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Rainfall, Agricultural Output and Persistent Democratization

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We examine the effect of rainfall on agricultural output and democratization in the world's most agricultural countries. As in the agricultural economics literature, we find that the relationship between rainfall and agricultural output has an inverted U-shape, as agriculture is harmed by both droughts and very wet conditions. We also find the effect of rainfall on agricultural output to be transitory. The relationship between rainfall and democratization is U-shaped in the short run, and this effect persists in the long run. Hence democratic transitions outlast the (transitory) rainfall shocks that started the democratization process. The U-shaped relationship between rainfall and democratization is consistent with rainfall affecting democratization through its (inverted-U-shaped) effect on agricultural output.

INTRODUCTION

We examine the effect of rainfall on agricultural output and democratization in the world's most agricultural countries. We focus on these countries as the vast majority were ruled by non-democratic regimes before 1950, but today nearly half of them are democratic. Moreover, the large economic weight of agriculture in these countries makes rainfall a source of exogenous, and potentially transitory, variation in agricultural output over time. Hence the world's most agricultural countries since 1950 are a logical time and place to examine the effect of shocks to rainfall and agricultural output on democratic transitions.

The effect of economic shocks on democratization is discussed by Haggard and Kaufman (1995), Geddes (1999), Acemoglu and Robinson (2006), Burke and Leigh (2010), Brückner and Ciccone (2011), Caselli and Tesei (2016), and Dorsch and Maarek (2020). We contribute by examining whether economic shocks can result in *persistent* democratization even when shocks are transitory. Put differently, our analysis focuses on the question of whether democratic transitions outlast the economic shocks that triggered the democratization process. More broadly, we also contribute to the literature on the economic determinants of democratization (e.g. Przeworski and Limongi 1997; Barro 1999; Acemoglu *et al*. 2008; Aidt and Franck 2015; Aidt and Leon 2016) and on whether political institutions are shaped permanently by random events at critical junctures (e.g. Lipset 1959; Mahoney 2001; Capoccia and Kelemen 2007; Acemoglu and Robinson 2012; Benati and Guerriero 2021).

The two main theories of democratization that we draw on are Acemoglu and Robinson (2001, 2006) and Besley and Persson (2019). Both theories imply that transitory shocks can start a process leading to permanent democratization depending on certain predetermined factors. The constellations of predetermined factors where this is a possibility can be thought of as *democratic tipping points* and our analysis can be seen as checking on the existence of such tipping points.

We start by examining the effect of rainfall on agricultural output since 1961 (the start date of the agricultural output dataset) in the world's most agricultural countries. This group is defined as countries with agricultural GDP shares in the top quintile of the distribution, or equivalently, as countries with agricultural GDP shares above the Sub-Saharan African median. We choose this cut-off as it is used in the analysis by Brückner and Ciccone (2011) of the effect of rainfall on short-run democratization in Sub-Saharan Africa since 1980. (We also examine the persistence of democratization for this group of countries and time period.) As in the agricultural economics literature, we find that the relationship between rainfall and agricultural output has an inverted U-shape as agricultural output is harmed by both droughts and very wet conditions (e.g. Schlenker and Lobell 2010; Lobell *et al.* 2011). We also find the effect of rainfall on agricultural output to be transitory.

We go on to examine the relationship between rainfall and democratization in the world's most agricultural countries since 1945 (different democratization datasets have different start and end dates). We find the relationship to be U-shaped in the short run. This relationship persists in the long run. The U-shaped relationship between rainfall and democratization is consistent with rainfall affecting democratization through its inverted-U-shaped effect on agricultural output. The U-shaped relationship between rainfall and democratization holds for all three of the main dichotomous political regime classifications that we use: the classification of Acemoglu *et al.* (2019), of Geddes *et al.* (2014), and of Przeworski *et al.* (2000) as updated by Cheibub *et al.* (2010) and Bjørnskov and Rode (2020). It also holds using the Polity Project polity score (Marshall *et al.* 2014), the Freedom House index of political rights (Freedom House 2014) and the recent dichotomous political regime classification of Gründler and Krieger (2021).

Two theories of political transitions that fit our empirical examination are Acemoglu and Robinson (2001, 2006) and Besley and Persson (2019). The main conclusion of both theories is that transitory shocks can trigger persistent democratization. In Acemoglu and Robinson (2001, 2006), countries are initially ruled by non-democratic regimes. The disenfranchised poor majority can contest the authoritarian rule. As the opportunity cost of doing so is lower following transitory negative economic shocks, such shocks may put the disenfranchised in a temporary position to demand democratization. As a result, transitory negative economic shocks can lead to democratization.[1] Democratization may be followed by non-democratic reversal or may be permanent, depending on the constellation of several factors—income inequality and the cost of coups, for example. We refer to the constellations of preconditions where a transitory economic shock would lead to persistent democratization as *democratic tipping points*. The persistence of democratization plays an important role in Acemoglu and Robinson's theory of political transitions. The disenfranchised poor could demand policy concessions rather than contest authoritarian rule. When they demand democratization, it is because democratization is more difficult to reverse. Put differently, the demand for democratization is based on the expectation that democratization will tend to persist beyond the transitory events that backed up democratization demands. In Besley and Persson (2019), there is also a conflict of interest over democratic institutions between a political elite and its opposition. But the political elite chooses whether to instal a democracy or an autocracy in each time period. A key factor for this decision is the proportion of individuals with democratic values who may fight for democracy against autocracy. This proportion evolves endogenously. The model gives rise to a complementarity between the number of individuals holding democratic values and democracy that can create persistent democratization following transitory shocks.

Our empirical work contributes to the literature on the economic determinants of democratization; see Przeworski and Limongi (1997), Barro (1999), Przeworski *et al.* (2000), Acemoglu *et al.* (2008), Brückner and Ciccone (2011), Aidt and Franck (2015), Aidt and Leon (2016), Caselli and Tesei (2016), Benati *et al.* (2019), Dorsch and Maarek (2020), and Benati and Guerriero (2021). Our work is most closely related to Brückner and Ciccone (2011). They examine whether adverse rainfall shocks opened a window of opportunity for democratization in Sub-Saharan Africa over the 25-year period from 1980 to 2004. Their main finding is that adverse rainfall shocks led to short-run democratic improvements in the group of 21 countries with agricultural GDP shares above the Sub-Saharan-African median, but not in the group of 20 countries with agricultural GDP shares below the median. With Brückner and Ciccone (2011), we have in common that we also examine the effect of rainfall shocks on democratization. There are four main differences. First, we examine whether democratization persists after the window of opportunity opened by adverse rainfall shocks has closed. Brückner and Ciccone (2011) examine solely the impact of rainfall shocks on short-run changes in democratic institutions.[2] Second, we build on the evidence in agricultural economics that the relationship between rainfall and agricultural output has an inverted U-shape, as agriculture is harmed by both droughts and very wet conditions. Brückner and Ciccone (2011) assume a monotonic effect of rainfall on output and on the probability of democratization in their empirical analysis. Specifically, they assume that output and the probability of democratization depend on the log-level of rainfall, which imposes monotonicity but allows for weaker marginal effects at higher levels of rainfall. In our Online Appendix we show that results using this specification point in the same direction as the quadratic specification on which we focus. Third, we look at the most agricultural countries in the world for the longest possible period since 1945, which results in a substantially larger and longer sample. Fourth, in addition to measuring democratization using the Polity Project combined polity score as in Brückner and Ciccone (2011), we incorporate the political regime classifications of Acemoglu *et al.* (2019) and Geddes *et al.* (2014), the revision by Bjørnskov and Rode (2020) of the original Przeworski *et al.* (2000) regime classification, and the Gründler and Krieger (2021) political regime classification obtained with machine learning.

Our work is also related to Acemoglu *et al.* (2008) and Benati and Guerriero (2021). With Acemoglu *et al.* (2008), we have in common that we examine the economic determinants of democratization over shorter and longer periods. The main difference is that we focus on democratization following transitory economic shocks, while Acemoglu *et al.* (2008) analyse the effect of more persistent changes in income.[3] With Benati and Guerriero (2021), we have in common that we look at long-run institutional change following weather shocks. Their evidence is for Bronze Age Mesopotamia, while we focus on the world's most agricultural countries after 1945.

The paper is structured as follows. Section I presents the data and the empirical specifications. Sections II and III discuss our empirical results and their robustness. Section IV concludes.

I. Data and Empirical Framework

Data

We measure agricultural output using the real crops production index from the United Nations Food and Agricultural Organization (FAOSTAT 2016). We employ this index to examine the effect of rainfall on agricultural output in countries grouped by their average share of agriculture in GDP. The data for agricultural GDP shares are from the World Development Indicators (World Bank 2016) and are available since 1970. Table 1

TABLE 1
AGRICULTURAL OUTPUT AND DEMOCRATIZATION DATA COVERAGE FOR THE WORLD'S MOST AGRICULTURAL COUNTRIES

	FAO real agricultural output		Acemoglu *et al.* (2019) political regime data		Przeworski *et al.* (2000) political regime data		Geddes *et al.* (2014) political regime data		Polity IV Project combined polity score		Freedom House index of political rights	
Country	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
Afghanistan	1961	2013	1960	2010	1946	2010	1950	2010	1946	2000	1972	2013
Albania	1961	2013	1960	2010	1946	2010	1950	2010	1946	2013	1972	2013
Bhutan	1971	2013	1971	2010					1971	2013	1972	2013
Burkina Faso	1961	2013	1961	2010	1961	2010	1961	2010	1961	2013	1972	2013
Burundi	1963	2013	1961	2010	1963	2010	1963	2010	1963	2013	1972	2013
Cambodia	1961	2013	1961	2010	1954	2010	1954	2010	1954	2013	1972	2013
Central African Republic	1961	2013	1961	2010	1961	2010	1961	2010	1961	2013	1972	2012
Chad	1961	2013	1961	2010	1961	2010	1961	2010	1961	2013	1972	2013
Comoros	1976	2013	1961	2010					1976	2013	1976	2013
Equatorial Guinea	1969	2013	1961	2010					1969	2013	1972	2013
Ethiopia	1993	2013	1961	2010	1946	2010	1950	2010	1946	2013	1972	2013
Ghana	1961	2013	1961	2010	1958	2010	1958	2010	1960	2013	1972	2013
Guinea-Bissau	1974	2013	1961	2010	1975	2010	1975	2010	1974	2013	1974	2013
Laos	1961	2013	1961	2010	1954	2010	1954	2010	1954	2013	1973	2013
Liberia	1961	2013	1961	2010	1946	2010	1950	2010	1946	2013	1972	2013
Madagascar	1961	2013	1961	2010	1961	2010	1961	2010	1961	2013	1972	2013
Malawi	1965	2013	1961	2010	1965	2010	1965	2010	1965	2013	1972	2013
Mali	1961	2013	1961	2010	1961	2010	1961	2010	1961	2013	1972	2013
Mauritania	1961	2013	1961	2010	1961	2010	1961	2010	1961	2013	1972	2013
Mozambique	1976	2013	1961	2010	1976	2010	1976	2010	1976	2013	1976	2013
Myanmar (Burma)	1961	2013	1961	2010	1949	2010	1950	2010	1949	2013	1972	2013
Nepal	1961	2013	1961	2010	1946	2010	1950	2010	1946	2013	1972	2013
Niger	1961	2013	1961	2010	1961	2010	1961	2010	1961	2013	1972	2013
Papua New Guinea	1976	2013	1961	2010					1976	2013	1976	2013
Rwanda	1963	2013	1961	2010	1963	2010	1963	2010	1963	2013	1972	2013
Sierra Leone	1962	2013	1961	2010	1962	2010	1962	2010	1962	2013	1972	2013
Solomon Islands	1979	2013	1961	2010					1979	2013	1979	2013
Somalia	1961	2013	1961	2010	1961	1991	1961	1991	1961	2013	1972	2013
Sudan	1961	2010	1961	2010	1957	2010	1957	2010	1957	2010	1972	2010
Togo	1961	2013	1961	2010	1961	2010	1961	2010	1961	2013	1972	2013
Uganda	1963	2013	1961	2010	1963	2010	1963	2010	1963	2013	1972	2013
Vietnam	1977	2013	1961	2010					1977	2013		

Notes
The table shows the data coverage for countries with agricultural GDP shares in the top quintile of the 1970–2013 distribution. Start and end years indicate the first and the last years of observation, respectively, and omitted years indicate that data were not available for that particular country. Real agricultural output is measured by the real crops production index from the United Nations Food and Agricultural Organization (FAO).

contains the start and end dates of the real crops production index for countries with 1970–2013 agricultural GDP shares above the Sub-Saharan-African median or, what turns out to be equivalent, countries with agricultural GDP shares in the top quintile of the distribution. This sample is a logical starting point as the median agricultural GDP share in Sub-Saharan Africa is the cut-off used in Brückner and Ciccone (2011). The main difference between their analysis and ours is that we include all countries in the world with agricultural GDP shares above this cut-off.

The rainfall data that we use come from the US Government's National Oceanic and Atmospheric Administration, and the temperature data come from the US Government's Center for Environmental Prediction. These data are available globally on a grid of approximately 50×50 km at the equator since 1945. Country–year rainfall and temperature are measured as average annual rainfall and average temperature within a country's territory.

We use three main datasets that classify regimes into democracies or non-democracies, and two multivalued measures of democratic quality. The three main dichotomous regime classifications are those of Acemoglu *et al.* (2019), Geddes *et al.* (2014)[4] and Przeworski *et al.* (2000), as updated by Cheibub *et al.* (2010) and Bjørnskov and Rode (2020). The Acemoglu *et al.* (2019) classification is available for the broadest sample of countries and combines information from several different sources.[5] The two multivalued indices measuring the quality of democratic institutions that we use are the Polity Project combined polity score and the Freedom House index of political rights (Marshall *et al.* 2014; Freedom House 2014). We drop so-called interregnum years when according to the Polity Project there is no government controlling most of the territory. Former colonies are included only since independence, and we require countries to have been independent for at least 25 years (about half our sample period). Start and end dates of the different democratization measures for countries with agricultural GDP shares in the top quintile of the distribution are in Table 1. Our sixth measure of democratization is based on the dichotomous political regime classification that Gründler and Krieger (2021) derive using machine learning.

The measures of democratization that we use differ in definitions, as explained in detail in the papers cited in the previous paragraph. For example, Geddes *et al.* (2014) code a competitive election for the executive as democratization only if a person other than the previous authoritarian incumbent, or someone allied with the incumbent, wins the election. They also use a different timing rule when coding the start date of democratic government (more about this below). As a result, the different measures of democratization that we use indicate a somewhat different timing for democratic change. Figure 1 illustrates these trends for the world's most agricultural countries and, for comparison, all countries. Trends are similar, but there are more ups and downs for the world's most agricultural countries.

Empirical framework

The estimating equation for the effect of rainfall on real agricultural output follows the agricultural economics literature; see Schlenker and Lobell (2010), Lobell *et al.* (2011) and Maertens (2021), for example. The literature finds that the within-country relationship between rainfall and agricultural output is quadratic and has an inverted U-shape. The effect of rainfall on agricultural output in country c and year t is

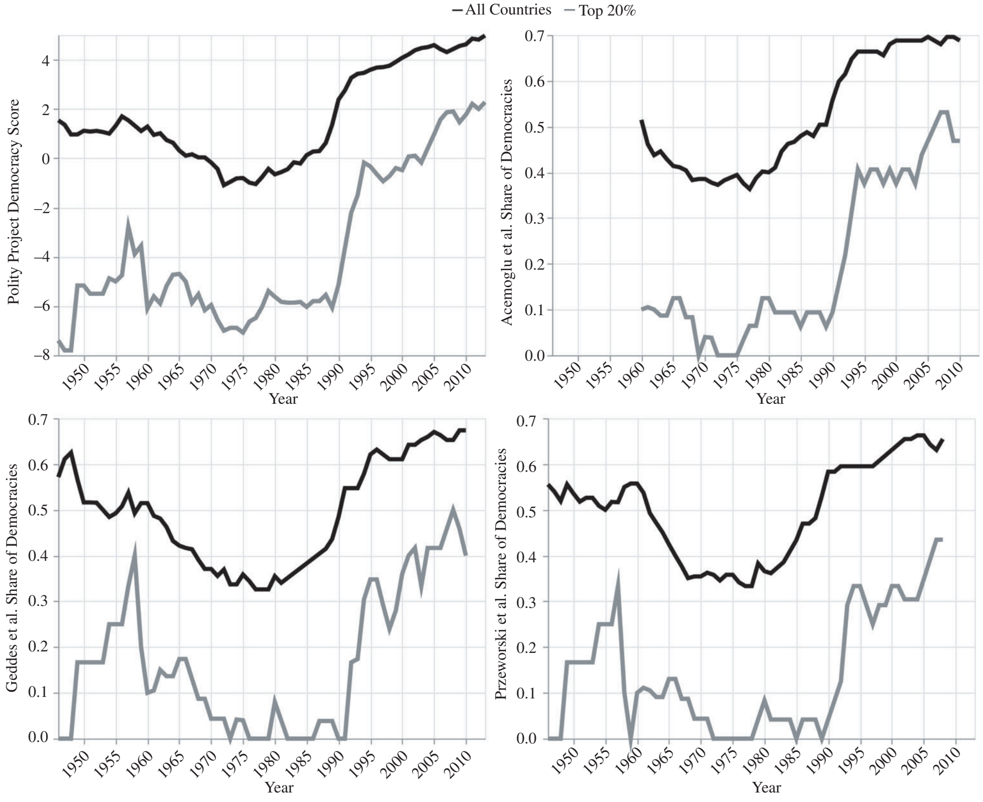

FIGURE 1. Democratization trends in the world's most agricultural countries.
Notes: Democratization trends illustrated clockwise starting with the upper-left panel: the Polity Project combined polity score; the share of democracies according to Acemoglu *et al*. (2019); the share of democracies according to Przeworski *et al*. (2000) as updated by Cheibub *et al*. (2010) and Bjørnskov and Rode (2020); and the share of democracies according to Geddes *et al*. (2014). The black line is for all countries, and the grey line is for countries with average 1970–2013 agricultural GDP shares in the top quintile of the distribution.

$$\begin{aligned} (1)\qquad & RealAgriculturalOutputIndex_{c,t} = Controls_{c,t} \\ & +\left(a_0 R_{c,t} + b_0 R^2_{c,t}\right) + \left(a_1 R_{c,t-1} + b_1 R^2_{c,t-1}\right) + \left(a_2 R_{c,t-2} + b_2 R^2_{c,t-2}\right) + \epsilon_t, \end{aligned}$$

where the three terms of the form $aR + bR^2$ capture the (quadratic) within-country effect of rainfall at different lags, and $Controls_{c,t}$ always include (i) country fixed effects, (ii) year fixed effects, (iii) country-specific linear time trends, and (iv) linear-quadratic terms for temperature that match the lag structure of the rainfall variable. The quadratic specification allows the relationship between rainfall and agricultural output to have an inverted U-shape. In this case, additional rainfall would increase agricultural output for rainfall levels to the left of the peak of the inverted U, but additional rainfall would decrease agricultural output for rainfall levels to the right of the peak of the inverted U. That is, there could be too little or too much rain as far as agricultural productivity is concerned. The method of estimation is least squares with heteroscedastic and autocorrelation-consistent (HAC) standard errors that are robust to both arbitrary heteroscedasticity and serial correlation.[6]

The estimating equation for the effect of rainfall on democratization outcomes in country c between years $t-1$ and T mirrors the equation for agricultural output:

$$Democratization^{T}_{c,t-1} = Controls_{c,t} + \left(a_0 R_{c,t} + b_0 R^2_{c,t}\right) + \left(a_1 R_{c,t-1} + b_1 R^2_{c,t-1}\right) + \left(a_2 R_{c,t-2} + b_2 R^2_{c,t-2}\right) + \epsilon_t, \quad (2)$$

with the three terms of the form $aR + bR^2$ and $Controls_{c,t}$ as for equation (1). Year fixed effects play an important role as they capture global factors driving the probability of democratization—for example, the dissolution of the Soviet Union in 1991. The estimation method is the same as for equation (1).

For $T = 1$, the specification in equation (2) allows us to examine the short-run relationship between rainfall and democratization, as in Brückner and Ciccone (2011). By varying T, we can examine the effect of rainfall on short-run and longer-run democratization; see Acemoglu *et al.* (2008) for a similar approach.

Democratization between years $t-1$ and T in equation (2) is measured in two main ways. The first measure is a democratization indicator based on dichotomous political regime classifications. The democratization indicator takes value 1 if the country is classified as a non-democracy in year $t-1$ but a democracy in year T. If the country is a non-democracy in year $t-1$ and a non-democracy in year T, then the democratization indicator takes value 0. The democratization indicator between years $t-1$ and T is not defined if the country is a democracy in year $t-1$. The second measure of democratization is based on the change in multivalued indices measuring the quality of democratic institutions.

The model in equations (1) and (2) has two interesting implications. First, if the relationship between rainfall and agricultural output in equation (1) is an inverted U-shape, and the effect of rainfall on democratization is through agricultural output, then the relationship between rainfall and democratization in equation (2) should be U-shaped. Second, the maximum of the inverted-U-shaped relationship between rainfall and agricultural output should be at the same level of rainfall as the minimum of the U-shaped relationship between rainfall and democratization.

II. Empirical Results: Rainfall and Agricultural Output

We first examine the effect of rainfall on agricultural output in countries grouped by agricultural GDP shares.

Table 2 summarizes our results on the effect of rainfall on agricultural output using equation (1). Columns (1)–(4) contain results for different subgroups of countries. These subgroups are based on average agricultural GDP shares over the 1970–2013 period (agricultural GDP shares are available only since 1970). Column (5) contains the results for all countries with agricultural output data.

Column (1) of Table 2 shows the results for the 32 countries with an average GDP share of agriculture in the top quintile of the distribution, or equivalently, all countries with agricultural GDP shares above the Sub-Saharan African median. This is the sample of the world's most agricultural countries on which we will focus. As already mentioned, this sample is a logical starting point as it uses the same cut-off for the agricultural GDP share as in the Brückner and Ciccone (2011) analysis for Sub-Saharan Africa. But while Brückner and Ciccone (2011) include only Sub-Saharan African countries in their

TABLE 2
RAINFALL AND AGRICULTURAL OUTPUT SINCE 1960: EFFECT BY SHARE OF AGRICULTURE IN GROSS DOMESTIC PRODUCT

	Top quintile agricultural countries (1)	All countries except top quintile agricultural countries (2)	Top quarter agricultural countries (3)	Top tercile agricultural countries (4)	All countries (5)
Rainfall t	2.221***	0.021	1.033*	−0.123	0.302
	(0.636)	(0.392)	(0.534)	(0.429)	(0.367)
Quadratic rainfall t	−0.059***	−0.004	−0.031***	−0.001	−0.010
	(0.014)	(0.009)	(0.012)	(0.010)	(0.009)
Rainfall $t-1$	0.134	−0.045	−0.389	−0.577	0.026
	(0.638)	(0.397)	(0.516)	(0.362)	(0.367)
Quadratic rainfall $t-1$	−0.010	−0.004	0.003	0.009	−0.007
	(0.015)	(0.010)	(0.012)	(0.008)	(0.009)
Rainfall $t-2$	0.264	−0.426	−0.294	−0.363	−0.208
	(0.626)	(0.404)	(0.496)	(0.365)	(0.374)
Quadratic rainfall $t-2$	−0.002	0.006	0.008	0.008	0.001
	(0.014)	(0.010)	(0.012)	(0.008)	(0.009)
Countries	32	129	41	53	161
Observations	1515	5936	1934	2444	7451
R-squared	0.065	0.009	0.041	0.013	0.013

Notes
The left-hand-side variable is an index of real agricultural output. Countries are assigned to subsamples by the average share of agriculture in GDP over the 1970–2013 period. The specification includes country fixed effects, year fixed effects, and linear and quadratic contemporaneous and lagged temperature effects. The numbers in parentheses are HAC standard errors that are robust to both arbitrary heteroscedasticity and serial correlation.
*, **, *** denote significance at the 10%, 5%, 1% level, respectively.

analysis, we include all countries in the world with agricultural GDP shares above this cut-off. The relationship between rainfall in year t and agricultural output in year t in column (1) is statistically significant and inverted U-shaped. The effect of lagged rainfall is statistically insignificant.[7] Approximately 15% of the rainfall observations are to the right of the peak in agricultural output. To get a sense of the strength of the contemporaneous effect, we calculate the percentage decrease in agricultural output caused by the median year-on-year drop in rainfall between years $t-1$ and t, starting at the median level of rainfall in year $t-1$. We refer to this shock as the median year-on-year negative rainfall shock. The implied decrease in agricultural output is around 1 percentage point. As the average share of agriculture in GDP in countries in the top quintile of the distribution is 40%, the implied effect on GDP of the median year-on-year negative rainfall shock is around −0.4%.

Column (2) of Table 2 considers countries whose average share of agriculture in GDP is outside the top quintile of the distribution (the complement of countries in column (1)). Now the contemporaneous effect of rainfall on agricultural output is also statistically insignificant.

Columns (3) and (4) of Table 2 consider countries with shares of agriculture in GDP in the top quarter and the top tercile of the distribution, respectively. For countries in the top quarter of the distribution in column (3), the relationship between rainfall in year t and agricultural output in year t is statistically significant and inverted U-shaped. The implied contemporaneous effect of the median year-on-year negative rainfall shock on agricultural output is around −0.3%, less than one-third of the effect that we estimated in countries with agricultural GDP shares in the top quintile of the distribution. When combined with the average GDP share of agriculture in the top quarter of the distribution, this yields an effect of the median year-on-year negative rainfall shock on GDP of −0.1%. This effect is substantially weaker than the −0.4% GDP effect that we estimate in countries with agricultural GDP shares in the top quintile of the distribution. For countries in the top tercile of the distribution in column (4), the contemporaneous effect of rainfall on agricultural output becomes statistically insignificant and the implied effect of a median negative rainfall shock on agricultural output is basically zero.

There are two explanations for the drop-off in the effect of rainfall on agricultural output as one moves outside the group of countries with agricultural GDP shares in the top quintile. The first factor is a greater use of irrigation systems. There is very little irrigation in countries in the top quintile of the distribution of agricultural GDP shares. According to the World Development Indicators (World Bank 2016), the median share of irrigated agricultural land in these countries over the 2001–10 period was around 0.7% (very few data are available for earlier years). Outside the group of countries in the top quintile of the distribution of agricultural GDP shares, the share of irrigated agricultural land is much higher. For example, the median share of irrigated agricultural land in countries with agricultural GDP shares in the top tercile but not the top quintile of the distribution was around 9%. A second factor likely to play a role is that rainfall is measured over a country's entire territory. In less agricultural countries, more of the measured rainfall is not over agricultural land and hence will not have an effect on agricultural output.

Finally, column (5) of Table 2 shows that the effect of rainfall on agricultural output is statistically insignificant when all countries are included in the empirical analysis.

III. Empirical Results: Rainfall and Persistent Democratization in the World's Most Agricultural Countries

Now we examine the effect of rainfall on different measures of democratic change in the world's most agricultural countries.

We start with our results using measures of democratization based on dichotomous political regime classifications, and then turn to the results using multivalued indices of democratic quality.

Democratization based on dichotomous political regime classifications

Table 3 summarizes the short-run and longer-run effects of rainfall on democratization in countries with agricultural GDP shares in the top quintile of the distribution. We use three main indicators of democratization based on dichotomous political regime classifications: (i) Acemoglu *et al.* (2019); (ii) Przeworski *et al.* (2000) as updated by Cheibub *et al.* (2010) and Bjørnskov and Rode (2020); and (iii) Geddes *et al.* (2014). The number of countries and observations per country depend on the measure of democratization as datasets differ in terms of countries and time periods covered (see Table 1).

Acemoglu et al. democratization Panel A of Table 3 summarizes the short-run and longer-run effects of rainfall on democratization when the measure of democratization in estimating equation (2) is based on the political regime classification of Acemoglu *et al.* (2019), which we refer to as Acemoglu *et al.* for short. The democratization indicator between years $t-1$ and T is defined only if the country is classified as a non-democracy in year $t-1$. The indicator takes value 1 if the country is a democracy in year T, and value 0 if the country is a non-democracy in year T. The panel contains results for the effect of rainfall on the probability that a non-democracy in year $t-1$ is a democracy in year t (1 year later), in year $t+2$ (3 years later), in year $t+4$ (5 years later), and in year $t+9$ (10 years later).

The main finding is that the relationship between rainfall in year t and the probability of democratization is U-shaped and statistically significant for democratization 1, 3, 5 and 10 years later. Hence the effect of within-country rainfall variation on democratization is persistent.[8] To get a sense of the magnitude of the effect of rainfall on democratization, consider a negative rainfall shock in year t equal to the median year-on-year drop in rainfall in the world's most agricultural countries. Suppose that this shock affects a country following a year where the rainfall level was equal to the median. Our estimates in Panel A of Table 3 imply that this negative shock increases the probability that a non-democracy at $t-1$ is a democracy 1 year later by around 1.5 percentage points. The probability that a non-democracy at $t-1$ is a democracy 3, 5 and 10 years later increases by between 2 and 3 percentage points.

Online Appendix Tables 1 and 2 contain a robustness analysis of the results using the Acemoglu *et al.* democratization indicator. Online Appendix Table 1 shows that results are robust when we exclude years where according to Geddes *et al.* (2014), the country is controlled by foreign nations or there is no government controlling most of the country's territory. Parts A–C of Online Appendix Table 2 show results when we drop or add countries one by one depending on their agricultural GDP share. Results are robust, especially for longer-term democratization.

Przeworski et al. democratization Panel B of Table 3 summarizes the short-run and longer-run effects of rainfall on democratization when the measure of democratization in equation (2) is based on the political regime classification of Przeworski *et al.* (2000) as updated by Cheibub *et al.* (2010) and Bjørnskov and Rode (2020), which we refer to as Przeworski *et al.* for short. The main finding is that the relationship between rainfall in year t and the probability of democratization is U-shaped and statistically significant for democratization between years $t-1$ and t (1 year later), year $t+2$ (3 years later), year $t+4$ (5 years later), and year $t+9$ (10 years later).[9] Hence the Przeworski *et al.* democratization indicator also points to a persistent effect of within-country rainfall variation on democratization. The estimates in Panel B of Table 3 imply that the median year-t negative rainfall shock increases the probability that a non-democracy at $t-1$ is a democracy 1 year later by around 1.5 percentage points. The median negative rainfall shock continues to be defined as the median year-on-year drop in rainfall starting at the median level of rainfall. The median year-t negative rainfall shock increases the probability that a non-democracy at $t-1$ is a democracy 3, 5 and 10 years later by between 2 and 3 percentage points.

Parts A–C of Online Appendix Table 3 show that results are robust when we drop or add countries one by one depending on their agricultural GDP share.

TABLE 3
RAINFALL AND DEMOCRATIZATION SINCE 1960: FROM SHORT TO LONG TERM

	Panel A: Acemoglu *et al.* (2019) data				Panel B: Przeworski *et al.* (2000) data				Panel C: Geddes *et al.* (2014) data			
	Democratization between $t-1$ and				Democratization between $t-1$ and				Democratization between $t-1$ and			
	t (1-year) (1)	$t+2$ (3-year) (2)	$t+4$ (5-year) (3)	$t+9$ (10-year) (4)	t (1-year) (5)	$t+2$ (3-year) (6)	$t+4$ (5-year) (7)	$t+9$ (10-year) (8)	t (1-year) (9)	$t+2$ (3-year) (10)	$t+4$ (5-year) (11)	$t+9$ (10-year) (12)
Rainfall t	−0.031**	−0.044**	−0.065***	−0.056**	−0.031**	−0.043**	−0.057***	−0.042**	−0.012	−0.011	−0.035*	−0.041*
	(0.016)	(0.020)	(0.022)	(0.022)	(0.015)	(0.020)	(0.021)	(0.021)	(0.011)	(0.017)	(0.019)	(0.021)
Quadratic rainfall t	0.001*	0.001*	0.001**	0.001**	0.001*	0.001*	0.001**	0.001	0.000	0.000	0.000	0.001
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
Rainfall $t-1$	0.015	−0.008	−0.035*	−0.051**	0.011	−0.020	−0.025	−0.044**	−0.033**	−0.032*	−0.045**	−0.037*
	(0.011)	(0.021)	(0.019)	(0.024)	(0.012)	(0.018)	(0.018)	(0.020)	(0.015)	(0.019)	(0.019)	(0.019)
Quadratic rainfall $t-1$	−0.000	−0.000	0.001	0.001**	−0.000	0.000	0.000	0.001*	0.001*	0.001*	0.001**	0.001*
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)
Rainfall $t-2$	−0.016	−0.060***	−0.044**	−0.051**	−0.021	−0.034*	−0.019	−0.029	0.014	−0.018	−0.028*	−0.033*
	(0.015)	(0.019)	(0.018)	(0.024)	(0.013)	(0.017)	(0.016)	(0.021)	(0.012)	(0.017)	(0.016)	(0.020)
Quadratic rainfall $t-2$	0.000	0.001**	0.001*	0.001**	0.000	0.001	0.000	0.000	−0.000	0.000	0.000	0.001
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)

TABLE 3
CONTINUED

	Panel A: Acemoglu *et al.* (2019) data				Panel B: Przeworski *et al.* (2000) data				Panel C: Geddes *et al.* (2014) data			
	Democratization between $t-1$ and				Democratization between $t-1$ and				Democratization between $t-1$ and			
	t (1-year) (1)	$t+2$ (3-year) (2)	$t+4$ (5-year) (3)	$t+9$ (10-year) (4)	t (1-year) (5)	$t+2$ (3-year) (6)	$t+4$ (5-year) (7)	$t+9$ (10-year) (8)	t (1-year) (9)	$t+2$ (3-year) (10)	$t+4$ (5-year) (11)	$t+9$ (10-year) (12)
Countries	31	31	31	30	26	26	26	26	26	26	26	26
Observations	1132	1100	1069	975	1054	1016	981	895	1049	1012	978	899
R-squared	0.016	0.043	0.051	0.029	0.029	0.031	0.032	0.020	0.017	0.024	0.051	0.037

Notes
The left-hand-side variable in columns (1), (5) and (9) is a democratization indicator that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at t (1 year later), and value 0 otherwise. The left-hand-side variable in columns (2), (6) and (10) is an indicator variable that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at $t+2$ (3 years later), and value 0 otherwise. The left-hand-side variable in columns (3), (7) and (11) is an indicator variable that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at $t+4$ (5 years later), and value 0 otherwise. The left-hand-side variable in columns (4), (8) and (12) is an indicator variable that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at $t+9$ (10 years later), and value 0 otherwise. The classification of democratic and non-democratic regimes in columns (1)–(4) is based on Acemoglu *et al.* (2019). The classification of democratic and non-democratic regimes in columns (5)–(8) is based on Bjørnskov and Rode (2017), who extend the dataset of Cheibub *et al.* (2010) and Przeworski *et al.* (2000). The classification of democratic and non-democratic regimes in columns (9)–(12) is based on Geddes *et al.* (2014). The included countries are with an average share of agriculture in GDP over the 1970–2013 period in the top quintile of the distribution. The specification includes country fixed effects, year fixed effects, and linear and quadratic contemporaneous and lagged temperature effects. The specification also includes a linear and quadratic term for rainfall lagged by 3 years, but these terms are generally statistically insignificant and not reported for brevity. The numbers in parentheses are HAC standard errors that are robust to both arbitrary heteroscedasticity and serial correlation.
*, **, *** denote significance at the 10%, 5%, 1% level, respectively.

TABLE 4
RAINFALL AND DEMOCRATIZATION SINCE 1960: FROM SHORT TO LONGER TERM, GRÜNDLER AND KRIEGER (2021) DATA

	Gründler and Krieger (2021) data				
	Democratization between $t-1$ and				
	t (1-year) (1)	$t+1$ (2-year) (2)	$t+2$ (3-year) (3)	$t+4$ (5-year) (4)	$t+9$ (10-year) (5)
Rainfall t	−0.019	−0.029**	−0.053***	−0.034*	−0.040*
	(0.012)	(0.014)	(0.017)	(0.020)	(0.021)
Quadratic rainfall t	0.000	0.001*	0.001**	0.001	0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Rainfall $t-1$	−0.002	−0.033**	−0.022	−0.043**	−0.027
	(0.010)	(0.015)	(0.016)	(0.018)	(0.021)
Quadratic rainfall	0.000	0.001**	0.000	0.001**	0.001
$t-1$	(0.000)	(0.003)	(0.000)	(0.000)	(0.001)
Rainfall $t-2$	−0.030**	−0.019	−0.024	−0.032*	−0.011
	(0.013)	(0.015)	(0.018)	(0.018)	(0.020)
Quadratic rainfall	0.001**	0.000	0.000	0.001	0.000
$t-2$	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Countries	30	30	30	30	30
Observations	1265	1264	1246	1213	1139
R-squared	0.021	0.025	0.033	0.029	0.009

Notes
The left-hand-side variables in all columns are democratization indicators based on the classification of democratic and non-democratic regimes of Gründler and Krieger (2021). The left-hand-side democratization indicator in column (1) takes value 1 if a country that is an autocracy at $t-1$ is a democracy at t (1 year later), and value 0 otherwise. The left-hand-side democratization indicator in column (2) takes value 1 if a country that is an autocracy at $t-1$ is a democracy at $t+1$ (2 years later), and value 0 otherwise. The left-hand-side democratization indicator in column (3) takes value 1 if a country that is an autocracy at $t-1$ is a democracy at $t+2$ (3 years later), and value 0 otherwise. The left-hand-side democratization indicator in column (4) is an indicator variable that takes value 1 if a country that is an autocracy at $t-1$ is a democracy at $t+4$ (5 years later), and value 0 otherwise. The left-hand-side democratization indicator in column (5) takes value 1 if a country that is an autocracy at $t-1$ is a democracy at $t+9$ (10 years later), and value 0 otherwise. The included countries are all countries with an average share of agriculture in GDP over the 1970–2013 period in the top quintile of the distribution. The specification includes country fixed effects, year fixed effects, and linear and quadratic contemporaneous and lagged temperature effects. The specification also includes a linear and quadratic term for rainfall lagged by 3 years, but these terms are generally statistically insignificant and not reported for brevity. The numbers in parentheses are HAC standard errors that are robust to both arbitrary heteroscedasticity and serial correlation.
*, **, *** denote significance at the 10%, 5%, 1% level, respectively.

Geddes et al. democratization Panel C of Table 3 summarizes the short-run and longer-run effects of rainfall on democratization when the democratization indicator in equation (2) is based on the political regime classifications of Geddes *et al.* (2014), which we refer to as Geddes *et al.* for short. The results again indicate a statistically significant, U-shaped relationship between rainfall and the probability of democratization over different time periods. The timing of the rainfall effect is somewhat different than for Przeworski *et al.* democratizations. In particular, it is rainfall in year $t-1$ that is statistically significant over all time periods. Differences in timing are not particularly surprising as different political regime classifications use different definitions and measurement criteria. The difference between the Geddes *et al.* and the Przeworski *et al.* regime classifications that matters most for the difference in the timing of the rainfall effect in Panel C of Table 3 is that Geddes *et al.* do not follow 'the convention' (their words) in coding the start date of democratic regimes. If a democratic regime becomes established in year t, then the convention is to code 31 December as the start date. This is the rule used by Przeworski *et al.*, for example. Geddes *et al.* use 1 January of the subsequent year instead. To see how these rules can affect the results, imagine that a negative year-t rainfall shock causes democratization in year t. With the 31 December rule for regime start dates, this democratization event is recorded in year t and researchers would observe that negative year-t rainfall shocks lead to democratization in year t. With the 1 January rule for start dates, the democratization event is recorded in year $t+1$ and researchers would observe that negative year-t rainfall shocks lead to democratization in year $t+1$ (or, put differently, that year-t democratizations are related to negative rainfall shocks in year $t-1$).

Because of the unconventional rule for the start dates of democratic regimes used by Geddes *et al.*, we illustrate the strength of the effect of the median year-on-year negative rainfall shock on the probability of Geddes *et al.* democratizations in two different ways. Our first approach is based on the estimates of the rainfall effect in $t-1$ in Panel C of Table 3. They yield that the median negative rainfall shock in year $t-1$ increases the probability that a non-democracy at $t-1$ is a democracy 1 year later by around 0.8 percentage points. The increase in the probability that a non-democracy at $t-1$ is a democracy 3 years later is around 1 percentage point, and the increase in the probability that a non-democracy at $t-1$ is a democracy 5 and 10 years later is around 2 percentage points. Our second approach recodes the start dates of democratic regimes in the Geddes *et al.* dataset according to the convention, re-estimates the specification in Panel C of Table 3 using this recoded data, and then uses these estimates in our calculations. This yields that the median negative rainfall shock in year t increases the probability that a non-democracy at $t-1$ is a democracy 1 and 3 years later by around 1.5 percentage points. The increase in the probability that a non-democracy at $t-1$ is a democracy 5 and 10 years later is around 2 percentage points.

Parts A–C of Online Appendix Table 4 show results when we drop or add countries depending on their agricultural GDP share. Results are robust, especially for longer-term democratization.

Gründler and Krieger democratization Table 4 summarizes the relationship between rainfall and short-run and longer-run democratization when the democratization indicator in equation (2) is based on the dichotomous political regime classification that Gründler and Krieger (2021) derive using machine learning. In addition to the effects on democratization in years t, $t+2$, $t+4$ and $t+9$ in Table 3, we also show the effect in $t+1$. It can be seen that the Gründler and Krieger democratization indicator, like the democratization indicators in Table 3, also yields a relationship between rainfall and the probability of democratization in year t that is U-shaped and statistically significant. However, the timing differs compared to Table 3 as it is rainfall in year $t-2$ that is statistically significant. This discrepancy disappears for democratization in year $t+1$ and thereafter.

Agricultural output and democratization If the effect of rainfall on democratization is through agricultural output, then the inverted-U-shaped relationship between rainfall and agricultural output should translate into a U-shaped relationship between rainfall and democratization. Put differently, the relationship between rainfall and the probability of democratization should be the flipped image of the relationship between rainfall and agricultural output.[10] Moreover, the minimum of the U-shaped relationship between rainfall and the probability of democratization should be at a similar rainfall level as the maximum of the inverted-U-shaped relationship between rainfall and agricultural output. That is, the rainfall level that maximizes agricultural output should be similar to the rainfall level that minimizes the probability of democratization.

Figure 2 examines whether this is the case. The inverted-U-shaped solid black curve shows the relationship between rainfall in year t and agricultural output in year t (measured on the left-hand scale). This effect is calculated using the estimates in column (1) of Table 2. The peak of the inverted U is at a level of rainfall equal to the 85th percentile of the rainfall distribution. The maximum variation in agricultural output associated with rainfall variation is around 20 percentage points.

The U-shaped curves of Figure 2 show the relationship between rainfall and the probability of democratization between years $t-1$ and t (measured on the right-hand

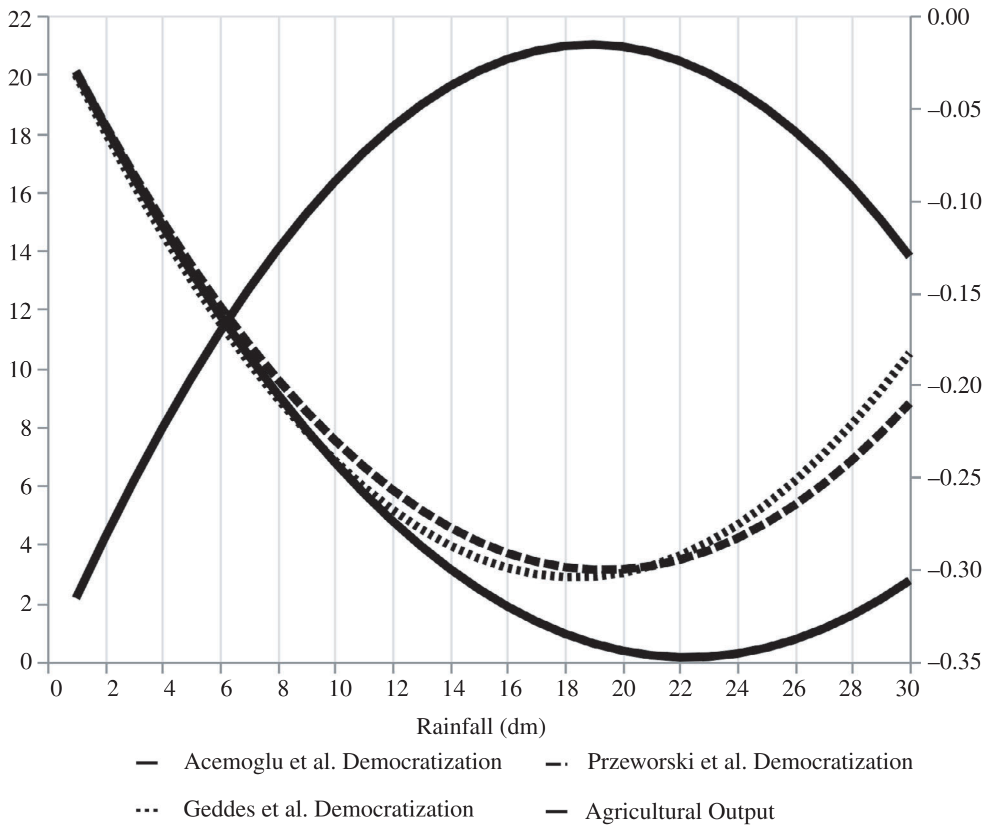

FIGURE 2. Effect of rainfall on real agricultural output and on the probability of democratization.
Notes: The inverted-U-shaped line is the effect of rainfall in year t on agricultural output in year t measured on the left-hand axis. The three U-shaped lines are the effects of rainfall on the probability of democratization between years $t-1$ and t (1 year later) for the three main dichotomous classifications of democratic and non-democratic regimes used: Acemoglu *et al.* (2019), Przeworski *et al.* (2000) as updated by Cheibub *et al.* (2010) and Bjørnskov and Rode (2020), and Geddes *et al.* (2014).

scale). The solid black curve is based on the Acemoglu *et al.* democratization indicator. The estimates used to obtain the effect of rainfall in year t on democratization in year t are those in column (1) of Table 3. The U-shaped relationship between rainfall and democratization is consistent with the effect of rainfall working through its inverted-U-shaped effect on agricultural output. Moreover, the rainfall level where the inverted-U-shaped relationship between rainfall and agricultural output reaches its maximum is similar to the rainfall level where the U-shaped relationship between rainfall and the probability of democratization reaches its minimum. A formal hypothesis test cannot reject that the two levels of rainfall are the same at any standard confidence level. The maximum variation in the probability of democratization associated with rainfall variation is around 35 percentage points.

The U-shaped dashed curve in Figure 2 illustrates the relationship between rainfall in year t and the probability of a Przeworski *et al.* democratization between years $t-1$ and t. This effect is calculated using the estimates in column (5) of Table 3. It can be seen that the effect of rainfall on Przeworski *et al.* democratizations is also consistent with rainfall affecting democratization through its inverted-U-shaped effect on agricultural output. The rainfall level where the inverted-U-shaped relationship between rainfall and agricultural output reaches its maximum continues to be similar to the rainfall level where the U-shaped relationship between rainfall and the probability of democratization reaches its minimum. A formal hypothesis test cannot reject that these rainfall level are the same at any standard confidence level. The maximum variation in the probability of democratization associated with rainfall variation is around 30 percentage points.

The U-shaped dotted curve in Figure 2 shows the relationship between rainfall and the probability of a Geddes *et al.* democratization between years $t-1$ and t. Because of the unconventional rule for start dates of different regimes used by Geddes *et al.*, the figure shows the probability of a Geddes *et al.* democratization as a function of rainfall in year $t-1$. This effect is calculated using the estimates in column (9) of Table 3. The effect of rainfall on democratization is again consistent with rainfall affecting democratization through its inverted-U-shaped effect on agricultural output. The maximum variation in the probability of democratization associated with rainfall variation is around 30 percentage points.

Hence, as would be expected if the effect of rainfall on democratization is through agricultural output, the inverted-U-shaped relationship between rainfall and agricultural output translates into U-shaped relationships between rainfall and the probability of democratization. The maximum variation associated with rainfall is around 20 percentage points for agricultural output and around 30–35 percentage points for the probability of democratization.

Figure 3 illustrates the empirical fit of the inverted-U-shaped relationship between rainfall and agricultural output for the world's most agricultural countries in Table 2 using an augmented-component-plus-residual plot. These plots are useful for checking on quadratic and other non-linear relationships; see Ashraf and Galor (2013), Duranton *et al.* (2014), Ashraf and Michalopoulos (2015), and Maertens (2021), for example. The horizontal axis measures rainfall, and the vertical axis measures agricultural output. The inverted-U-shaped curve is agricultural output predicted by rainfall and rainfall squared. The grey dots are predicted agricultural output plus the residuals from the regression of agricultural output on all the right-hand-side variables in Table 2. The plot indicates that the quadratic (inverted-U-shaped) relationship describes the data well. Figures 4, 5 and 6 show augmented-component-plus-residual plots of the relationship between rainfall and the probability of democratization for our three main dichotomous political regime

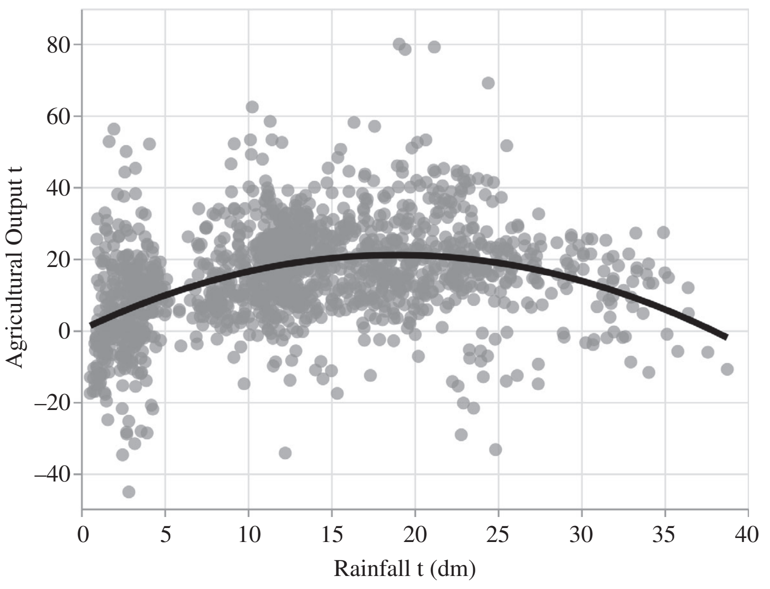

FIGURE 3. Agricultural output: augmented component plus residual plots.
Notes: Empirical fit of the inverted-U-shaped effect of rainfall in year t on agricultural output in year t using an augmented-component-plus-residual plot. The vertical axis represents agricultural output explained by rainfall and its square plus the residuals from the (full) regression of agricultural output on all the right-hand-side variables in Table 2.

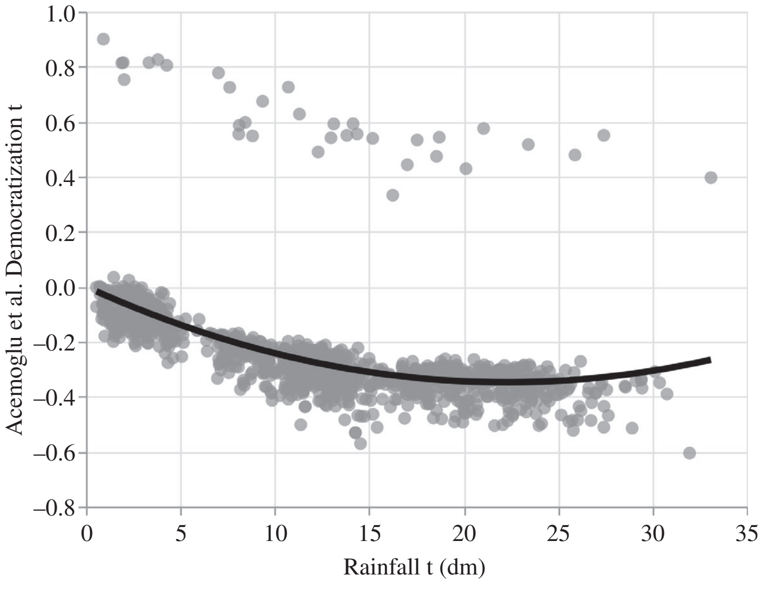

FIGURE 4. Augmented component plus residual plots for Acemoglu *et al*. democratization.
Notes: Empirical fit of the U-shaped effect of rainfall in year t on the probability of democratization between years $t-1$ and t based on the classification of democratic and non-democratic regimes of Acemoglu *et al*. (2019). The vertical axis represents the probability of democratization explained by rainfall and its square plus the residuals from the (full) regression of the democratization indicator on all the right-hand-side variables in Table 3.

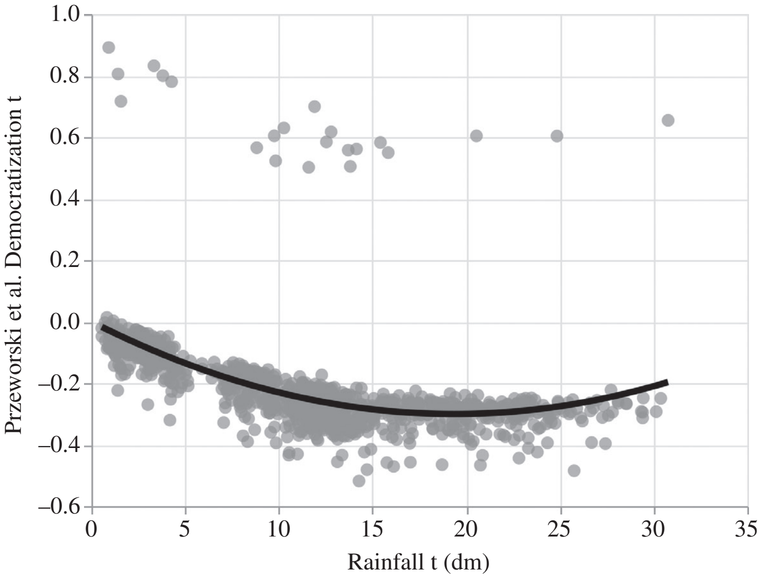

FIGURE 5. Augmented component plus residual plots for Przeworski *et al*. democratization.
Notes: Empirical fit of the U-shaped effect of rainfall in year t on the probability of democratization between years $t-1$ and t based on the classification of democratic and non-democratic regimes of Przeworski *et al*. (2000) as updated by Cheibub *et al*. (2010) and Bjørnskov and Rode (2020). The vertical axis represents the probability of democratization explained by rainfall and its square plus the residuals from the (full) regression of the democratization indicator on all the right-hand-side variables in Table 3.

classifications. The horizontal axis measures rainfall, and the vertical axis measures the probability of democratization. The U-shaped curves are the probability of democratization predicted by rainfall and rainfall squared. The grey dots are the predicted probability of democratization plus the residuals from the regression of the three different democratization indicators on all the right-hand-side variables in Table 3. These plots also indicate that the quadratic (U-shaped) relationship describes the data well.

Online Appendix Figure 1 illustrates the fit of the quadratic (inverted-U-shaped) relationship between rainfall and agricultural output, and the quadratic (U-shaped) relationship between rainfall and democratization, using separate binned scatterplots for the linear and quadratic terms. These plots also indicate that the quadratic relationship describes the data well.

Democratization in Sub-Saharan Africa since 1980 Table 5 summarizes the short-run and longer-run effects of rainfall on democratization for the subsample of Sub-Saharan African countries in Table 3, focusing on the period since 1980. This allows us to examine whether rainfall has a persistent effect on democratization in the region and during the more recent time period considered by Brückner and Ciccone (2011). The sample has somewhat less than half of the observations of the longest possible sample with all countries with agricultural GDP shares in the top quintile of the distribution. In addition to the effects on democratization in years t, $t+2$, $t+4$ and $t+9$, we also show the effect in year $t+1$. The results are for the Acemoglu *et al*. and the Przeworski *et al*. democratization indicators. Results for the Geddes *et al*. democratization indicator are

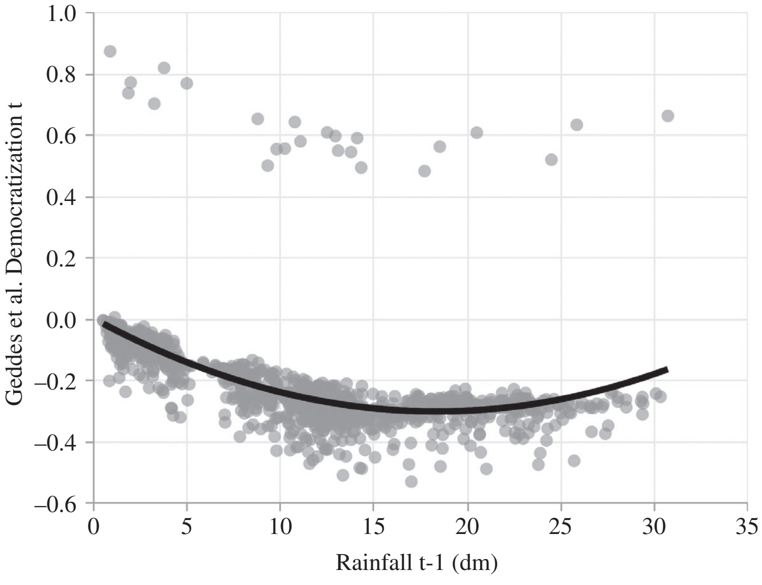

FIGURE 6. Augmented component plus residual plots for Geddes *et al.* democratization.
Notes: Empirical fit of the U-shaped effect of rainfall in year t on the probability of democratization between years $t-2$ and $t-1$ based on the classification of democratic and non-democratic regimes of Geddes *et al.* (2014). The vertical axis represents the probability of democratization explained by rainfall and its square plus the residuals from the (full) regression of the democratization indicator on all the right-hand-side variables in Table 3. See the text for details on the convention used by Geddes *et al.* (2014) to date the start of regime transitions.

similar. The main finding is that rainfall continues to have a U-shaped effect on democratization in the short run and the longer run. A difference with the results in Table 3 is the timing of the rainfall effect for the Acemoglu *et al.* democratization indicator, and that the effect sets in only after two years.

Democratization based on multivalued indices

Table 6 summarizes the short-run and longer-run effects of rainfall on democratic change using the multivalued Polity Project combined polity score and the Freedom House index of political rights (Marshall *et al.* 2014; Freedom House 2014).

Combined Polity Project score Panel A of Table 6 summarizes our findings on the effects of rainfall on short-run and longer-run democratic change when the left-hand side of estimating equation (2) is democratic improvement as measured by the change in the Polity Project combined polity score towards more democratic institutions. This score ranges from −10 to 10, with higher values indicating more democratic institutions. The Polity Project convention is that countries with a score smaller than or equal to ula$t$ (1 year later), year $t+2$ (3 years later), year $t+4$ (5 years later), and year $t+9$ (10 years later). The effect of rainfall in year t is statistically significant and implies a U-shaped relationship over all time periods. The implied effect of the median negative rainfall shock in year t on the improvement in the polity score between years $t-1$ and t is around 0.12 polity points after 1 year and around 0.3 points after 3 years. Over 5-year and 10-year periods, the improvement in the polity score is around 0.35 points.[11]

TABLE 5
RAINFALL AND DEMOCRATIZATION IN SUB-SAHARAN AFRICA SINCE 1980: FROM SHORT TO LONG TERM

	Panel A: Acemoglu *et al*. (2019) data					Panel B: Przeworski *et al*. (2000) data				
	Democratization between $t-1$ and					Democratization between $t-1$ and				
	t (1-year) (1)	$t+1$ (2-year) (2)	$t+2$ (3-year) (3)	$t+4$ (5-year) (4)	$t+9$ (10-year) (5)	t (1-year) (6)	$t+1$ (2-year) (7)	$t+2$ (3-year) (8)	$t+4$ (5-year) (9)	$t+9$ (10-year) (10)
Rainfall t	−0.016	0.003	−0.038	−0.104***	−0.111***	−0.094***	−0.071**	−0.053	−0.098***	−0.065*
	(0.024)	(0.026)	(0.030)	(0.036)	(0.031)	(0.031)	(0.032)	(0.036)	(0.035)	(0.039)
Quadratic rainfall t	0.000	0.000	0.001	0.002***	0.003***	0.003***	0.002**	0.002	0.003***	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Rainfall $t-1$	0.024	−0.010	−0.048	−0.069*	−0.126***	0.028	0.032	−0.010	−0.058	−0.102**
	(0.022)	(0.030)	(0.034)	(0.037)	(0.032)	(0.020)	(0.033)	(0.035)	(0.042)	(0.042)
Quadratic rainfall	−0.001	0.000	0.001	0.002*	0.003***	−0.001	−0.001	0.000	0.001	0.003**
$t-1$	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
Rainfall $t-2$	−0.024	−0.063*	−0.113***	−0.089**	−0.100***	−0.008	−0.052	−0.068	−0.091**	−0.036
	(0.025)	(0.034)	(0.035)	(0.035)	(0.038)	(0.025)	(0.036)	(0.044)	(0.039)	(0.046)
Quadratic rainfall	0.001	0.001	0.003***	0.002**	0.003***	−0.000	0.002	0.002	0.003**	0.001
$t-2$	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)

TABLE 5
CONTINUED

	Panel A: Acemoglu *et al.* (2019) data					Panel B: Przeworski *et al.* (2000) data				
	Democratization between $t-1$ and					Democratization between $t-1$ and				
	t (1-year) (1)	$t+1$ (2-year) (2)	$t+2$ (3-year) (3)	$t+4$ (5-year) (4)	$t+9$ (10-year) (5)	t (1-year) (6)	$t+1$ (2-year) (7)	$t+2$ (3-year) (8)	$t+4$ (5-year) (9)	$t+9$ (10-year) (10)
Countries	22	22	22	22	22	20	20	20	20	20
Observations	478	466	456	437	381	435	422	411	388	323
R-squared	0.022	0.024	0.047	0.048	0.098	0.083	0.044	0.043	0.069	0.072

Notes
The left-hand-side variable in columns (1) and (6) is a democratization indicator that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at t (1 year later), and value 0 otherwise. The left-hand-side variable in columns (2) and (7) is an indicator variable that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at $t+1$ (2 years later), and value 0 otherwise. The left-hand-side variable in columns (3) and (8) is an indicator variable that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at $t+2$ (3 years later), and value 0 otherwise. The left-hand-side variable in columns (4) and (9) is an indicator variable that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at $t+4$ (5 years later), and value 0 otherwise. The left-hand-side variable in columns (5) and (10) is an indicator variable that takes value 1 if a country that is a non-democracy at $t-1$ is a democracy at $t+9$ (10 years later), and value 0 otherwise. The classification of democratic and non-democratic regimes in columns (1)–(5) is based on Acemoglu *et al.* (2019). The classification of democratic and non-democratic regimes in columns (5)–(10) is based on Bjørnskov and Rode (2017), who extend the dataset of Cheibub *et al.* (2010) and Przeworski *et al.* (2000). The countries included in the analysis are all Sub-Saharan African countries with an average share of agriculture in GDP over the 1970–2013 period in the top quintile of the distribution or, equivalently, with an average share of agriculture in GDP above the Sub-Saharan African median. The specification includes country fixed effects, year fixed effects, and linear and quadratic contemporaneous and lagged temperature effects. The specification also includes a linear and quadratic term for rainfall lagged by 3 years, but these terms are generally statistically insignificant and not reported for brevity. The numbers in parentheses are HAC standard errors that are robust to both arbitrary heteroscedasticity and serial correlation.
*, **, *** denote significance at the 10%, 5%, 1% level, respectively.

TABLE 6
RAINFALL AND DEMOCRATIC IMPROVEMENTS SINCE 1960: FROM SHORT TO LONG TERM

	Panel A: Polity Project democratic improvement				Panel B: Polity Project democratization				Panel C: Freedom House political rights			
	Polity improvement between $t-1$ and				Polity democratization between $t-1$ and				Political rights improvement between $t-1$ and			
	t (1-year)	$t+2$ (3-year)	$t+4$ (5-year)	$t+9$ (10-year)	t (1-year)	$t+2$ (3-year)	$t+4$ (5-year)	$t+9$ (10-year)	t (1-year)	$t+2$ (3-year)	$t+4$ (5-year)	$t+9$ (10-year)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Rainfall t	−0.225*	−0.654***	−0.667***	−0.619**	−0.013	−0.051**	−0.052**	−0.035	−0.063**	−0.160***	−0.272***	−0.238***
	(0.127)	(0.220)	(0.245)	(0.257)	(0.015)	(0.020)	(0.020)	(0.023)	(0.027)	(0.048)	(0.069)	(0.070)
Quadratic	0.005*	0.015***	0.013**	0.012**	0.000	0.001**	0.001*	0.001	0.001**	0.003***	0.006***	0.004**
rainfall t	(0.003)	(0.005)	(0.006)	(0.006)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Rainfall $t-1$	−0.092	−0.129	−0.220	−0.198	−0.008	−0.023	−0.015	−0.005	0.000	−0.115**	−0.128**	−0.206***
	(0.106)	(0.193)	(0.211)	(0.276)	(0.011)	(0.017)	(0.018)	(0.023)	(0.022)	(0.045)	(0.061)	(0.078)
Quadratic	0.002	0.002	0.004	0.005	0.000	0.000	0.000	0.000	0.000	0.002**	0.002*	0.003**
rainfall $t-1$	(0.003)	(0.004)	(0.005)	(0.007)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)
Rainfall $t-2$	−0.337**	−0.486***	−0.301	−0.120	−0.040**	−0.066***	−0.034**	−0.009	−0.076***	−0.158***	−0.068	−0.229***
	(0.137)	(0.186)	(0.198)	(0.269)	(0.017)	(0.018)	(0.017)	(0.024)	(0.028)	(0.048)	(0.061)	(0.077)
Quadratic	0.009**	0.011**	0.007	0.002	0.001**	0.001***	0.001	0.000	0.001**	0.003***	0.001	0.004**
rainfall $t-2$	(0.003)	(0.004)	(0.005)	(0.006)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)

TABLE 6
CONTINUED

	Panel A: Polity Project democratic improvement				Panel B: Polity Project democratization				Panel C: Freedom House political rights			
	Polity improvement between $t-1$ and				Polity democratization between $t-1$ and				Political rights improvement between $t-1$ and			
	t (1-year) (1)	$t+2$ (3-year) (2)	$t+4$ (5-year) (3)	$t+9$ (10-year) (4)	t (1-year) (5)	$t+2$ (3-year) (6)	$t+4$ (5-year) (7)	$t+9$ (10-year) (8)	t (1-year) (9)	$t+2$ (3-year) (10)	$t+4$ (5-year) (11)	$t+9$ (10-year) (12)
Countries	30	30	30	30	30	30	30	30	31	31	31	31
Observations	1073	1003	941	846	1101	1070	1032	946	1078	910	808	677
R-squared	0.033	0.069	0.075	0.050	0.024	0.073	0.078	0.053	0.034	0.072	0.073	0.059

Notes
The left-hand-side variables in columns (1)–(4) are the improvements in the Polity IV Project combined polity score in non-democracies over different time periods. The left-hand-side variable in column (1) is the improvement in the polity score between years $t-1$ and t; the left-hand-side variable in column (2) is the improvement in the polity score between years $t-1$ and $t+2$; the left-hand-side variable in column (3) is the improvement in the polity score between years $t-1$ and $t+4$; and the left-hand-side variable in column (4) is the improvement in the polity score between years $t-1$ and $t+9$. The left-hand-side variables in columns (5)—(8) are indicators for democratization over different time periods constructed as the democratization indicators in Table 3. The classification of democratic and autocratic regimes is based on the Polity IV Project combined polity score. The left-hand-side variables in columns (9)–(12) are the improvements in political rights over different time periods measured by the Freedom House political rights index. The left-hand-side variable in column (9) is the improvement in political rights between years $t-1$ and t; the left-hand-side variable in column (10) is the improvement in political rights between years $t-1$ and $t+2$; the left-hand-side variable in column (11) is the improvement in political rights between years $t-1$ and $t+4$; and the left-hand-side variable in column (12) is the improvement in political rights between years $t-1$ and $t+9$. The included countries are all countries with an average share of agricultural in GDP over the 1970–2013 period in the top quintile of the distribution. The specification includes country fixed effects, year fixed effects, and linear and quadratic contemporaneous and lagged temperature effects. The specification also includes a linear and quadratic term for rainfall lagged by 3 years but these terms are generally statistically insignificant and not reported for brevity. The numbers in parentheses are HAC standard errors that are robust to both arbitrary heteroscedasticity and serial correlation.
*, **, *** denote significance at the 10%, 5%, 1% level, respectively.

Panel B of Table 6 contains our results for the effect of rainfall on a democratization indicator based on the dichotomized Polity Project combined polity score. We follow the convention and classify countries with a polity score smaller than or equal to −1 as non-democracies, and countries with a polity score greater than or equal to 1 as democracies. The results indicate a statistically significant, U-shaped relationship between rainfall and the probability of democratization over different time periods. The rainfall effect is a bit weaker than for the improvement in the polity score in panel A (a more granular measure), but overall, results are similar.

Freedom House political rights Panel C of Table 6 summarizes our findings on the effects of rainfall on short-run and longer-run democratic change when the left-hand side of estimating equation (2) is democratic improvement as measured by the Freedom House index of political rights. This index ranges from 1 to 7, with higher values indicating fewer political rights. Put differently, an improvement in political rights corresponds to a drop in the political rights index. To make results more directly comparable with those using the Polity Project combined polity score, where higher values indicate more democratic institutions, we use the negative of the Freedom House political rights index as the basis of our empirical work. This leaves the range of the index unchanged but ensures that positive changes over time correspond to improvements in political rights. As in the case of the combined polity score, we focus on improvements in political rights and drop years where political rights deteriorate. (Results including negative changes are similar; see Online Appendix Table 6.)[12]

Panel C of Table 6 shows our results for the effect of rainfall on improvements in the Freedom House index of political rights. The effect of rainfall in year *t* on improvements in political rights is statistically significant and implies a U-shaped relationship over all time periods.[13] The implied effect of the median negative rainfall shock in in year *t* is an improvement in political rights of around 0.03 points over 1 year. Over a 3-year period, the increase in political rights is around 0.08 points. Over 5-year and 10-year periods, the improvement in political rights implied by the median negative rainfall shock rises to around 0.12 points.

Democratization in Sub-Saharan Africa since 1980 Table 7 summarizes the short-run and longer-run effects of rainfall on democratic change as measured in Table 6 for the subsample of Sub-Saharan African countries since 1980. Rainfall continues to have a U-shaped short-run and longer-run effect on democratization despite the large drop in sample size. The main difference with the results in Table 6 is the timing of the rainfall effects.

IV. Conclusion

As agriculture is harmed by both droughts and very wet conditions, the effect of rainfall on agricultural output is inverted-U-shaped (e.g. Schlenker and Lobell 2010; Lobell *et al.* 2011). We confirm this inverted-U-shaped relationship for the world's most agricultural countries and also show that the effect of rainfall on agricultural output is transitory. The relationship between rainfall and democratization is U-shaped, which is consistent with rainfall affecting democratization through its inverted-U-shaped effect on agricultural output. Moreover, the U-shaped relationship between rainfall and democratization persists in the long run. Hence, as hypothesized by Acemoglu and Robinson (2001, 2006)

TABLE 7
RAINFALL AND DEMOCRATIC IMPROVEMENTS IN SUB-SAHARAN AFRICA SINCE 1980: FROM SHORT TO LONG TERM

	Panel A: Polity Project democratic improvement				Panel B: Polity Project democratization				Panel C: Freedom House political rights			
	Polity improvement between $t-1$ and				Polity democratization between $t-1$ and				Political rights improvement between $t-1$ and			
	t (1-year) (1)	$t+2$ (3-year) (2)	$t+4$ (5-year) (3)	$t+9$ (10-year) (4)	t (1-year) (5)	$t+2$ (3-year) (6)	$t+4$ (5-year) (7)	$t+9$ (10-year) (8)	t (1-year) (9)	$t+2$ (3-year) (10)	$t+4$ (5-year) (11)	$t+9$ (10-year) (12)
Rainfall t	−0.116	−0.567*	−0.979**	−0.656*	0.007	−0.044*	−0.100***	−0.080**	−0.044	−0.140*	−0.386***	−0.225*
	(0.200)	(0.309)	(0.400)	(0.353)	(0.021)	(0.027)	(0.035)	(0.035)	(0.042)	(0.078)	(0.098)	(0.126)
Quadratic rainfall t	0.003	0.017**	0.020**	0.016	0.000	0.001	0.002**	0.002**	0.001	0.003*	0.009***	0.004
	(0.004)	(0.008)	(0.010)	(0.010)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)
Rainfall $t-1$	−0.027	−0.055	−0.333	−0.154	−0.006	−0.047*	−0.059*	−0.048	0.073***	−0.086	−0.062	−0.192
	(0.180)	(0.293)	(0.392)	(0.370)	(0.021)	(0.026)	(0.033)	(0.034)	(0.028)	(0.074)	(0.093)	(0.136)
Quadratic rainfall $t-1$	0.001	−0.002	0.007	0.006	0.000	0.001	0.001	0.001	−0.001**	0.002	0.000	0.003
	(0.005)	(0.007)	(0.009)	(0.011)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.004)
Rainfall $t-2$	−0.330	−0.857**	−0.444	0.207	−0.052**	−0.131***	−0.085***	−0.047	−0.110**	−0.248***	−0.166*	−0.423***
	(0.233)	(0.344)	(0.384)	(0.359)	(0.024)	(0.031)	(0.033)	(0.034)	(0.043)	(0.072)	(0.088)	(0.135)
Quadratic rainfall $t-2$	0.011*	0.020**	0.013	−0.006	0.001**	0.003***	0.002**	0.001	0.002**	0.005***	0.004*	0.010***
	(0.006)	(0.008)	(0.009)	(0.009)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)

TABLE 7
CONTINUED

	Panel A: Polity Project democratic improvement				Panel B: Polity Project democratization				Panel C: Freedom House political rights			
	Polity improvement between $t-1$ and				Polity democratization between $t-1$ and				Political rights improvement between $t-1$ and			
	t (1-year) (1)	$t+2$ (3-year) (2)	$t+4$ (5-year) (3)	$t+9$ (10-year) (4)	t (1-year) (5)	$t+2$ (3-year) (6)	$t+4$ (5-year) (7)	$t+9$ (10-year) (8)	t (1-year) (9)	$t+2$ (3-year) (10)	$t+4$ (5-year) (11)	$t+9$ (10-year) (12)
Countries	22	22	22	21	22	22	22	21	22	22	22	21
Observations	454	424	392	349	463	444	416	357	616	508	445	362
R-squared	0.039	0.055	0.062	0.057	0.028	0.087	0.069	0.044	0.045	0.103	0.109	0.087

Notes
The left-hand-side variables in columns (1)–(4) are the improvements in the Polity IV Project combined polity score in non-democracies over different time periods. The left-hand-side variable in column (1) is the improvement in the polity score between years $t-1$ and t; the left-hand-side variable in column (2) is the improvement in the polity score between years $t-1$ and $t+2$; the left-hand-side variable in column (3) is the improvement in the polity score between years $t-1$ and $t+4$; and the left-hand-side variable in column (4) is the improvement in the polity score between years $t-1$ and $t+9$. The left-hand-side variables in columns (5)—(8) are indicators for democratization over different time periods constructed as the democratization indicators in Table 3. The classification of democratic and autocratic regimes is based on the Polity IV Project combined polity score. The left-hand-side variables in columns (9)–(12) are the improvements in political rights over different time periods measured by the Freedom House political rights index. The left-hand-side variable in column (9) is the improvement in political rights between years $t-1$ and t; the left-hand-side variable in column (10) is the improvement in political rights between years $t-1$ and $t+2$; the left-hand-side variable in column (11) is the improvement in political rights between years $t-1$ and $t+4$; and the left-hand-side variable in column (12) is the improvement in political rights between years $t-1$ and $t+9$. The countries included in the analysis are all Sub-Saharan African countries with an average share of agriculture in GDP over the 1970–2013 period in the top quintile of the distribution or, equivalently, with an average share of agriculture in GDP above the Sub-Saharan African median. The specification includes country fixed effects, year fixed effects, and linear and quadratic contemporaneous and lagged temperature effects. The specification also includes a linear and quadratic term for rainfall lagged by 3 years but these terms are generally statistically insignificant and not reported for brevity. The numbers in parentheses are HAC standard errors that are robust to both arbitrary heteroscedasticity and serial correlation.
*, **, *** denote significance at the 10%, 5%, 1% level, respectively.

and Besley and Persson (2019), democratic transitions can outlast the (transitory) shocks that started the democratization process.

To get a sense of the magnitude of the longer-run effect of rainfall on democratization, consider an adverse rainfall shock equal to the median year-on-year drop in rainfall in the world's most agricultural countries. Suppose that this shock affects a country following a year where the rainfall level was equal to the median. Our estimates of the effect of rainfall on agricultural output imply that this shock lowers contemporaneous agricultural output by around 1 percentage point, but does not affect agricultural output in the longer run. Our estimates of the effect of rainfall on democratization imply that the adverse rainfall shock makes it around 2 percentage points more likely that the country will be democratic 10 years later.

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NOTES

1. While this view fits with our empirical work, it is not the only possibility. For example, an alternative possibility to which Aidt and Leon (2016) point is that agricultural-output shocks could trigger internal migration, and the tension that this causes in the receiving regions could spark riots and ultimately demands for democratization.
2. Brückner and Ciccone (2011) also estimate specifications where short-run democratic change is linked to rainfall shocks as well as lagged democracy indices. These democracy indices capture the persistence of all democratization events, including democratization events driven by persistent socioeconomic shocks in the country or persistent shocks to the international political environment. Our interest is specifically in the persistence of democratization events that are triggered by transitory shocks.
3. Dell (2012) also examines longer-run effects of transitory rainfall shocks. She shows that local variation in drought severity just before the Mexican Revolution affected long-run local development.
4. Using the regime classification of Geddes *et al.* (2014), we code a country as democratic if it is a democracy or if it is ruled by a provisional government overseeing its transition to democracy. We drop years where according to them the country is not independent, it is occupied by a foreign nation, or there is no government controlling most of the territory.
5. Acemoglu *et al.* (2019) combine information from Freedom House and Polity IV, supplemented by dichotomous measures from Cheibub *et al.* (2010) and Boix *et al.* (2013).
6. We also estimate the equation using (log)GDP per capita from the Penn World Tables (PWT) on the left-hand side of equation (1), but find no significant effects, probably because of the quite extreme noise in PWT GDP for low-income countries; see Johnson *et al.* (2013).
7. Maertens (2021) also finds the effect of lagged rain on agricultural output to be statistically insignificant in a very similar empirical specification estimated for Sub-Saharan African countries only. This remains true when he controls for rainfall over agricultural land during the growing season. Schlenker and Lobell (2010) and Lobell *et al.* (2011) assume a contemporaneous effect only in their empirical specifications.
8. We also find a statistically significant and U-shaped effect of rainfall on democratization between years $t-1$ and $t+14$ (15 years later). We focus on democratization periods of up to 10 years because the number of observations decreases with the length of the democratization period.
9. We also find a statistically significant and U-shaped effect of rainfall on democratization between years $t-1$ and $t+14$ (15 years later).
10. Online Appendix Table 5 shows results when, following Brückner and Ciccone (2011), we assume that the probability of democratization depends on the log-level of rainfall. Results point in the same direction but indicate a somewhat different timing than when using the quadratic specification on which we focus.
11. We also find a statistically significant and U-shaped relationship between rainfall and democratic improvement between years $t-1$ and $t+14$ (15 years later). Panels A1 and A2 of Online Appendix Figure 2 illustrate the empirical fit of the U-shaped effect using augmented-component-plus-residual plots.

12. We are not looking at results in non-democracies only as the Freedom House political rights index is not used to classify countries into democracies and non-democracies.
13. Panels B1 and B2 of Online Appendix Figure 2 illustrate the empirical fit of the U-shaped relationship between rainfall and improvements in political rights using augmented-component-plus-residual plots.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix Tables 1–6
Appendix Figures 1–2