Irrigation and Autocracy

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Abstract

We show that societies with a history of irrigation-based agriculture have been less likely to adopt democracy compared to societies with a history of rainfed agriculture. Rather than actual irrigation, our empirical analysis is based on how much irrigation potentially can increase yields. Irrigation potential is derived from a range of exogenous geographic factors, and reverse causality is therefore ruled out. The link between irrigation and institutions exists both at the cross-country level, and at the subnational level in premodern societies surveyed by ethnographers.

1 Introduction

Since the Enlightenment, no concept has drawn more attention from social scientists and political philosophers than democracy. It has even been said that democracy is the worst form of government except all those other forms that have been tried from time to time.[1] From an

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[1] Remark by Winston Churchill in a speech in the House of Commons November 11, 1947.

economic perspective, it is closely related to secure property rights, the rule of law, and other institutions believed to be conducive to long term economic development. Autocratic regimes, by contrast, are prone to growth-reducing rent seeking by the ruling elite.[2] Understanding the roots of democracy and autocracy is therefore an important question, not only because democracy is desireable in itself, but also because it is a determinant of global inequality.

We investigate a specific geographical source of present day institutions, namely whether a society in historical times was dependent on large scale irrigation. The link between irrigation and autocracy was noted both by Adam Smith, John Stuart Mill, and Karl Marx, but it is perhaps most forcefully articulated by Karl August Wittfogel in *Oriental Despotism*.[3] Wittfogel argues that the construction and maintenance of large scale irrigation systems required a strong leadership, which in historical times meant a centralization of power in the hands of a despotic ruler. The ability to control water resources gave the despot more sway over his subjects than in areas with widespread rainfed agriculture. In turn, this made it possible to increase rent-seeking to levels unknown in Europe without fearing revolt. Wittfogel gives ancient Egypt, Mesopotamia, India, China, and the Andean and Mexican civilizations as examples.[4]

Oriental Despotism has been hotly debated and is routinely dismissed by anthropologists and historians.[5] Arguably, Wittfogel takes his theory too far, but based on two different data sets, we confirm that he was right about the basic empirical link between irrigation and autocracy.

The cornerstone in our analysis is a measure of irrigation *potential.* It is based on geographical factors and unaffected by institutions. So, by using irrigation potential rather than actual irrigation as explanatory variable, reverse causality is ruled out. Moreover, irrigation potential is correlated with historical use of irrigation across premodern societies surveyed by ethnographers.

With the irrigation potential measure in hand, we show that countries with a high irriga-

[2]See, *e.g.*, Acemoglu and Robinson (2012) for a recent book-length discussion.

[3]Smith (1776 [1999]) book IV, chapter IX, Mill (1848) p. 20-21, Marx (1853), and Wittfogel (1957). While irrigation is not mentioned explicitly, Smith (1776 [1999]) discusses the differences between Europe and the great irrigation-based civilizations in Egypt, India, and China.

[4]Wittfogel (1957) p. 24.

[5]See, *e.g.*, Toynbee (1958), Leach (1959), Needham (1959), Mann (1986), or Fukuyama (2011).

tion potential are more likely to be autocratic today as measured by the Polity IV index of democracy. Likewise, ethnographic societies in areas with high irrigation potential were more likely to be ruled by an elite that based its power on control of natural resources. In both data sets the relationships are statistically significant and robust to a wide range of control variables.

There is a large literature investigating the link between autocracy and irrigation, but it is entirely based on case studies.[6] Our contribution is to go beyond the case studies found in the anthropological and historical literature and look for more systematic evidence. To our knowledge we are the first to test the theory using statistical methods.[7]

We do not interpret our results as showing that irrigation has a strong direct impact on institutions today. It seems implausible that Sweden, say, would turn autocratic overnight if climatic change were to produce conditions similar to those of Egypt, especially since agriculture is so relatively unimportant to the modern Swedish economy. Instead, the observed link between irrigation and present day autocracy should be viewed as a manifestation of a historical process. Power structures forged in premodern times as a consequence of irrigation-based agriculture made countries less susceptible to the waves of democratizations that have flowed across the world since the 19th century. The argument resonates with string of recent contributions to the economics literature dealing with instiutional persistence. Notable examples are North (1990), Engerman and Sokoloff (2000), Acemoglu *et al.* (2001) and Nunn (2007). Our analysis is thus embedded in this line of research.

While our results are consistent with *Oriental Despotism*, the channel through which irrigation has shaped autocratic institutions may well be different from what Wittfogel suggested. For instance, Mayshar *et al.* (2012) argue that irrigated agriculture made yields more predictable and thus an easier object to tax. Predictability also made serfdom or share cropping more viable compared to areas with rainfed agriculture. Local land lords may therefore have

[6] Examples are Leach (1959) and Toynbee (1958) along with numerous others. See Mitchell (1973) and Hunt and Hunt (1976) for overviews of the literature.

[7] Since precipitation is one determinant of irrigation potential, partial exceptions are Midlarsky (1995) and Haber and Menaldo (2010), who study two different links between rainfall and institutions. But as shown empirically in Section 4, irrigation potential is a stronger determinant of present day autocracy.

been relatively more powerful in irrigated societies and better able to withstand democratization, much in the same way as Engerman and Sokoloff (2000) argue it was the case in plantation based economies in the New World.[8] The results from the ethnographic data supports this notion.

Many historical determinants of institutions have been suggested, but we show that the effect of irrigation does not work through channels known in the literature to have had an impact on present day institutions. These include income levels, as argued by Lipset (1959), natural resource abundance, as argued by Ross (2001), and, perhaps most notably, colonization. Acemoglu *et al.* (2001), Feyrer and Sacerdote (2009), Olsson (2009), Dell (2010) and Hariri (forthcoming), among others, show that European colonialism exported institutions to other parts of the world. Reassuringly, the statistical relationship between irrigation potential and autocracy remains both in a subsample of non-colonies, and in a subsample of former colonies. The effect of irrigation on autocracy is smaller across former colonies, however, and our results are therefore consistent with the view that European presence had a long lasting impact on institutions.

The paper is organized as follows. In Section 2, we review the theoretical link between large scale irrigation and present day institutions. Section 3 describes the methodological approach used in the empirical analysis, particularly with respect to our measure of irrigation potential. Armed with an empirical strategy, we proceed to test the link between irrigation and autocracy on two data sets: cross country data in Section 4, and a more disaggregated data set based on ethnographic studies in Section 5. Section 6 concludes.

2 The Theory of Irrigation and Autocracy

The concept of oriental despotism has existed in one form or another in European intellectual discourse for millenia. Aristotle, Herodotus, Montesqieu and Hegel, to name a few, all considered Middle Eastern and Asian institutions less representative and more despotic than what they were used to in Europe. Karl Marx dubbed it the Asiatic Mode of Production

[8]Engerman and Sokoloff (2000) argue that some crops were better suited for extractive enterprise by ruling elites. Hence, in these areas, the ruling elite managed to grasp more power and to keep it.

and, inspired by Adam Smith and other classical economists, argued that the ability to control water was one reason for the state's dominance in the irrigation dependent societies in Asia.[9] Expanding on their analysis, Wittfogel (1957) called it *the hydraulic society*, allthough he kept *Oriental Despotism* as the title of his book to maintain the connection to the earlier literature. We follow Wittfogel (1957) and use the term hydraulic society to mean the set of institutions that evolved in historical times in areas where agriculture relied on large scale irrigation.[10] As explained below, however, we do not believe that the institutions were exactly as Wittfogel envisioned them.

Wittfogel came under heavy fire after the publication of *Oriental Despotism*, but most of the criticism was aimed at aspects of his theory that we are not interested in. Particularly, Wittfogel's claim that irrigation was a cause of state formation has been refuted by scores of anthropologists and archaeologists who have shown that the emergence of the state preceeded large scale irrigation by centuries, even millenia.[11] Let us therefore be clear. The hypothesis we investigate is not about the origin of the state, it is about whether areas with irrigation based agriculture are more autocratic today.

In this section we spell out the hypothesis in greater detail. First, we describe a number of channels through which irrigation shapes institutions and the distribution of power. Second, we argue that these institutions can perpetuate through time and affect a society's resilience to democratization.

2.1 The hydraulic society

Agriculture in hydraulic societies differed from rainfed agriculture in several crucial aspects that tilted power in favor of a landed elite or a centralized government at the expense of the

[9] Marx (1853). See O'Leary (1989) for an account of the history of thought on the asiatic mode of production.

[10] The hydraulic society should be distinguished from what Wittfogel (1957) called hydroagriculture. The difference is a matter of scale. In the hydraulic society, farmers are dependent on a common irrigation system of canals and dams. In hydroagriculture, farmers are dependent on irrigation, but the geographical conditions make coordination unneccessary or impossible. Wittfogel mentions Japan as an example of the latter. For further discussion, see Price (1994).

[11] See, *e.g.*, Carneiro (1970).

peasants.[12] Irrigated agriculture relied, for instance, on public works like dams and canals which required the mobilization of a large labor force. Moreover, the problem of allocating water between plots created an interdependence among farmers not found in rainfed societies.

Both the building of irrigation systems and the problem of allocating water required an institutional framework that could handle coordination problems, preventing free-riding and solving disputes over scarce water resources when irrigated areas were too large to be managed by kin. In pre-modern times, where only primitive technologies were available, the most efficient solution is likely to have been a strong authoritarian leadership. This could either be in the hands of a pharao-like despot, as Wittfogel envisioned, or in the hands of a local landed elite. The geographer Commadore B. Fisher, observing early 20th century Persia, noted that:

> *"Because of the expense and the difficulty of cooperative effort on the part of small landowners, these irrigation systems are privately owned and tend to perpetuate the feudal system which is well organized in Persia today. A wealthy family can purchase an extensive tract of desert land, make a large investment in a water system, and attract hundreds of tenants who are eager to make their homes around the water supply. Under the need of water and the difficulty of securing it, these tenants are easily reduced to virtual slavery."*[13]

Admittedly, irrigation systems can be built and maintained in a completely decentralized fashion, as Ostrom (1990) shows. Although exceptions can be found, such arrangements are inherently unstable due to the bargaining process involved and tend to be short-lived compared to centralized systems.[14] Moreover, in historical times when property rights were less secure, decentralized irrigation systems were likely to be expropriated by rent-seeking rulers or elites. A transfer of power the other way is less likely. Compared to rainfed agriculture where the source of water is uncontrollable, it is relatively easy to control the water supply in most irrigated systems at low costs. One needs only to guard and govern the section of the irrigation system close to the physical source of water.

[12] Whether the central authorities and landed elites were secular or based their power on religious beliefs is not central to our argument.

[13] Fisher (1928).

[14] See, *e.g.*, Ostrom and Gardner (1993), footnote 15.

Another mechanism through which irrigation can affect institutions is related to transparency. As pointed out by Mayshar *et al.* (2012), the observability of the amount of water allocated to the individual plot in irrigated areas increased the transparency in agricultural production. Such transparency made taxation easier. In Egypt, for example, accurate estimates of yields could be calculated in advance by observing the height reached by the annual floods, and taxes could be set accordingly.[15] Ease of taxation reduced the bargaining power of the population when the rulers were in need of revenue, which, as argued by Bates and Lien (1985), made the rulers less likely to offer representation in return for tax payments.

Transparency also meant that tax collection and the daily management of irrigation systems could be delegated to local land lords without causing moral hazard problems. The central government could simply calculate the amount owed to the state and punish the land lords if they failed to provide the government with its share. Decentralized control of the water, particularly in Egypt, has often been used to dismiss Wittfogel's hypothesis.[16] Yet, it may in fact be a reflection of the government's ability to excercise control in a hydraulic society.

Perhaps more importantly, the transparency in agricultural production provided by irrigation made absentee landlordism based on sharecropping or outright serfdom more attractive. The land owner did not need to monitor effort directly as shirking could be prevented by promising severe punishment if the tenant or serf failed to produce the amount of crops predicted by the water allocated to the plots. Large land holdings were therefore more economically attractive in irrigated societies than in rainfed areas and, as a consequence, a centralization of land ownerhip in the hands of an elite or a despotic state were more likely to occur. The tendency was reinforced by the high fixed costs of building and maintaining irrigation systems as explained by Commadore B. Fisher in the quote above.[17]

[15] Cooper (1976) documents this procedure. See also Mayshar *et al.* (2012).

[16] *E.g.*, Manning (2012).

[17] Serfdom and sharecropping seems to have been the norm in the ancient hydraulic societies identified by Wittfogel (1957). An interesting case analyzed by Mayshar *et al.* (2012) is Mesopotamia. Agriculture in Lower Mesopotamia (Babylonia) was fed by water from Tigris and Euphrates, and land ownership was concentrated with a small, but powerful elite. Independent owner-occupied farms were, by contrast, prevalent in Upper Mesopotamia where agriculture was chiefly rainfed. A more recent example is documented by Islam *et al.* (1997), who show that the correlation between the share of land with canal irrigation and the share of land

2.2 Resistance to democratization

Monopolization of water, ease of monitoring and elite-controlled agriculture reduced the economical and political power of the general population in hydraulic societies compared to their rulers. Whether the rulers were landed elites or despotic governments is not central to our argument. What matters is that open access to compete for power was highly unappealing to them, as it would erode their power bases.[18] That was not unique to hydraulic societies, but the centralization of power fostered by irrigation made elites or despots in such societies better able to respond to popular revolt, and thereby fend off calls for democracy.

The argument is analogous to the Engerman and Sokoloff (2000) analysis of how the interplay between geography and colonization shaped institutions in the Americas. They argue that areas suitable for cash crops like sugar and cotton became dominated by large plantations worked by slaves or indentured servants. Even when slavery was abolished, the ruling elites maintained their land ownership and much of their political power. Democracy would disturb this position of power, and the elites consequently supported autocratic regimes. Areas only suitable for grains or livestock, on the other hand, were mainly inhabited by independent smallholders and therefore more susceptible to democracy.

The present day link between irrigation and autocracy is according to our argument a result of power structures and institutions forged through the course of history. Moreover, such institutional persistence is self-perpetuating if increased representation may spur economic growth, which itself could drive further development of representative institutions. For instance, as shown by Easterly (2007), Galor *et al.* (2009) and Gallego (2010), societies with a relatively egalitarian pattern of land ownership are more likely to foster human capital promoting institutions. Countries which were initially more autocratic should consequently grow more slowly and therefore develop democracy even later.

tilled by tenants was 0.58 across districts in Punjab in the early 1920s.

[18] Indeed, moves towards broad representation have often been accompanied by land reform. See Conning and Robinson (2002).

3 Methodology and irrigation data

To test whether societies with high dependency on irrigation are more autocratic, we estimate regressions on the form:

$$institutions_i = \alpha_0 + \alpha_1 irrigation\ potential_i + X_i'\beta + u_i \tag{1}$$

where i indexes countries in Section 4 and ethnographic societies in Section 5. The measure of *institutions* will be different depending on the level of disaggregation, so we leave it unspecified for now. X is a vector of control variables and u is an error term. The effect of irrigation on *institutions* is captured by the coefficient α_1.

Our explanatory variable is *irrigation potential* rather than actual irrigation. There are three reasons for this. First, actual irrigation is likely to be endogenous. For example, higher income could lead to more investments in irrigation. If democratic institutions are conducive to economic development this would bias our estimate of α_1. Furthermore, strong autocratic regimes may have been better able to undertake large irrigation works, which could lead to problems with reverse causality.[19] Second, there is, to our knowledge, no reliable historical measure of national irrigation. Third, even if we could obtain a historical irrigation measure, this would reflect irrigation in a particular year, which is problematic since we believe that the level of autocracy today is a product of a long, accummulated history of irrigation.

For these reasons we use data on irrigation potential taken from the Food and Agriculture Organization (FAO)'s global Agroecological Zones (GAEZ) 2002 database.[20] For each $0.5\text{x}0.5^o$ grid cell FAO computes the potential yield of irrigated agriculture relative to rainfed agriculture using climatic and geographic data. The construction of the yield increase data at the grid-cell level boils down to the following four steps:

1. Does the soil quality and the distribution of temperature and sunlight hours across the year allow for production of crops at all? If no, the cell is classified as unsuitable for agriculture. Otherwise, proceed to step 2.

[19] This has often been used to criticize Wittfogel (1957), see, *e.g.*, Fukuyama (2011).

[20] Our empirical strategy is similar to that of Nunn and Qian (2011), who use agricultural suitability for growing potatoes as a source of exogenous variation in actual potato cultivation.

2. Is there enough precipitation for crop production? If no, and if there is no source of water nearby, the cell is classified as unsuitable for agriculture. If there is enough precipitation and/or a nearby source of water proceed to step 3.

3. Compute the rainfed crop yield using data on soil fertility and the yearly distribution of temperature, sunlight hours, and precipitation. Compute the irrigated crop yield using data on soil fertility and the yearly distribution of temperature and sunlight hours while assuming that there is always sufficient amount of water available for optimal crop growth.

4. Compute the percentage increase in crop yield obtained by using irrigation compared to rainfed agriculture. Use this number to place the cell in one of the five following impact classes: 1: 0%, 2: 1-20%, 3: 20-50%, 4: 50-100%, and 5: >100%.

The resulting data is depicted in Figure 1. Now, we can aggregate the measure of irrigation impact classes up to the relevant unit of observation. We do this in the following way:

$$irrigation\ potential = \frac{arable\ land\ where\ yield\ increase\ from\ irrigation\ > x\%}{arable\ land}, \qquad (2)$$

where x should be intepreted as the minimum return to irrigation where it is economically viable given the costs of construction and maintenance; *irrigation potential* is therefore the fraction of total arable land where irrigation is worthwhile. Arable land is the sum of the area of impact classes 1 through 5. In order to settle with one measure of irrigation potential, we need to find the cut-off value, x.

3.1 Finding the cut-off value x

Technological progress means that the cut-off value x is likely to have been higher historically than it is the case today. Mechanization and development of new types of irrigation (*e.g.*, sprinkler irrigation) has reduced costs. At the same time, the development of new types of seed, fertilizer, and pesticides has made the *absolute* gain from irrigation larger in each impact

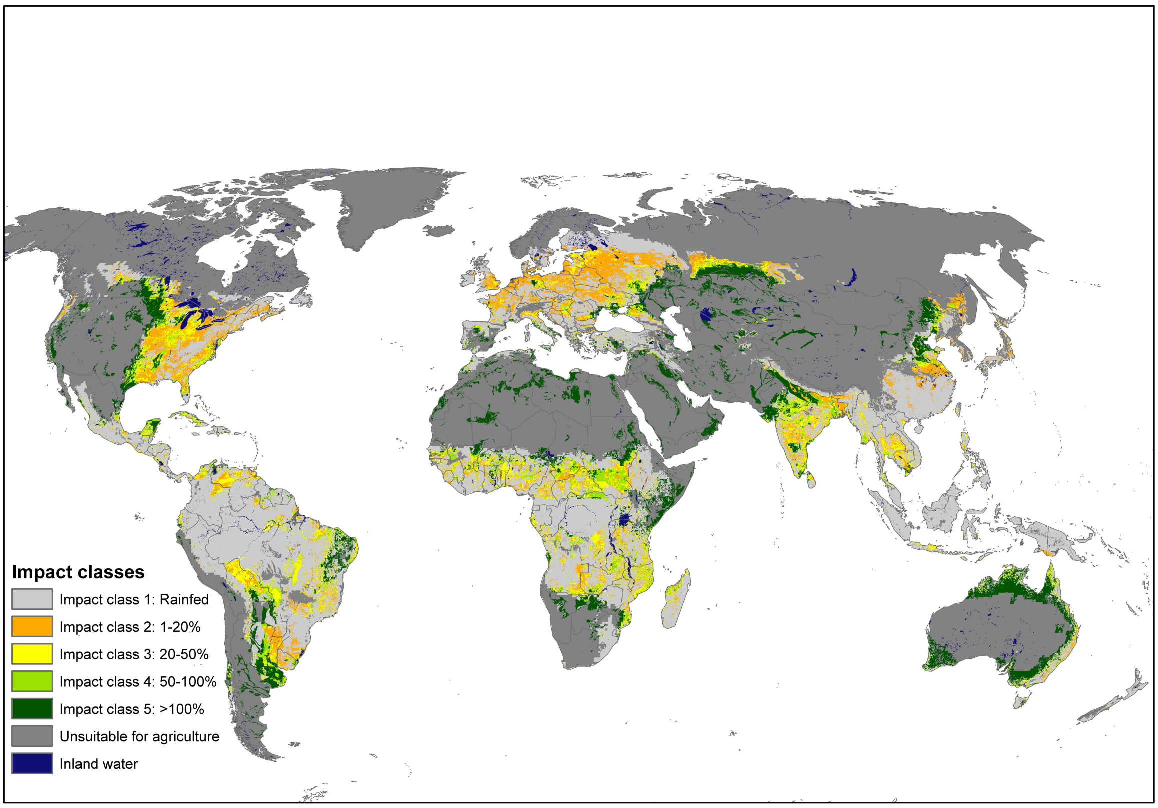


Figure 1: Irrigation impact classes.

Sources: Impact classes: Food and Agriculture Organization (FAO)'s global Agroecological Zones (GAEZ) 2002 database, Country borders: http://www.thematicmapping.org.

class. So, while it is likely to be profitable to adopt irrigation in areas where irrigation can increase crop yields by only 1-20% today, it was probably not the case historically.

To find out which cut-off to use in our empirical analysis, we investigate how irrigation potential based on different values of x correlate with actual irrigation use in pre-industrial societies. To this end we take the data from the Ethnographic Atlas constructed by Murdock (1967). The dataset comprises historical information on 1167 societies scattered across the globe.[21] 319 of these societies had intensive agriculture at the time of observation. Of these, 126 had irrigated intensive agriculture. For each society we calculate the irrigation potential within a 200 km radius of the society centre. Seven of the 319 societies are placed on small islands where no irrigation potential data is available, and the sample is consequently reduced to 312 observations.

Table 1 shows the simple correlations between actual irrigation and irrigation potential, changing the cut-off levels for the yield gain such that we include a consecutively larger fraction of land as we move down the rows. Actual irrigation correlates significantly with irrigation potential, independent of the cut-off level. However, the correlation coefficient is smaller when the cut-off is lower. We therefore use $x = 100\%$ in our empirical analysis. Our results are robust to using a lower cut-off, albeit significance falls, as countries that had no irrigation historically are more likely to get a score different from zero.

Table 1: Correlations between actual and potential irrigation

	Actual irrigation
Irrigation potential (>100%)	0.314***
Irrigation potential (>50%)	0.298***
Irrigation potential (>20%)	0.272***
Irrigation potential (>0%)	0.208***
Observations	312

Notes: Each row represents a correlation between actual and potential irrigation across ethnographic societies. Actual irrigation is a dummy variable = 1 if agriculture is irrigation-based and 0 if it is rainfed. Irrigation potential (>x%) is the fraction of arable land where the yield increase obtained from irrigation is larger than x%, where x = 100, 50, 20, and 0, respectively. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively.

[21] The Ethnographic Atlas is discussed in more detail in Section 5.

3.2 The measure of irrigation potential

In our empirical analysis we define *irrigation potential* as the fraction of arable land where the yield gain from irrigation is more than 100% (impact class 5 in Figure 1).[22] It therefore ranges continuously from 0 to 1, where 1 means that irrigation can more than double agricultural production everywhere in the region. We call this full irrigation potential. Examples of countries with *irrigation potential* = 1 are Egypt, Turkmenistan, and Qatar. Conversely, *irrigation potential* = 0 when irrigation is not economically profitable (given the cut-off value of 100%) anywhere in the region. Examples of countries with irrigation potential = 0 are United Kingdom, Denmark, and Macedonia.[23] Countries with intermediate levels of irrigation potential include Argentina (0.42), Jordan (0.54), and Namibia (0.56).

4 Evidence across countries

In our cross-country analysis, the outcome variable is the degree of democracy in a society as measured by the *polity*2 index from the Marshall *et al.* (2010) Polity IV database.[24] The index ranges from -10 to +10, where +10 is a full democracy with free elections, strong constraints on the executive, and well protected civil liberties. Examples of countries with a score of 10 is the United States, the United Kingdom, and Sweden. The only countries to score a -10 are Saudi Arabia and Oman, but places like Uzbekistan, Belarus, North Korea, and Eritrea are close. Following Hariri (forthcoming), we average the *polity*2 index over the post-Cold War period (1991-2010) to reduce the noise from institutional volatility in politically unstable countries.[25]

Column (1) of Table 2 shows the simple correlation coefficient between irrigation and the

[22] One concern is that geographic factors that enter directly into the *irrigation potential* may be better at predicting historical irrigation use. Appendix Table 8 shows that this is not the case.

[23] These countries would have a much higher irrigation potential, if we used the lowest cut-off level of >0%, which is in line with the relatively high present day irrigation levels in these countries. This supports the idea that present day costs related to irrigation are fairly low, meaning that a lower benefit is need in order to be willing to engage in irrigation agriculture.

[24] The data is available online from www.systemicpeace.org/polity/polity4.htm.

[25] The results are robust to using only year 2010.

*polity*2 index. The relation is negative and highly significant. Countries with a higher irrigation potential are therefore more autocratic. Taken at face value, the estimate implies that a region with no irrigation potential will be 9.7 points more democratic on the 21 point scale than a country with full irrigation potential. A large effect, but it is perhaps even more noteworthy that irrigation potential alone explains 22.7% of the variation in the *polity*2 index.

4.1 Geographical control variables

Irrigation potential is related to a host of other geographical variables that potentially could drive the result. In this subsection we show that this is not the case. In column (2), continent dummies (Europe, Asia, North America, South America, Africa, and Oceania) are included in the regression. The estimate of interest decreases slightly because Africa and Asia have significantly higher irrigation potential and, at the same time, are more autocratic than the average country. A proxy for development or institutional quality often used in the empirical literature is distance to the Equator. As shown in column (3), countries further away from the Equator are indeed more democratic, but the coefficient on irrigation potential is unchanged and still highly significant.

A range of geographical variables enter directly into our measure of irrigation potential, including (in the numerator) precipitation, temperature, and soil quality, and (in the denominator) arable land. We control for each of these factors one by one in columns (4)-(7).[26] Only the share of arable land is individually significant, and the inclusion of these control variables has neglegible impact on the irrigation potential coefficient.

Haber and Menaldo (2010) show that precipitation exerts a non-linear effect on political institutions, with intermediate levels of rainfall being the most conducive to democracy. They argue that this relationship is a proxy for the climatic suitability for growing cereals, a class of crops which are storable and have only modest returns to scale in their production. Storability allows for an accumulation of surplus, which, according to Haber and Menaldo (2010), historically has permitted trade and specialization. Modest scale returns created a more equal distribution of property, an argument closely related to ours. Combined, Haber and Menaldo

[26] See Data Appendix A for data description and sources.

Table 2: Polity2 and irrigation potential - geographical control variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*
Irrigation potential (%)	-9.726***	-5.786***	-6.546***	-5.697***	-6.320***	-5.990***	-8.144***		-6.732**	-6.883**
	(1.386)	(1.543)	(1.564)	(1.497)	(2.148)	(1.486)	(1.921)		(2.826)	(3.314)
Absolute latitude			0.071**							0.103
			(0.033)							(0.064)
Temperature				-0.097						0.088
				(0.067)						(0.135)
Precipitation					-0.378			5.785**	-1.270	2.960
					(0.898)			(2.323)	(3.493)	(3.631)
No/few soil constraints						5.941				6.472
						(4.963)				(4.756)
Arable land (%)							-3.181**			-3.626*
							(1.439)			(1.896)
Squared precipitation								-1.796*	0.336	-0.469
								(0.935)	(1.208)	(1.209)
Observations	160	160	160	160	160	160	160	160	160	160
R-squared	0.227	0.480	0.493	0.489	0.481	0.485	0.495	0.452	0.481	0.510
Continent dummies	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2-index, which measures how democratic political institutions are. It ranges from -10 (least democratic) to 10 (most democratic) and is computed as an average of yearly values from 1991-2010. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where the yield increase obtained from irrigation is larger than 100%. All geographic variables are computed by averaging over the modern-day borders of the country. Temperature is average daily temperature in ^{o}C. Precipitation is the average daily precipitation in meters. No/few soil contraints is the fraction of land where there are no or few constraints to crop growth. Arable land is the fraction of land where the climate, soil quality, and water sources permit crop growth. All variables are described in more detail in the Data Appendix. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

(2010) contend that these charactaristics of cereal production gave rise to stronger property rights, human capital investments, and the development of representative institutions.

In our regressions, we proxy the nonlinear relationship between rainfall and democracy by adding precipitation and precipitation squared as control variables. Column (8) shows that the nonlinear relationship exists when irrigation potential is excluded from the regression. However, if we include irrigation potential in column (9), both rainfall terms become insignificant individually and jointly, and even change signs.[27]

Column (10) includes all geographical control variables together. The coefficient on irrigation potential is still negative and highly significant.The added-variable plot of column (10) of Table 2 shown in Figure 2 confirms visually that our finding is not driven by a particular country or group of countries.[28] A range of other geographical control variables suggested in the

[27] Confirmed by an F-test with a p-value of 0.897.

[28] The result also holds if we exclude the 10 countries with *irrigation potential* $=1$, the 44 countries with *irrigation potential* $=0$, or all 54 countries at the same time (results not shown here). If anything, the level of significance and the estimate rise in absolute value.

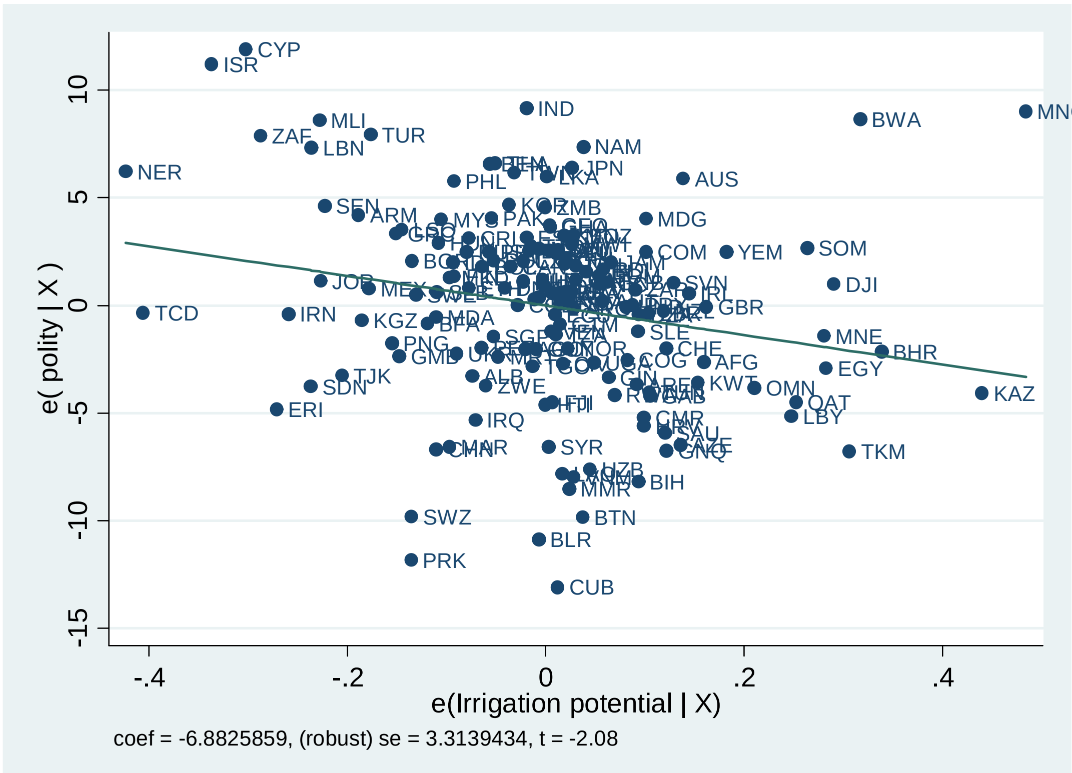


Figure 2: AV-plot of irrigation potential vs polity2 from regression in Table 2, Column (10)

literature to influence economic development or institutions were also tested (see Appendix B, Table 9), but none of these explain any significant variation in the polity index in addition to that explained by irrigation.[29] More importantly, none of them affect our estimate of interest.

4.2 Historical control variables

That institutions are persistent over time is hardly controversial, and a corollary of this is that history matters. In Table 3, we deal specifically with two aspects of the historical process that have drawn attention in the literature: the consequences of a developmental head start and colonization.

We carry the significant geography control variables from the previous section (continent

[29] These include: malaria ecology, distance to coast or navigable river, land within tropics, terrain ruggedness, total area, and a dummy for whether a country is landlocked or not.

dummies and arable land) with us. The sample in Table 3 is somewhat restricted by data availability compared to Table 2 and therefore, column (1) shows the relation between irrigation and democracy in the new and smaller sample. The irrigation potential coefficient decreases, but not significantly so. The standard errors are somewhat larger.

As argued by Diamond (1997) and shown empirically by Hibbs and Olsson (2004), among others, an early onset of the Neolithic Revolution has been associated with a developmental head start that has persisted to this day.[30] If an early start predicts democracy today and at the same time is correlated with irrigation, our result might be biased. We include a measure of years since the Neolithic Revolution constructed by Putterman and Trainor (2006) in column (2).[31] For similar reasons, we include the Bocksette and Putterman (2007) State Antiquity Index and the population density in 1500 AD in columns (3) and (4).[32]

Only population density in 1500 AD explains a significant share of the polity index. The coefficient on population density is positive, indicating that areas more densely populated historically became more democratic. This result seems at odds with the reversal of fortune argument put forward by Acemoglu *et al.* (2002), who argue that densely populated regions colonized by European powers received fewer European settlers bringing democratic institutions with them from their home country. However, as shown in Section 4.5 where we deal with colonization in more detail by splitting the sample in former colonies and non-colonies, the estimated coefficient on population density is mainly driven by countries that were never colonized by Europeans (including Europe). As shown in column (5), colonization does not appear to affect present day institutions in the full sample. But given the amount of attention paid to colonization and institutional development, we go a bit further into the question in Section 4.5.

[30] The term 'Neolithic Revolution' refers to the point in time when a society evolved from relying entirely on hunting and gathering to relying on settled agriculture.

[31] Using instead Putterman's (2008) migration-adjusted years since the Neolithic Revolution produces similar results.

[32] These variables are potentially endogenous and this could bias the main results. Hence, the estimates reported below should be interpreted with caution.

Table 3: Polity2 and irrigation potential - other control variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*fh_free*
Irrigation potential (%)	-7.577***	-6.890**	-7.565***	-7.176***	-7.643***	-7.757***	-7.122***	-5.959**	-8.018***	0.709***
	(2.507)	(2.684)	(2.612)	(2.435)	(2.549)	(2.498)	(2.468)	(2.710)	(1.891)	(0.255)
Arable land (%)	-3.062*	-3.298**	-3.068**	-3.502**	-3.219**	-3.419**	-1.954	-3.401**	-3.833***	0.161
	(1.555)	(1.494)	(1.539)	(1.516)	(1.547)	(1.640)	(1.530)	(1.534)	(1.303)	(0.199)
Years since Neolithic		-0.423						-0.489		
		(0.373)						(0.364)		
State Antiquity Index			-0.050					-0.939		
			(0.963)					(1.036)		
Pop density, 1500				0.140***				0.146***	0.113**	-0.006
				(0.042)				(0.052)	(0.043)	(0.005)
Colony dummy					0.445			-0.283	0.948	-0.129
					(1.743)			(1.748)	(1.474)	(0.211)
Oil (1000barrels/day/cap)						-4.628		-6.436	-7.185***	0.883**
						(3.094)		(4.855)	(2.178)	(0.351)
(log)Real GDP/cap, 2000							1.062**	0.879*	0.949**	-0.278***
							(0.441)	(0.473)	(0.408)	(0.056)
Observations	137	137	137	137	137	137	137	137	154	168
R-squared	0.472	0.481	0.472	0.505	0.472	0.475	0.499	0.544	0.585	0.483
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable in columns (1)-(9) is the polity2-index which measures how democratic political institutions are. It ranges from -10 (least democratic) to 10 (most democratic) and is computed as an average of yearly values from 1991-2010. The dependent variable in column (10) is the democracy measure by Freedom House. It is an indicator variable measure 1 (free), 2 (partly free), and 3 (unfree). Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where the yield increase obtained from irrigation is larger than 100%. All geographic variables are computed by averaging over the modern-day borders of the country. Arable land is the fraction of land where the climate, soil quality, and water sources permit crop growth. Years since Neolithic is the years passed since agriculture was first introduced in a society within the modern-day borders of the country. The state antiquity index is a cumulative measure of how many years the country or any society within the country has been governed by a centralized state. Population density, 1500 is the population in year 1500 divided by the total area. The colony dummy takes on 1 if the country was ever colonized and 0 otherwise. Oil measures the yearly oil production per capita. log real GDP per capita is measured in PPP in 2000. All variables are described in more detail in the Data Appendix. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

4.3 Resources and income

Many of the high-irrigation potential countries are also oil rich, which could prove a curse for democracy.[33] To control for such potential resource curse, we include barrels of oil produced per capita in year 2000 in column (6). Again the irrigation estimate is unaltered. Although insignificant, more oil per capita is associated with less democracy as expected.

Another potential determinant of democracy is present day income, as famously suggested by Lipset (1959). Consequently, income rather than the channels we suggest may drive our results if irrigation is directly linked to economic development. A high irrigation potential could, for instance, have induced faster development by allowing for more densely populated societies and thus a greater division of labor. Or it could be negatively related to present day income if irrigated societies specialized in agricultural production and therefore failed to

[33] *E.g.*, Ross (2001).

develop modern industries.[34]

To check these possibilities we include (the logarithm of) real GDP per capita in year 2000 from Penn World Tables. As expected, richer countries are more democratic. But the effect does not seem to work through irrigation, since the estimated coefficient on irrigation potential is unchanged. Note, however, that including GDP today potentially could lead to an estimation bias due to endogeneity, so the results should be interpreted with caution.

4.4 Including all variables

Column (8) includes all variables described in the two previous subsections simultaneously. It reduces our estimate of interest somewhat, although not significantly. The variables that reduce the sample size compared to Table 2 are years since the Neolithic Revolution, the state antiquity index, and population density in 1500 AD. The two former turn out to be insignificant in column (8), and we therefore exclude them to get a larger sample in column (9). The irrigation potential coefficient is numerically larger and has smaller standard errors in the larger sample. Moreover, consistent with a resource curse, oil production is now negative and significant.

Most specifications in Table 2 and Table 3 indicate that the coefficient on irrigation potential is around 7, meaning that going from no irrigation potential to full irrigation potential will move a country 7 points toward democracy on the *polity*2 scale. Or, to give an example, Algeria as of 2010 ($polity2 = 2, irrigation\ potential = 0.79$) would be as democratic as Turkey ($polity2 = 7, irrigation\ potential = 0.08$) if it did not have a history of irrigation.

4.5 Further robustness

This subsection provides robustness checks of our cross-country analysis. First we use the freedom ratings by Freedom House as an alternative democracy indicator. Countries are categorized as being free, partly free, and unfree based on the amount of political rights and civil liberties they offer their citizen. By assigning numerical values 1 (free), 2 (partly free), and 3

[34] Matsuyama (1992), Galor and Mountford (2006, 2008), and Williamson (2011), among others, argue that such specialization in agricultural production might explain the unequal global distribution of income today.

(unfree), a freedom index is constructed. We call this variable fh_free. Note that now we expect that $\alpha_1 > 0$, which is indeed the case as Table 3, column (10) shows. Areas with higher irrigation potential are more likely to be classified as unfree, and significantly so. The size of the effect is slightly smaller than the estimate using the *polity*2 measure. The estimate equals 23% of the range in fh_free, compared to 33% of the *polity*2 measure.[35]

We now turn to a more thorough investigation of whether the link between irrigation and autocracy is caused by colonization. Table 4 splits the sample in two: a sample of the 60 countries that were never a colony (columns 1-2) and a sample of the 94 countries that were colonized at some point in time (columns 3-5). Together with arable land and continent dummies, we include the variables that turned out to be important in the previous section: population density in 1500 AD and oil production.

Table 4 shows that irrigation potential retains its sign and significance in both subsamples. However, irrigation has exerted a larger impact on autocracy in countries that were never a colony. The results are consistent with the large literature that documents how European conquest amounted to an institutional shock to the New World.[36] That colonization amounts to noise in such manner seems to be confirmed by the big differences in the R^2 in the two subsamples. This is also clear from the added-variable plots in Appendix B Figure 10.

In the last column of Table 4, we include malaria ecology in order to test the notion that the disease environment was crucial for the institutions set up by the colonial powers.[37] We do not find evidence for that hypothesis. The coefficient on irrigation stays unchanged.

Wittfogel (1957) argues that power in hydraulic societies often radiated from an irrigated

[35] Note that the Freedom House measure adds 14 countries to the sample. The coefficient on irrigation potential is unchanged (0.733, se=0.266) if we restrict the sample in column (10) to that in column (9) (not shown here). The sample in Table 2 would increase to 177 if we used the Freedom House measure instead of *polity*2.

[36] *E.g.*, Acemoglu *et al.* (2001, 2002), Engerman and Sokoloff (2000), Iyer and Banerjee (2005), Nunn (2007), Feyrer and Sacerdote (2009), Olsson (2009), Dell (2010), and Hariri (forthcoming).

[37] Acemoglu *et al.* (2001, 2002). They use settler mortality and not malaria ecology as a measure of the disease environment. It is admittedly a more direct measure, but is only available for a smaller sample of colonies. Moreover, settler mortality is insignificant in a regression based on the smaller sample where data is available.

Table 4: Polity2 and irrigation potential - colonies and non-colonies

	(1)	(2)	(3)	(4)	(5)
Dependent variable	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*
Sample	Never colonized	Never colonized	Former colonies	Former colonies	Former colonies
Irrigation potential (%)	-15.866***	-11.370***	-6.478***	-5.796**	-5.674**
	(2.865)	(3.627)	(1.547)	(2.385)	(2.435)
Arable land (%)		-2.540		-4.259**	-4.909**
		(2.060)		(1.885)	(1.920)
Pop density, 1500		0.142***		0.075	0.084
		(0.038)		(0.096)	(0.094)
Oil (1000barrels/day/cap)		-2.005		-6.203***	-6.306***
		(4.714)		(1.824)	(1.853)
Malaria ecology index					0.080
					(0.078)
Observations	60	60	94	94	94
R-squared	0.545	0.640	0.131	0.506	0.511
Continent dummies	No	Yes	No	Yes	Yes

Notes: OLS estimates of *polity2* on irrigation potential for varying samples. Columns (1) and (2) include only countries that were never colonized, while columns (3)-(5) include only countries that were once a colony. The dependent variable is the polity2-index, which measures how democratic political institutions are. It ranges from -10 (least democratic) to 10 (most democratic) and is computed as an average of yearly values from 1991-2010. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where the yield increase obtained from irrigation is larger than 100%. All geographic variables are computed by averaging over the modern-day borders of the country. Arable land is the fraction of land where the climate, soil quality, and water sources permit crop growth. Population density, 1500 is the population in year 1500 divided by the total area. Oil measures the yearly oil production per capita. Malaria ecology measures the contribution of vectors to the force of malaria transmission. All variables are described in more detail in the Data Appendix. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

core to rainfed regions. For instance, throughout most of history the power in China has been concentrated in the irrigated North East. The nationwide irrigation potential variable may therefore understate the importance of irrigation. Another robustness check is therefore to restrict the irrigation potential measure to a 200 km radius around capital cities, which is seen as a proxy for the original center of power in a given country.[38] As shown in Appendix B Table 12, our results are robust to using only irrigation potential around the capital city instead of irrigation potential within country boundaries.

5 Evidence from ethnographic societies

We now move back in history and from the country-level to a more disaggregated level. To this end we use data from the Ethnographic Atlas.[39] The Atlas is based on ethnographic

[38] Admittedly, the location of the capital may be endogenous and a bias may therefore be present in the regression.

[39] Murdock (1967).

evidence from traditional societies scattered around the globe, mostly from the 19th and early 20th century. The data set includes latitude and longitude for each society centre, and it is therefore possible to calculate our geographical variables at the local level using GIS software.

There is no direct measure of autocracy or democracy in the Ethnographic Atlas.[40] Instead we use social stratification as an indicator of the distribution of power in the society. The ethnographic societies are classified into five different groups based on the type of stratification prevalent: complex stratification, hereditary aristocracy, elite stratification, wealth distinctions, and no stratification. We use elite stratification as our dependent variable as it directly captures the sort of power distribution we are interested in.[41] A society with elite stratification is, according to the definition given in the Ethnographic Atlas, a society "...in which an elite class derives its superior status from, and perpetuates it through, control over scarce resources, particularly land, and is thereby differentiated from a propertyless proletariat or serf class."

We construct a variable called *elite*, which equals 1 if the society has elite stratification and 0 if it is placed in one of the other categories.[42] With this definition, 40 societies out of a total of 770 societies where data is available are coded as $elite = 1$.[43] Before running regressions at the disaggregated level, we check whether the *elite* variable is indeed a good indicator of subsequent autocratic institutions. To this end, we average our elite variable across observations within each country and compare the results to the present day *polity*2 index. The correlation is -0.23 and significant, indicating that areas with elite stratification historically are more likely to have turned into autocratic states today.[44] We also check that elite is a better measure than the other

[40] There are some democracy indicators in the related Standard Cross-Cultural Sample (SCCS). Unfortunately, there are too few observations for our purpose, and mostly from societies of hunters and gatherers where irrigation is not relevant to the distribution of power.

[41] Admittedly, power may be centralized in societies with hereditary aristocracy. Yet, without control of resources, an aristocracy is likely to have faced more constraints on their execution of power than a ressource controlling elite.

[42] In some cases there are two classification systems prevailing at the same time. Here, we set elite equal to one if one of the systems are elite stratification.

[43] We restrict the sample to include only societies using agriculture since irrigation does not matter for stratification in a society without it. Moreover, there are no nonagricultural societies with elite stratificatione.

[44] There are in total 115 present day countries with one or more observations of ethnographic societies that

Table 5: Simple correlations between polity2 and social stratification variables

	$Polity2$
Stratification based on:	
- Absence among free men	0.08
- Wealth distinctions	-0.13
- Elite control of resources	-0.23**
- Dual (hereditary astocracy)	-0.11
- Complex (social classes)	0.19**
Observations	115

Notes: Simple correlations between the polity2 index and the five stratification groups across 115 countries. The stratification measures are aggregated up to the country level using present day borders. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

stratification categories. Table shows the simple correlation between the *polity*2 index and the 5 stratification categories. Elite stratification has the highest correlation coefficient with the polity index among all 5 categories. The second highest correlation, which is also the only other significant coefficient, is that for complex stratification. However, this coefficient has the opposite sign; societies with a complex stratification are more likely to end up with democratic institutions today. Since complex stratification is vaguely defined, no clear conclusions can be drawn from this correlation. We conclude that elite stratification seems to be the best measure of historical institutions leading to autocracy.

We run regressions of the form:

$$elite_i = \alpha_0 + \alpha_1 irrigation\ potential_i + X_i' \beta + u_i \tag{3}$$

where $i = 1, ..., 770$ indexes ethnographic societies. We expect that $\alpha_1 > 0$, meaning that irrigation fostered elite stratification. *irrigation potential* and all the geographical control variables are calculated within a 200 km radius of the society centre. In addition to continent fixed effects, we include 55 language group fixed effects since a shared language indicates a shared cultural and historical background. We thereby remove variation in the elite variable caused by a shared culture and history.

The simple regression coefficient between *irrigation potential* and *elite* is shown in Table 6, column (1). It is 0.168 and highly significant. When language fixed effects are introduced in column (2), the estimated coefficient more than doubles. The effect of irrigation on elite stratification therefore seems to have happened within cultural groups rather than between

we can match with the *polity*2 measure. 27 of the countries have elite based societies.

Table 6: Elite stratification and irrigation potential - geographical control variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable	*elite*	*elite*	*elite*	*elite*	*elite*	*elite*	*elite*	*elite*	*elite*
Irrigation potential (%)	0.168***	0.325***	0.326***	0.319***	0.322***	0.316***	0.212***	0.327***	0.125**
	(0.041)	(0.104)	(0.104)	(0.103)	(0.105)	(0.101)	(0.066)	(0.105)	(0.057)
Year			-0.021						-0.004
			(0.050)						(0.061)
Absolute latitude				0.079					0.191
				(0.077)					(0.175)
Precipitation					-0.041				0.106
					(0.108)				(0.173)
Temperature						3.583			9.285
						(2.452)			(5.637)
Arable land							-0.156		-0.233
							(0.121)		(0.141)
No/few soil constraints (%)								-0.050	0.050
								(0.112)	(0.078)
Observations	770	770	770	770	770	770	770	770	770
R-squared	0.057	0.221	0.221	0.221	0.221	0.224	0.230	0.221	0.243
Continent and 55 language dummies	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates of elite on irrigation potential for ethnographic societies. The dependent variable, elite, is a dummy variable equal to one if the society is socially stratified and ruled by an elite which bases its power on control of a natural resource, and zero otherwise. All geographic variables are computed using the grid cells within 200 km of the society centre. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where the yield increase obtained from irrigation is larger than 100%. Year is the year of observation of the ethnographic society. Precipitation is the average daily precipitation in meters. Temperature is average daily temperature in ^oC. No/few soil contraints is the fraction of land where there are few or little soil constraints which inhibit crop growth. Arable land is the fraction of land where the climate, soil quality, and water sources permit crop growth. All variables are described in more detail in the Data Appendix. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors clustered at the language-group level in parentheses.

them.

Column (3) in Table 6 includes the year a given society was observed with no consequence for the results. Likewise, columns (4)-(9) show that all the geographical control variables are insignificant both included individually and jointly.

It could be that elite stratification requires a certain level of economic development absent in primitive societies. If that is the case, the estimated effect of irrigation potential could run through development, and not through the channels outlined in this paper. We therefore control for settlement complexity and agricultural intensity in Table 7 (variables described in the Data Appendix). This does not affect the results.

Note that our dependent variable is a dummy variable, and one might argue that a nonlinear model is preferred to OLS. Column (5) of Table 7 estimates the same relation using probit estimation instead of OLS. The conclusion is unaltered: Irrigation potential exerts a positive and highly significant influence on the probability of elite stratification.

The evidence across ethnographic societies therefore supports the theory. The coefficient

Table 7: Elite stratification and irrigation potential - development control variables

	(1)	(2)	(3)	(4)	(5)
Dependent variable	*elite*	*elite*	*elite*	*elite*	*elite*
Estimation method	OLS	OLS	OLS	OLS	probit
Irrigation potential (%)	0.325***	0.326***	0.315***	0.314***	1.649***
	(0.104)	(0.105)	(0.079)	(0.080)	(0.229)
Agricultural intensity		-0.000		0.002	-0.036
		(0.009)		(0.010)	(0.103)
Settlement complexity			-0.006	-0.006	0.019
			(0.015)	(0.015)	(0.089)
Observations	770	770	770	770	770
R-squared	0.221	0.221	0.222	0.222	0.352[a]
Continent and 55 language dummies	Yes	Yes	Yes	Yes	Yes

Notes: Estimates of elite on irrigation potential for ethnographic societies, columns (1)-(4) estimated with OLS, column (5) estimated with probit. The dependent variable, elite, is a dummy variable equal to one if the society is socially stratified and ruled by an elite which bases its power on control of a natural resource, and zero otherwise. All geographic variables are computed using the grid cells within 200 km of the society centre. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where the yield increase obtained from irrigation is larger than 100%. Settlement complexity measures, on a scale from 1 to 8, the permanency and density of settlements. Agricultural intensity runs from 1 to 4, where 1 is casual agriculture and 4 is intensive agriculture. All variables are described in more detail in the Data Appendix. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively. All regressions include a constant. Robust standard errors clustered at the language-group level in parentheses.
[a] The R-squared from the probit estimation is the pseudo R-squared.

on irrigation potential is positive and highly significant throughout all specifications. Ethnographic societies in areas where irrigation was worthwhile are more likely to have been dominated by a resource controlling elite that, in turn, might have inhibited democratization later on.

6 Conclusion

We have tested the theory that societies with a history of irrigation-based agriculture have developed more autocratic institutions compared to societies with a history of rain-fed agriculture. Such a link has been hypothesized by many prominent scholars throughout history, including Marx (1853) and Wittfogel (1957). Yet, we are, to our knowledge, the first to have tested the theory directly using statistical methods.

Since adoption of irrigation may be influenced by existing institutions or the degree of economic development, we use a measure of irrigation potential to estimate a causal effect of historical irrigation on autocracy. The measure is correlated with historical use of irrigation in premodern societies.

We find that countries in areas with a high potential for irrigation are more autocratic today as measured by the *polity2* index from the Polity IV database. Our results are robust to a wide range of geographical, climatic, and historical control variables. According to our estimates, the difference between a country with no irrigation potential and a country with full irrigation potential is about seven points on the 21 point *polity2* scale. Or, to be concrete, the difference in irrigation potential can account for the gap in institutional quality between Turkey and Algeria. At a more disaggregated level, we document that ethnographic societies in areas with a high irrigation potential are more likely to be ruled by a natural resource-controlling elite.

As the example with Turkey and Algeria shows, the magnitudes involved are quite large. Contemporary effects of irrigation on institutions are unlikely to generate such differences, and we therefore argue that our result is an outcome of a long run historical process. Irrigation in pre-modern societies fostered, for instance, a concentration of land ownership in the hands of a small elite opposed to democratization, much in the same way as plantations and slavery according to Engerman and Sokoloff (2000) had a lasting impact on institutions in the Americas. Other links between historical irrigation use and present day democracy are conceivable, but our empirical methodology does not allow us to separate them. Yet, our results from the ethnographic data set indicate that concentration of ressources played an important role.

Our results contribute to the growing literature on the origins of institutions. Much attention has been paid to economic development and to historical contingencies related to, for example, colonization. However important these determinants might be, a significant fraction of global variation in institutional quality can still be traced to more deeply rooted geographic factors. Sources of water is one, as we show in this paper, but there are most likely many others since the livelihood of the vast majority of humanity until very recently has depended directly on the whims of Mother Nature.

A Data Appendix

Many variables in our analysis are based on grid-cell data. We use GIS software and a shapefile of borders from www.thematicmapping.org to convert them to country averages. The capital city and Etnographic Atlas calculations are done within a 200 km radius of the city or society centre.

Variable	Description	Source
Absolute latitude	Distance in decimal degrees to the Equator from centre of the country, capital city or ethnographic society.	Centroids calculated from country boundaries from www.thematicmapping.org.
Arable land	Share of total area, which is arable according to the impact class measure (impact classes 1+2+3+4+5).	Shapefile of irrigation impact classes: Plate 47 of FAO's 2002 GAEZ database: www.iiasa.ac.at/Research/LUC/SAEZ/
Area in the tropics	Share of total area, which is located in the geographic tropics	Calculated by Nunn and Qian (2011)
Colony dummy	Dummy equal to 1 if the country is included in Olsson's (2009) sample of colonies, zero otherwise.	Olsson (2009)
Continent dummies	Include Europe, Asia, North America, South America, Africa, and Oceania.	
Irrigation potential (>x%)	Share of arable land, where irrigation can increase agricultural yields by more than x%, where x=100, 50, 20, and 0. Our main measure of irrigation potential has x=100, which means that it measures the share of total arable land, where irrigation can more than double agriculture production (impact class 5).	Shapefile of irrigation impact classes: Plate 47 of FAO's 2002 GAEZ database: www.iiasa.ac.at/Research/LUC/SAEZ/
Irrigation potential in capital city	Similar to the cross country irrigation potential measure, just calculated within 200 km of the current capital city.	Same source as cross-country irrigation potential.
Land within 100 km of coast or river	Precent of total area which lies within 100 km of ice-free coast or navigable river, defined by Center for International Development, Harvard.	Shapefile from: www.hks.harvard.edu/centers/cid
Landlocked	Dummy equal to one if the country has no direct access to the sea, 0 otherwise.	
Malaria ecology index	Stability of malaria transmission.	Global malaria ecology index from Kiszewski et al (2004): http://www.ajtmh.org/content/70/5/486.full
Oilpop2000	1000 barrels of crude oil, NGPL, and other liquids per day per capita in year 2000.	U.S. Energy Information Administration: www.eia.gov
Polity index	Index of the degree of democracy of a state. Score ranges from -10 (least democratic) to +10 (most democratic). We have calculated the average over the years 1991-2010.	Polity IV Project: www.systemicpeace.org/polity/polity4.htm
Population density 1500	Population in year 1500 as a share of total land area.	Dataset by Comin et al. (2010)
Precipitation	Average precipitation over the period 1901-2000, in 1000 mm.	Country data: www.cru.uea.ac.uk/cru/data/hrg/
Real GDP per capita	The natural logarithm of real GDP per capita in 2000, the rgdpl2 variable from Penn World Tables version 7.0.	pwt.econ.upenn.edu/php_site/pwt70/pwt70_form.php
Ruggedness	The Terrain Ruggedness Index	Nunn and Puga (2012)
No/few soil constraints	Soil fertility is calculated using FAO's data on soil constraints combined, encompassing soil depth, fertility, drainage, texture, chemical and terrain slope constraints. Soil fertility measures the share of total area, which has only few or no soil constraints.	Shapefile of soil constraints: Plate 27 of FAO's 2002 GAEZ database: www.iiasa.ac.at/Research/LUC/SAEZ/
Statehistory	Bocksette and Putterman's (2007) state antiquity index. Measures state antiquity from year AD 1 - 1950, where a value of zero indicates no government above the tribal/chiefdom level for the entire period, 1 indicates presence of local government with substantial foreign oversight for the entire period.	www.econ.brown.edu/fac/Louis_Putterman/antiquity%20index.htm
Temperature	Average temperature over the period 1901-2000.	Country data: www.cru.uea.ac.uk/cru/data/hrg/
Total area	Total area in 1000 km, excluding inland water.	Calculated from the shapefile: thematicmapping.org/downloads/world_borders.php
Years since the Neolithic Revolution	Number of years (in thousands) since the country first adopted settled agriculture.	www.econ.brown.edu/fac/louis_putterman/agricultural%20data%20page.htm

B Additional Empirical Results

Table 8: Actual irrigation and potential irrigation incl controls

	(1)	(2)	(3)	(4)
Dependent variable	irri	irri	irri	irri
Irrigation potential (>100%)	0.598***			
	(0.126)			
Irrigation potential (>50%)		0.600***		
		(0.139)		
Irrigation potential (>20%)			0.485***	
			(0.140)	
Irrigation potential (>0%)				0.300**
				(0.124)
Absolute latitude	-0.068	-0.058	0.006	0.058
	(0.432)	(0.431)	(0.436)	(0.444)
Precipitation	0.002*	0.002*	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Temperature	-0.001	-0.003	-0.003	0.001
	(0.007)	(0.007)	(0.008)	(0.007)
Land with no/few soil constraints (%)	0.011	0.009	0.101	0.230
	(0.237)	(0.239)	(0.242)	(0.240)
Year	-0.227	-0.231	-0.219	-0.228
	(0.347)	(0.347)	(0.358)	(0.364)
Observations	298	298	298	298
R-squared	0.302	0.293	0.268	0.243
Continent dummies	Yes	Yes	Yes	Yes

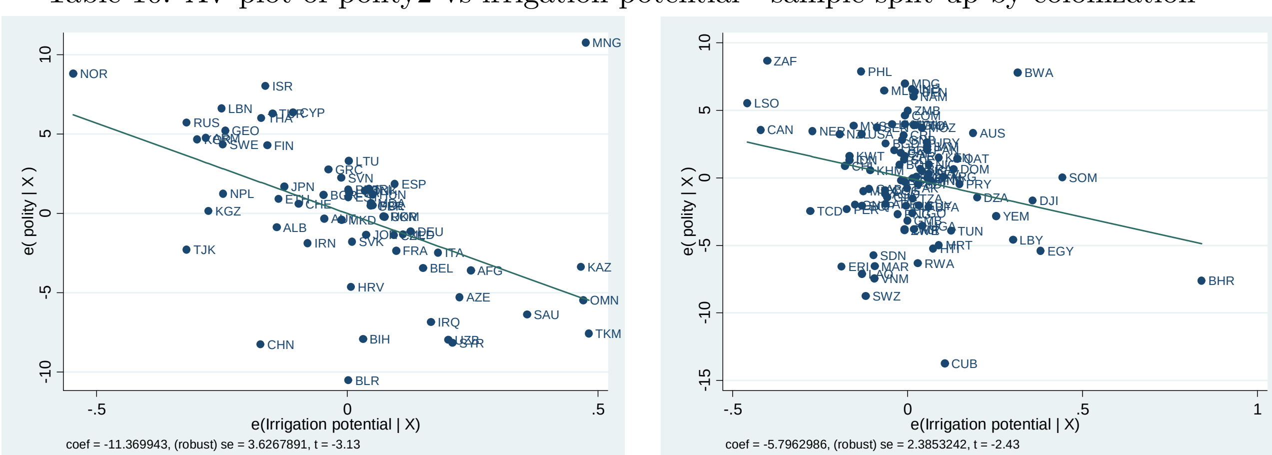
Notes: OLS estimates of actual irrigation on irrigation potential across ethnographic societies. Actual irrigation is a dummy variable which takes on the value 1 if agriculture is irrigation-based and 0 if it is rainfed.All geographic variables are computed using the grid cells within 200 km of the society centre. Irrigation potential ($>x\%$) is the fraction of arable land where the yield increase obtained from irrigation is larger than $x\%$. x takes on the values 100, 50, 20, and 0, respectively. Precipitation is the average daily precipitation in meters. Temperature is average daily temperature in ^oC. No/few soil contraints is the fraction of land where there are few or little constraints which inhibit crop growth. All regressions include a constant. Robust standard errors in parentheses. ***, **, * indicate significance at the 1, 5, and 10% level, respectively.

Table 9: Polity2 and irrigation potential - further geographic control variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*
Irrigation potential (%)	-8.156***	-9.223***	-8.322***	-8.139***	-8.440***	-8.291***	-7.937***	-9.427***
	(1.925)	(2.026)	(1.999)	(1.954)	(2.061)	(2.008)	(1.970)	(2.498)
Arable land (%)	-3.200**	-4.073**	-3.428**	-3.270**	-3.845**	-2.370	-2.802*	-3.281
	(1.449)	(1.636)	(1.486)	(1.490)	(1.701)	(1.689)	(1.556)	(2.225)
Terrain ruggedness, 100 m.		-0.385						-0.331
		(0.388)						(0.449)
Landlocked			-1.051					-0.419
			(0.999)					(1.222)
Malaria ecology index				0.013				0.024
				(0.074)				(0.076)
Land within 100km of coast/river (%)					1.616			1.739
					(1.401)			(1.575)
Land within tropics (%)						-0.011		-0.016
						(0.016)		(0.017)
Total area							0.000	0.000
							(0.000)	(0.000)
Observations	158	158	158	158	158	158	158	158
R-squared	0.490	0.494	0.495	0.490	0.495	0.492	0.493	0.506
Continent dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates. The dependent variable is the polity2-index, which measures how democratic political institutions are. It ranges from -10 (least democratic) to 10 (most democratic) and is computed as an average of yearly values from 1991-2010. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where the yield increase obtained from irrigation is larger than 100%. All geographic variables are computed by averaging over the modern-day borders of the country. Arable land is the fraction of land where the climate, soil quality, and water sources permit crop growth. Ruggedness measures the variability of altitude. The malaria ecology index measures the contribution of vectors to the force of malaria transmission. All variables are described in more detail in the Data Appendix. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

Table 10: AV-plot of polity2 vs irrigation potential - sample split up by colonization



Panel A. Never colonized

Panel B. Former colonies

Notes: Added variables plot, corresponding to columns (2) and (4) of Table 4, where X = continent dummies, arable land, population density 1500, oil.

Table 12: Polity2 and irrigation potential - capital cities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*	*polity2*
Irrigation potential (%)	-8.086***	-5.737***	-5.115**	-5.710***	-5.474***	-5.752***	-5.818***	-5.543**	-4.513**	-6.219***
	(1.798)	(2.096)	(2.175)	(2.139)	(1.985)	(2.099)	(2.097)	(2.170)	(2.212)	(1.831)
Arable land (%)		-1.565	-1.919	-1.599	-2.121	-1.621	-1.818	-0.566	-2.176	-2.272*
		(1.513)	(1.503)	(1.523)	(1.436)	(1.415)	(1.599)	(1.521)	(1.415)	(1.325)
Years since Neolithic			-0.442						-0.498	
			(0.366)						(0.364)	
State Antiquity Index				-0.174					-1.077	
				(0.910)					(1.026)	
Pop density, 1500					0.144***				0.152***	0.118**
					(0.046)				(0.055)	(0.048)
Colony dummy						0.182			-0.524	0.514
						(1.791)			(1.730)	(1.516)
Oil(1000barrels/day/cap)							-3.852		-5.905	-7.688***
							(3.635)		(5.408)	(2.312)
(log)Real GDP/cap, 2000								1.125**	0.917*	0.983**
								(0.454)	(0.491)	(0.432)
Observations	137	137	137	137	137	137	137	137	137	154
R-squared	0.141	0.462	0.472	0.462	0.496	0.462	0.464	0.492	0.539	0.572
Continent dummies	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: OLS estimates of polity2 on irrigation potential surrounding capital cities. The dependent variable is the polity2-index which measures how democratic political institutions are. It ranges from -10 (least democratic) to 10 (most democratic) and is computed as an average of yearly values from 1991-2010. Irrigation potential ranges from 0 to 1 and measures the fraction of arable land where the yield increase obtained from irrigation is larger than 100%, and is measured within a 200 km radius of the capital city. All geographic variables are computed by averaging over the modern-day borders of the country. Temperature is average daily temperature in ^{o}C. Precipitation is the average daily precipitation in meters. Land with no or few soil contraints is the fraction of land where there are few or little soil constraints which inhibit crop growth. Arable land is the fraction of land where the climate, soil quality, and water sources permit crop growth. All variables are described in more detail in the Data Appendix. ***, **, and * indicate significance at the 1, 5, and 10% level, respectively. All regressions include a constant. Robust standard errors in parentheses.

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