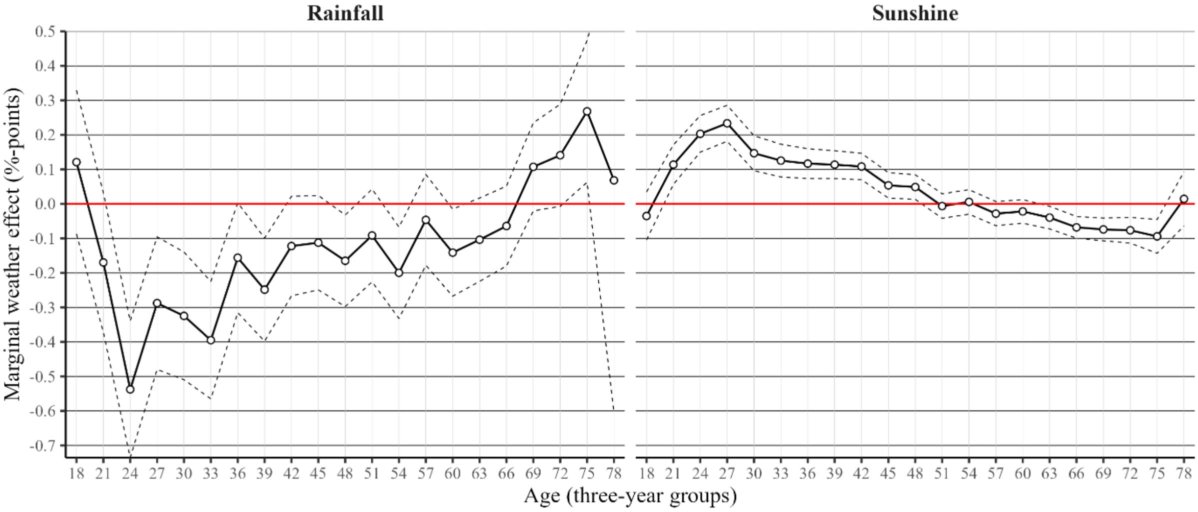
Heterogeneous weather effects and marginal voters

It is of pivotal interest if the increased cost of voting caused by bad weather exacerbates inequalities in turnout. If it does, the implications are major – for electoral outcomes and representation and, ultimately, for the legitimacy of democracy. Thus, we hypothesize that marginal voters are more susceptible to detrimental weather effects on their voting behavior – and likely also to the positive effects of nice weather. Specifically, we test age as a possible moderator of the influence of weather on the decision to vote modelled at the level of the individual. We focus on young voters because they have yet to establish a robust voting habit and routine and, consequently, might more readily be swayed by the perceived costs and benefits of the voting act, which among other factors depends on Election Day weather.

For the investigation of heterogeneous effects, we introduce interaction terms for weather-age in the panel model. We bin age in 20 three-year groups from 18 to 80 and treat it as a categorical variable to allow flexibility in the relationship between weather, turnout, and age (see Figure 4).

[4] Note that the same figure based on the simpler pooled model, presented in the appendix, shows the same non-linear pattern for the rainfall effect, only significantly stronger, whereas there is no clear moderation pattern for temperature.

Figure 4: The marginal effects of rainfall and sunshine conditional on age



Note: The graphs show marginal weather effects computed for each three-year age group between age 18 and 80. Estimates are based on the panel OLS model with interactions added between each weather variable (rainfall, sunshine, temperature) and age, i.e., an extension to Table 3, model 2. The temperature graph and similar graphs for the pooled model can be found in the appendix. The model includes the same control variables as reported in Table 3. 95% CIs with heteroscedastic-robust SEs.

Figure 4 shows how the partial effects of rainfall and sunshine are strongly moderated by voter age. The negative rainfall effect is very strong on young voters, especially around age 24-35, and gradually wanes and disappears for more mature voters. Strikingly, the effect is non-existent for the youngest first-time voters of age 18-20, who typically still live at home with their parents – a finding that perfectly mirrors the actual turnout rates depicted in Figure 1. The strongest marginal rainfall effect is -5.4 percentage points per cm for age 24-26 – a five times stronger effect than the average effect (see Table 3).[5]

Election Day sunshine shows the same pattern, i.e., a relatively strong effect on voters in their twenties followed by a gradual tapering off. Again, turnout in the youngest age group is unaffected, also by nice weather, whereas their slightly older peers, who have typically left their childhood home, are more susceptible to nice weather than the rest of the electorate.

In sum, the analysis strongly supports the hypothesis that marginal voters are more susceptible to exogenous changes to the costs and benefits of voting. Young voters, one known marginal voter group, are deterred from voting due to bad weather to a much larger degree than more mature voters are. But they are also drawn to the polls by the positive effect of nice weather to a higher degree, which shows the weather-voting effect is not merely

[5] When the graphs are drawn based on the pooled model (see appendix), which allows estimation that is effectively based on the complete data set, the same general patterns emerge, albeit more distinctly and with much larger effect size estimates. The strongest marginal rainfall effect, found for age 21-23, is an astronomical -14.4 percentage points per cm – or six times higher than the average effect in the pooled model.

negative, related to obstacles, costs, and inconvenience, but has a positive counterpart in nice weather, which makes voting a more pleasant and appealing activity. The implication is that how the weather on Election Day turns out potentially induces representational inequalities into the Election not just because of geography (if it rains in only one region of the country, fewer voters will turn out for election there), but crucially also between marginal voter groups and core voters.

Robustness checks

In the appendix, we report additional evidence and several robustness checks in support of the conclusions. First, we show that effect estimates are similar, generally just slightly higher, when only one weather variable is included in the panel model at a time, i.e., when we do not parse out the partial weather effects (see Table 4 in appendix). Secondly, we have argued that weather experiences tend to be distributed in an as-if random fashion, but we have nevertheless used a number of (time-variant) control variables to bolster the foundation for causal inference. We should be able to get similar results with fewer control variables. Table 5 in the appendix shows our main models with municipality-level controls removed and with all controls removed (except fixed effects). Effect sizes vary, but the general conclusion is the same for rainfall and sunshine (the temperature effect is less stable, which is also reflected in Table 3). Finally, we have reported heteroscedastic-robust standard errors throughout the article, although these may yield overly liberal statistical inferences as they do not take into account spatial dependence in the error terms. The typical remedy, cluster-robust standard errors, is not a feasible option because our panels are not nested within meaningful clusters due to the fact that voters move addresses (across households, polling places, municipalities, etc.). In the appendix, we instead provide support for our inferences by restricting our data in a way that allows the use of clustered standard errors. First, we restrict the data to individuals voting at the same polling place at both elections and cluster standard errors on – or around – polling stations. Secondly, we restrict the data to voters who remain within the same 1 km hexagon grid cell and compute standard errors clustered on grid cell. With these two restricted (and possibly biased) data sets, we get larger – cluster-robust – standard errors (and slightly different coefficients), but the main conclusions still retain strong support.[6]

[6] We also believe that using a different measurement window for the aggregation of Election Day weather treatments, e.g., 18, 24, or 30 hours, would produce similar effect estimates. Furthermore, a placebo test using mock weather observations from, e.g., a week before or after the elections should result in null findings. Both shall be reported in a future version of the paper.

Conclusion and discussion

The effects of weather on electoral turnout is an appealing illustration of the cost of voting theory. Bad weather on Election Day increases the cost of voting and we therefore would expect to see turnout declining as a consequence of rainfall. Despite conflicting conclusions, this is also the conclusion in our meta-analysis of 30 existing weather-turnout studies, which revealed that turnout is reduced by an average of -0.76 percentage points per centimeter of rainfall. However, this average effect is driven by the numerous studies that use aggregate research designs and the individual-level studies surprisingly yield insignificant results. To solve this puzzle, we have presented the first study of high-quality, validated individual-level turnout records for an entire electorate measured at two elections. With these data, we show that bad weather does indeed depress turnout. Specifically, each centimeter of rainfall, a fairly substantial amount, reduces the probability of voting by -1.1 percentage points. The rainfall effect is substantial and comparable, for example, to the effect of Get-Out-The-Vote campaigns, however the difference in turnout between a dry and wet election would still be smaller than, for instance, the difference between average turnout among women and men at the same elections (Hansen 2020).

We also find that higher levels of sunshine – more pleasant Election Day weather, in other words – significantly increases the probability of voting. Both findings correspond with the logic of the cost of voting. Bad weather increases the cost associated with transportation to and from the polling place, standing in line, etc., while pleasant weather reduces these same costs and makes the voting activity more appealing.

The effects of rainfall are non-linear, another finding that has not previously been demonstrated clearly. The negative influence that rainfall has on turnout increases at higher levels of already experienced rainfall, whereas the first few millimeters are inconsequential. This suggests that as we expect more extreme weather in the future due to a global heating, including more cloudbursts, we should expect to see participation in democratic elections severely affected by the weather.

We also find substantially stronger effect on young marginal voters who have typically left their childhood home recently and have not yet established a robust voting habit. The marginal negative turnout effect of rainfall on young voters in their mid-twenties is estimated at -5.4 percentage points per centimeter of rain, a five times stronger response than that of the average voter. A full centimeter of local rainfall on Election Day is a fairly uncommon event and, hence, a quite strong treatment, but a response of up to more than five percentage points in predicted turnout among the youngest voters is nevertheless remarkable.

This heterogeneity in susceptibility to the weather suggests that bad weather on Election Day increases the turnout gap between high and low propensity voters, between core and marginal voters, thus increasing inequalities in electoral participation and, in turn, democratic representation. If we look at the weather in Denmark over the last 30 years, we would, on average, expect 0.78 millimeter less rain on Election Day – and more sunshine as well – if the local elections were held in April (the driest month) instead of November. In fact, we predict that moving the elections to April would increase turnout among young voters by more than four percentage points, which is an impact well above most Get-Out-The-Vote campaigns, thus improving electoral equality.

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How bad weather excludes marginal voters from turning out for election

Appendix: Supplementary material

October 2021

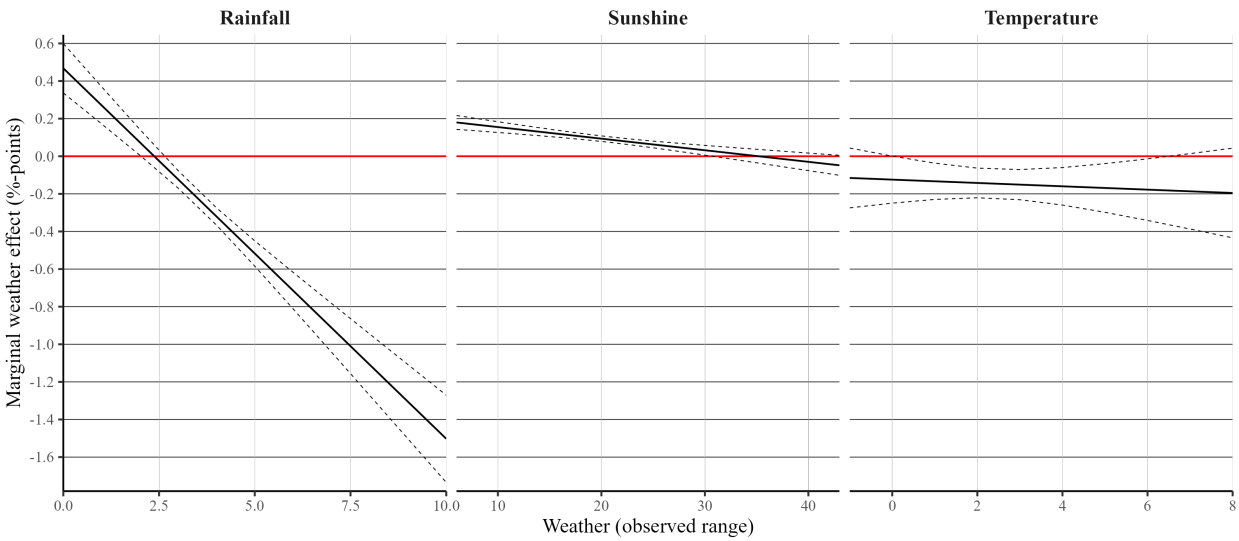

Figure 1: Marginal weather effects from non-linear OLS model. Estimates come from a pooled OLS model with rainfall, sunshine, and temperature as well as their squared terms, i.e., the same as Figure 3 in the article, but based on the pooled model instead of the panel model. 95% CIs (heteroscedastic-robust SEs).

Table 1: Pairwise correlations between weather variables.

Election	Parameter A	Parameter B	Pearson's r	P	N
2013	Radiation	Temperature	-0.44	0.00***	4,062,555
2017	Radiation	Temperature	-0.38	0.00***	3,793,094
2013	Precipitation	Temperature	0.31	0.00***	4,062,555
2017	Precipitation	Radiation	-0.22	0.00***	3,793,094
2017	Precipitation	Temperature	0.10	0.00***	3,793,094
2013	Precipitation	Radiation	0.00	0.00***	4,062,555

Note: Sorted from strongest to weakest correlation.

Table 2: Main models as logistic regressions

	Pooled model	Panel model
Rainfall	-0.0122***	-0.0210***
	(0.0011)	(0.0038)
Sunshine	0.0050***	0.0078***
	(0.0004)	(0.0014)
Temperature	-0.0004	0.0486***
	(0.0017)	(0.0056)
N	7,855,649	1,351,690
SEs	Robust	Robust
Election FE	X	X
Municipality FE	X	X
Voter FE		X

Note: The models are the same as in Table 3 of the manuscript estimated as logistic regression instead of OLS. Coefficients are log-odds. Models include controls for age, age squared, age cubed, ln(population), non-western immigrant population share, and closeness of the election. The pooled model furthermore control for (invariant) gender. ***p<0.001; **p<0.01; *p<0.05 with heteroscedastic-robust SEs (in parentheses).

Table 3: Non-linear regression model

	Non-Linear Weather Effects	
	Pooled model (OLS)	Panel model (OLS)
Rainfall	0.0047***	0.0008
	(0.0007)	(0.0006)
Sunshine	0.0022***	-0.0001
	(0.0003)	(0.0002)
Temperature	-0.0012	0.0045***
	(0.0006)	(0.0006)
Rainfall^2	-0.0010***	-0.0002**
	(0.0001)	(0.0001)
Sunshine^2	0.0000***	0.0000
	(0.0000)	(0.0000)
Temperature^2	0.0000	-0.0005***
	(0.0001)	(0.0001)
N	7,855,649	7,855,649
SEs	Robust	Robust
Election FE	X	X
Municipality FE	X	X
Voter FE		X

Note: First-order terms are to be interpreted as the marginal effect when the variable is held at zero. Models include controls for age, age squared, age cubed, ln(population), non-western immigrant population share, and closeness of the election. The pooled model furthermore control for (invariant) gender. ***p<0.001; **p<0.01; *p<0.05 with heteroscedastic-robust SEs (in parentheses).

Table 4: Main OLS regression Models with one weather variable at a time

	Rainfall		Sunshine		Temperature	
	Pooled	Panel	Pooled	Panel	Pooled	Panel
Rainfall	-0.0028***	-0.0018***				
	(0.0002)	(0.0002)				
Sunshine			0.0010***	0.0005***		
			(0.0001)	(0.0001)		
Temperature					0.0017***	0.0033***
					(0.0003)	(0.0003)
N	7,855,649	7,855,649	7,855,649	7,855,649	7,855,649	7,855,649
SEs	Robust	Robust	Robust	Robust	Robust	Robust
Election FE	X	X	X	X	X	X
Municipality FE	X	X	X	X	X	X
Voter FE		X		X		X

Note: All models include controls for age, age squared, age cubed, ln(population), non-western immigrant population share, and closeness of the election. Pooled models furthermore control for (invariant) gender. ***p<0.001; **p<0.01; *p<0.05 with heteroscedastic-robust SEs (in parentheses).

Table 5: Main OLS regression models with fewer control variables

	Pooled model (OLS)		Panel model (OLS)	
	No municipality controls	No controls	No municipality controls	No controls
Rainfall	-0.0018***	-0.0017***	-0.0010***	-0.0011***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Sunshine	0.0014***	0.0012***	0.0005***	0.0008***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Temperature	-0.0010***	-0.0002	0.0016***	0.0004
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
N	7,855,649	7,855,649	7,855,649	7,855,649
SEs	Robust	Robust	Robust	Robust
Election FE	X	X	X	X
Municipality FE	X	X	X	X
Voter FE			X	X
Individual controls	X		X	
Municipality controls				

Note: Individual-level controls are age, age squared, age cubed, and, in the pooled model, gender. Municipality-level controls are ln(population), non-western immigrant population share, and closeness of the election. ***p<0.001; **p<0.01; *p<0.05 with heteroscedastic-robust SEs (in parentheses).

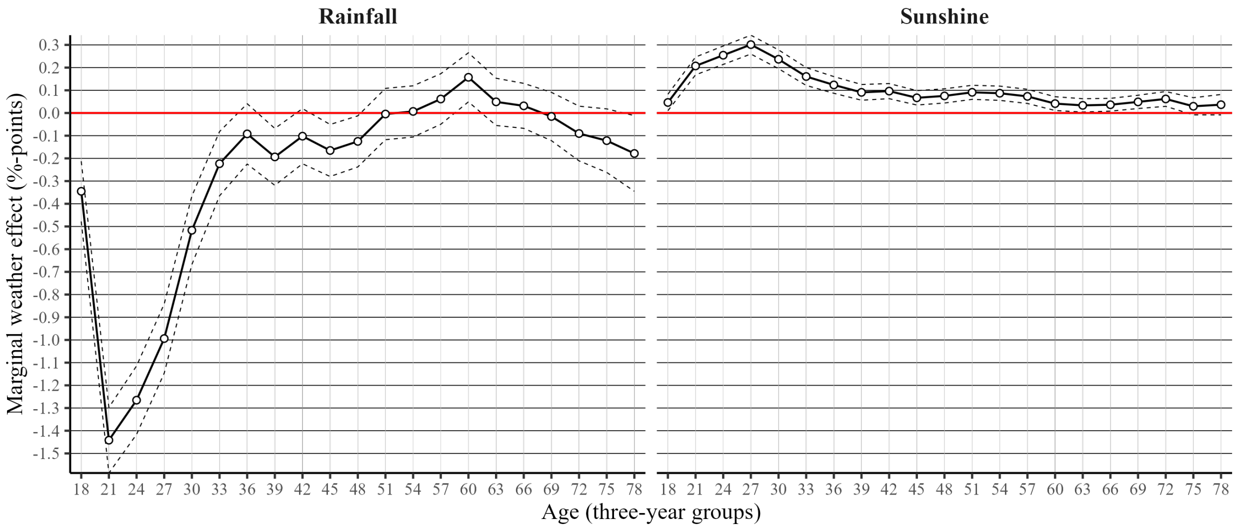

Figure 2: Marginal weather effects from interaction between age (three-year intervals) and rainfall, sunshine, and temperature, respectively. Estimates from pooled OLS model, i.e., the same as Figure 4 in article, but based on the pooled model instead of the panel model. 95% CIs (heteroscedastic-robust SEs).

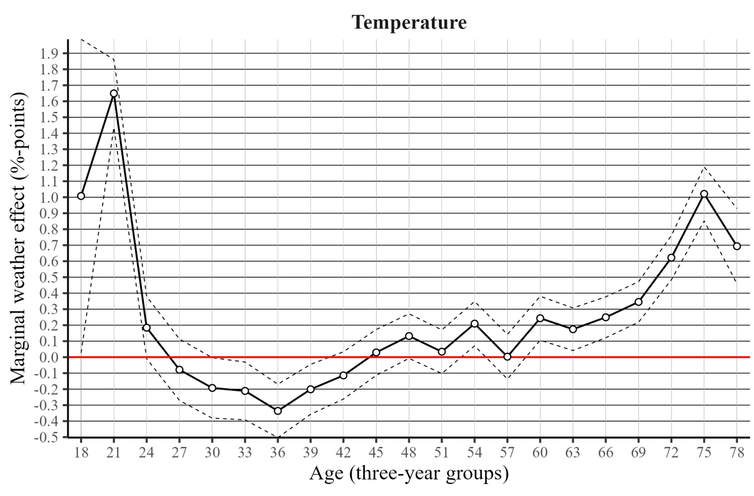

Figure 3: Marginal temperature effect from interaction between age (three-year intervals) and temperature. Estimates come from the panel OLS model with all three weather variables (see Figure 4 in article). 95% CIs (heteroscedastic-robust SEs).

Table 6: Main OLS regression models with clustered SEs and correspondingly restricted sample

	SEs clustered on polling place		SEs clustered on 1 km grid cells	
	Pooled model (OLS)	Panel model (OLS)	Pooled model (OLS)	Panel model (OLS)
Rainfall	-0.0024**	-0.0012**	-0.0026***	-0.0014***
	(0.0008)	(0.0004)	(0.0006)	(0.0003)
Sunshine	0.0009***	0.0002.	0.0008***	0.0003*
	(0.0002)	(0.0001)	(0.0002)	(0.0001)
Temperature	-0.0013	0.0020***	-0.0013	0.0016***
	(0.0015)	(0.0005)	(0.0010)	(0.0005)
N	6,009,615	6,009,615	5,738,959	5,738,959
SEs	Cluster-robust	Cluster-robust	Cluster-robust	Cluster-robust
Election FE	X	X	X	X
Municipality FE	X	X	X	X
Voter FE		X		X

Note: For this robustness check, the data set is restricted to individuals who remain associated with the same (1-2) polling place or (3-4) reside within the same 1 km hexagon grid cell between the elections in order to ensure that the panels are nested within clusters. Individual-level controls are age, age squared, age cubed, and, in the pooled models, gender. Municipality-level controls are ln(population), non-western immigrant population share, and closeness of the election. ***p<0.001; **p<0.01; *p<0.05; .p<0.1 with cluster-robust SEs (in parantethes) clustered on polling place and 1 km grid cells, respectively.

Appendix – continued…

Table 7: Meta-analysis of 30 studies on the effect of rain on turnout – additional information about designs

Source	Country	Election	Time frame	Design details	Effect of rain on turnout
Merrifield (1993)	United States	General election (off-year)	1982	State level, link to rain in state's largest city on Election day. Linear model with a range of state aggregated SES controls and institutional controls.	-2.36*** percentage points per centimeter rain.
Knack (1994)	United States	Presidential	1984, 1988	ANES (survey) combined with individual validated turnout link at country level to weather stations. Logit Maximum-Likelihood. Linear model with a range of individual SES and institutional controls.	Not significant.
Knack (1994)	United States	House	1986	*See above*	Not significant.
Shachar & Nalebuff (1999)	United States	Presidential	1948-1988	State level, link to state weather. Linear model with a few state aggregated SES controls and institutional controls. Most important closeness of the race.	-1.37*** percentage points per centimeter rain.
Shachar & Nalebuff (1999)	United States	Presidential	1948-1988	State level, link to state weather. Structural equations model with a few state aggregated SES controls and institutional controls. Most important closeness of the race.	-3.17*** percentage points per centimeter rain.
Gatrell & Bierly (2002)	United States (Kentucky)	Presidential, Governor, State Legislature	1990-2000	County level, linked to weather stations in the country. Linear OLS model with a elections, year, and country fixed effects as indirect control for SES. Control for race competitiveness, urban/rural, and temperature.	Not possible to calculate, but claims a negative significant effect of rain on turnout.
Lakhdar & Dubois (2006)	France	Parliament (first round)	1986, 1988, 1993, 1997, 2002	Country level (departments), linked to weather stations. Linear auxiliary regressions adjusted for rain trends and average weather. Controls for unemployment and temperature at country level. Fixed effects for country.	-1.5* percentage point per centimeter rain.
Gomez et al. (2007)	United States	Presidential	1948-2000	Counties level, link to weather stations to country. Linear model with a range of aggregated country SES and institutional controls. Use relative rainfall, lagged country turnout, year and election dummies. Maximum-Likelihood Random Effects linear model.	-0.33** percentage points per centimeter rain.
Fraga & Hersh (2010)	United States	Presidential	1948-2000	Counties level, link to weather stations to country. Linear model with a range of aggregated country SES and institutional controls (incl. average weather). Lagged country turnout, year and election dummies. Matching	-0.26** percentage points per centimeter rain. Stronger in uncompetitive states compared to competitive state, where is there is a

				applied (CEM) between control- and treatment group	slightly positive effect of rainfall.
Eisinga et al. (2012)	The Netherlands	Parliament	1971-2010	Municipality level, nearest weather station to municipal, linear model with a minimal of aggregated municipal SES controls. Fixed effect for municipality, Maximum likelihood hierarchical linear model	-0.41*** percentage points per centimeter rain.
Steinbrecher (2013)	Germany	Parliament	1994-2009	GNES (survey), individual (non-validated) turnout link to weather stations in their constituency. Logit model with few individual level SES controls and robust standard error by election.	Not significant.
Artés (2014)	Spain	Parliament	1986-2011	Municipality level, linked to weather stations to municipal, Linear model with a few aggregated municipality SES controls. Fixed effect for year. OLS with fixed effects (clustered standard error by municipality)	-0.53** percentage points per centimeter rain.
Lo Prete & Revelli	Italy	Multiple	2001-2010	Municipality level, IV study	Significant positive (first-stage) effect of dummy rainfall on turnout.
Persson et al. (2014)	Sweden	Parliament	1976-2000	Municipality level, linked to weather station to municipal, Linear model with a few aggregated municipality SES controls. Fixed effect for municipality. OLS with fixed effects (robust standard errors)	Not significant.
Persson et al. (2014)	Sweden	Parliament	1991 - 2006	SNES (survey), individual validated turnout link to weather stations. Range of register based SES controls. Linear multi-level models with year fixed effects.	Not significant.
Persson et al. (2014)	Sweden	Parliament	2002-2010	Register individual turnout (sample) linked to weather stations. Range of register based SES controls. Logit with year fixed effects and robust standard errors	Not significant.
Sforza (2014)	Italy	Parliament	2008, 2013	Municipality level for national elections. Linked to weather stations to each municipal. Linear OLS with set of municipality aggregated controls and regional fixed effects. Use dummy for rain on not.	Not possible to calculate, but the rain dummy variable show a negative significant effect of rain on turnout.
Arnold & Freier (2016)	Germany (North-Rhine Westphalia)	Municipalities and state	1975-2010	Municipality level, linked to weather stations to municipal, Linear model with a few aggregated municipality SES controls. Fixed effect for year and municipality. OLS with	-1.20*** percentage points per centimeter rain.

				fixed effects (robust standard errors)	
Fujiwara et al. (2016)	United States	Presidential	1952-2012	Country level, linked to weather stations. Linear model with a few of aggregated country SES. Country and year fixed effects. Adjust for trend in rainfall on the country level over time. Clustered standard error on the state level.	-0.55 ** percentage points per centimeter of rain.
Chen (2017)	Taiwan	Parliament	1998-2012	County level, linked to weather stations in the country. Linear model with a few aggregated county SES controls. Control for normal "weather" in country. Fixed effect for year. OLS with fixed effects (clustered standard error by county)	-1.59** percentage points per centimeter rain.
Cooperman (2017)	United States	Presidential	1948-2000	Counties level, link to weather stations to country. Linear model. Use standardized precipitation index that takes into account the clustered and historically nature and of weather across countries.	Not significant.
Horiuchi & Kang (2017)	United States	Presidential	1948-2000	Counties level, link to weather stations to country. Logit model with a range of aggregated country SES and institutional controls. Use relative rainfall, lagged country turnout, year and election dummies. Seemingly Unrelated Regressions (SUR) guarantee that party votes shares and abstainer sums to eligible voters. Logit model with bootstrapped coefficients.	-0.44** percentage points per centimeter rain.
Lee & Hwang (2017)	South Korea	Parliament and municipality	1995-1999	Municipality level, linked to weather stations to municipal, Linear model with a few aggregated municipality SES, seasonal, and institutional controls. OLS with robust standard errors.	-2.17* percentage points per centimeter of rain.
Arnold (2018)	Germany (Bavaria)	Municipalities (first-past-the-post system for mayor)	1946-2009	Municipality level, linked to weather station to municipal, Linear model with a few aggregated municipality SES controls. Fixed effect for municipality. OLS with fixed effects (robust standard errors)	-1.00*** percentage points per centimeter rain. Not significant in competitive races only.
Stockemer & Wigginton (2018)	Canada	Parliament	2004-2015	Electoral districts level linked to weather stations. OLS regression including Control for a few districts level aggregated SES, average temperature and closeness of the race. Fixed effect for district and year.	-1.13*** percentage points per centimeter rain.
Kang (2019)	South Korea	Parliament	2000, 2004,	Electoral districts level linked to weather stations. OLS regression including fixed effects for district	Not significant, but a negative significant

			2008, 2012	and year. Control for a few districts level aggregated SES and closeness of the race.	dummy variable for rain is reported.
Meier et al. (2019)	Switzerland	Direct democratic votes	1958-2014	Direct democratic votes on policy proposals, municipality-level, primary focus on rainfall and yes/no vote, proposal and municipality FEs	Significant negative dummy variable for rain is reported.
Rudolph (2019)	United Kingdom	Referendum (Brexit)	2016	Electoral districts level linked to weather stations. OLS regression including Control for a few districts level aggregated SES and share of Ukip.	-0.59** percentage points per centimeter rain.
Garcia-Rodriguez & Redmond (2020)	Ireland	Parliament (lower house)	1989-2016	Constituency level, link to weather stations to country. Linear model. Fixed effect for year. Rainfall weighted by constituency population. OLS interaction with fixed effects (clustered standard error by constituency). Range of SES used as controls.	-0.51** percentage points per centimeter rain.
Lind (2020)	Norway	Municipal	1972-2010	Municipality level, linked to weather stations to municipal, Linear model with an aggregated municipality SES controls, spatio-temporal trends, and average September rainfall. Fixed effect for municipality and year. OLS with fixed effects (clustered standard error by municipality, region, and year)	0.00339*** percentage points per centimeter rain.
Average					-0.76
Median					-0.51
Min					-3.17
Max					0.003
N (effective)					30 (25)

Notes: *p<0.1, **p<0.05, ***p<0.01. All results recalculated to centimeters. In studies that employ an instrumental variable approach, we only report the result of the first stage, i.e., the effect of rainfall on turnout. Because rainfall is the most dominant weather variable by far, we exclude other weather variables from this overview even when they are used. Studies that report non-significant effects are included in the average as 0.00. The effective N is 25 (five studies that use rainfall dummies are excluded). The studies are sorted by year of publication (oldest first) and, secondarily, first author.